Weather and Climate

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Weather and Climate

Without the Earth’s oceans and atmosphere, life would not exist on our planet. Our seas and sky act together to warm the Earth’s surface to habitable temperatures and level out the perpetual imbalance in solar radiation received at the Equator and the poles. But because both systems convey such a massive amount of energy, they are also the wellspring of many of the most important perils that endanger life and property. And now that we humans have altered substantially the makeup of both the atmosphere and the ocean, we should not expect them to act the same in the future as they have in the past.

The Weather and Climate Hub continues to help chart the course for research on the Earth's climate system at WTW and connect our colleagues and clients with top-tier experts in meteorology, climatology, and natural hazards. Our research portfolio is also expanding to understand and anticipate the social and economic effects of both sudden weather-related disasters, and chronic environmental problems caused, or made worse, by climate change. On top of all that, our team is looking beyond physical hazards to diagnose potential pitfalls along the road to carbon neutrality and Net Zero emissions and to survey the emerging landscapes of climate law and liability.

Owing to WTW's origins in the insurance and reinsurance industries, our Hub sponsors an impressive roster of projects directed at severe storms. Together with our academic and government partners, we are building better physical models for tropical cyclones, creating new methods to gauge the risks of tornado outbreaks and extreme windstorms, and mapping the prospect of severe hailstorms over the entire globe. We are also working to identify novel threats to human health such as dangerously high heat, and to leverage expertise in weather prediction to produce advance warnings of impending food insecurity, particularly those affecting children.

Many weather- and climate-related perils are also strongly intertwined and can combine to damage critical infrastructure or delay operations. Heavy rains from hurricanes can oversaturate soils and make rugged terrain more vulnerable to landslides. Drought that persists for several years will shrink water supplies and reduce agricultural productivity, but it can also set the stage for dust storms or wildfires later. New and ongoing research supported by our Hub is helping to meet the unique challenge of managing a disparate suite of perils in an increasingly correlated world.

Side by side our views on physical risks, the Weather and Climate Hub is widening its interests to consider the challenges and opportunities spun off by the leap to a greener, less carbon-intensive economy. Our first foray into transition risk has focused on efforts to decarbonize the global aviation system. We are also assisting financial institutions acting to align their investments with mitigation and adaptation goals and are enthusiastically cultivating new research partnerships on that topic.

Finally, our team is excited to support new research on the present and future risks of litigation tied to climate change. More and more commonly, parties that have suffered losses due to climate change are seeking redress from those they believe to be liable. But many organizations don't know where to begin to assess their exposure to climate litigation. Early in 2023, WTW will release a comprehensive report that will review key regulatory mandates related to climate liability and outline how industry can assess and reduce its climate litigation risk.

Thinking ahead, the Weather and Climate Hub will continue to buttress WTW's position as a global leader in risk solutions. We are preparing new projects that will weave together long-range climate forecasts and near-term weather simulations to yield more

realistic predictions of conditions on the ground for the next 5, 10, or 20 years. We also plan closer coordination with our Earth Risk and Flood and Water Management Risk hubs so we can better anticipate the potential threats of co-occurring or compounding risks from natural catastrophes.

> **What's the use of having developed a science well enough to make predictions if, in the end all we're willing to do is stand around and wait for them to come true?**
>
> F. Sherwood Roland
> University of California, Irvine

Through his research, the late Sherwood Roland – awarded the Nobel Prize for discovering that Chlorofluorocarbon (CFC) gases damaged the ozone layer – made clear that science is obligated to not only put a name to problems but also to cultivate effective and actionable solutions. Thanks to recent and spectacular progress in meteorology, climatology, and their cognate disciplines, we now have at hand a remarkable array of tools to predict weather- and climate-related hazards and moderate their effects. In the coming year, it will be our privilege to support all work by WTW and our research partners aimed at guarding against catastrophe and preparing for life on a warmer world.

Scott St. George
Head of Weather and Climate Risks

Daniel Bannister
Weather and Climate Risks Manager

Understanding global wind and rain risks due to tropical cyclones

Tropical cyclones (TCs) are a multi-peril phenomenon. When we think of TCs we first think of the destructive wind damage.

But TCs can also bring secondary perils such as catastrophic coastal storm surge, inland flash flooding and riverine flooding, which are often responsible for most fatalities Further cascades can also follow from indirect risks such as mudslides and compromised water quality. The impacts can vary depending on local topography and land use, which is an under-researched area that has required more focus.

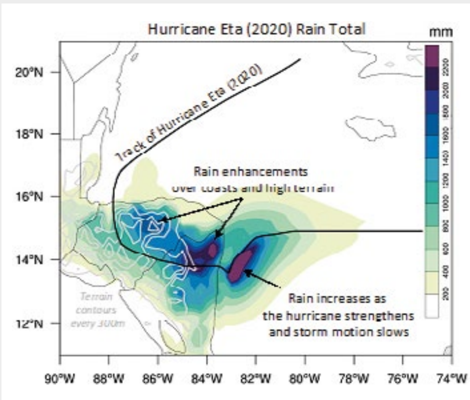
The WTW Research Network has been exploring these knock-on effects in partnership with the National Center for Atmospheric Research, building on our previous collaborations to join rainfall onto our existing capacity to model the wind footprint of tropical cyclones.

Our prior work gave us the ability to generate TCs wind footprints anywhere on Earth, and for both historical events and synthetic events based on hypothetical scenarios. The key advance of that wind model was the inclusion of realistic terrain and land use effects on the surface winds while retaining fast computational performance. This innovation was achieved by using a physical model of the TCs winds in the lowest two kilometers of the atmosphere. Close to the Earth's surface, winds speed up over hills and slow down over urban areas, which are factors that must be considered when simulating the total impact of TCs.

This physical modeling approach is now being applied to TCs rain. Here we are using an existing published TCs rain module and connecting it to our wind model to create physically consistent wind and rain footprints. This rain module includes the essential physical processes that generate rain within a TCs and does so extremely quickly.

A preliminary example of a rainfall footprint generated using this model is shown here for Hurricane Eta, which devastated parts of Central America in early November 2020. In our simulations, we see increased rain production just prior to landfall associated with the intensifying storm and slowing forward motion, and increased rainfall at the coast and over inland mountains.

Fig. 1: **TCs Rain modelling for Hurricane Eta**



Source: National Centre for Atmospheric Research

This new modeling technology will be used to provide a new perspective on the twin risks of wind and rain from tropical cyclones, both now and in the future. in a changing climate. We are excited to explore how wind and rain behave together as storms track inland, how wind-rain relationships differ among global regions, and how these relationships may change in a changing climate.

National Centre for Atmospheric Research

Dr. James Done is the director of the Capacity Center for Climate and Weather Extremes at the National Center for Atmospheric Research. He is a Senior Academic Fellow of the WTW Research Network. His research extends across a range of extreme weather and climate phenomena and connects with risk managers to strengthen the science and ensure business relevance. In recognition of his scientific leadership, he testified before the U.S. Congress on extreme weather in a changing climate. Dr. Done received his Ph.D. in Meteorology from the University of Reading, U.K. in 2003.

Confronting hailstorm risk: The latest efforts on hailstorm detection and modelling

Understanding the risk of hailstorms (in terms of frequency and intensity), under the background of ongoing climate change, is imperative. The development of extreme hailstorm climatologies, has advanced considerably in recent years, from using climate reanalysis data, to climate model outputs, and remotely-sensed observations.

When Hail Falls

Severe convective storms provide the perfect environment for large hail; they are characterised by very intense and deep updraft cores which take moisture from the lower parts of the atmosphere all the way to below freezing level. When large hail falls, it becomes one of the most destructive and costly types of severe weather, forming a significant contribution to natural hazard losses in various parts of the world. In South Africa, for example, hail has long been known to generate large amounts of damage to exposed assets, such as crops, buildings, infrastructure, and vehicles. One of the most widely documented and devastating hailstorms occurred on 28th November 2013, in the Gauteng province, with the reinsurance industry reporting estimated losses of ZAR 1.4 billion[1]. Therefore, understanding when and where such events could occur is essential, for both insurance pricing and preventive measures.

In comparison to other perils, the sporadic occurrence and highly localized effects of hail pose a particular challenge to hazard quantification, which forms the basis for any risk modelling. Records of hailfall, including size information, is limited to reports from volunteer observers or hailpad networks that operate in a few regions. Remote sensing data from either radar or satellite instruments is required to determine the spatial extent of hail events and to depict the geographic distribution of the hazard. Even though satellite data is a less accurate proxy for hail compared to radar, the big advantage is that this data cover (comparatively) larger domains almost homogeneously at high spatial resolution.

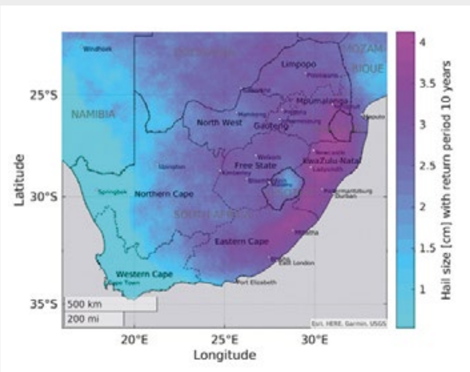
[1] Powell, C. L., & Burger, R. P. (2014). The severe Gauteng hailstorms of 28 November 2013.

Hailstorm Detection and Modelling

The WTW Research Network together with KIT have a long-standing cooperation with NASA in hail hazard and risk assessment to explore these challenges. These assessments use overshooting cloud tops (OT, defined as transient intrusions of tropospheric air into the lower stratosphere indicating an intense updraft of a thunderstorm cloud) as indicators for hail.

Over the past decade, hail risk models have been developed for Europe, Australia, and – most recently – for South Africa. Guided by 14 years of geostationary and low-Earth-orbiting satellite observations of convective storms, hail events were reconstructed from satellite OT data and filtered by reanalysis (ERA5) to estimate South Africa's hail hazard.

Fig. 1: **Maximum hail size occurring once in 10 years for grid cells across South Africa, computed as the lowest hail diameter class with the stochastic hail model.**



Source: [2]Punge, H. J., Bedka, K. M., Kunz, M., Bang, S. D., and Itterly, K. F.: Characteristics of hail hazard in South Africa based on satellite detection of convective storms, Nat.

To describe the spatio-temporal extent and characteristics of potential hail events in a reliable way, the research collaboration has developed a new methodology for the clustering and tracking of OTs.

According to the results[2], hailstorms mainly occur in the southeast of the country, along the Highveld, and around the eastern slopes. Figure 1 shows the hail diameter that can be expected once per decade at a given location. Events are most frequent from mid-November through February and peak in the afternoon, between 1300 and 1700 UTC. Multivariate stochastic modeling of event properties yields an event catalog spanning 25000 years. This stochastic event catalogue is then used to estimate, in combination with vulnerability and exposure data, hail risk for return periods of 200 years, a quantity required by the insurance industry.

In addition, scientists at NASA Marshall Space Flight Center have recently developed an algorithm that estimates a storm's probability of severe hail using low-Earth-orbiting passive-microwave instrument data[3]. Passive-microwave instruments measure upwelling radiation from the earth's surface, that is scattered away by large ice particles in some clouds, resulting in a distinct signature of hailstorms in the data. This signature is used to make a function that estimates the probability of severe hail in any storm observed by a given satellite, trained using ground-based reports of hail with at least 2.5-cm diameter in the U.S.. These probabilities can then be added up, smoothed for area and satellite orbit, and used to make a near-global climatology of

[2] Punge, H. J., Bedka, K. M., Kunz, M., Bang, S. D., and Itterly, K. F.: Characteristics of hail hazard in South Africa based on satellite detection of convective storms, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://nhess.copernicus.org/preprints/nhess-2021-342/

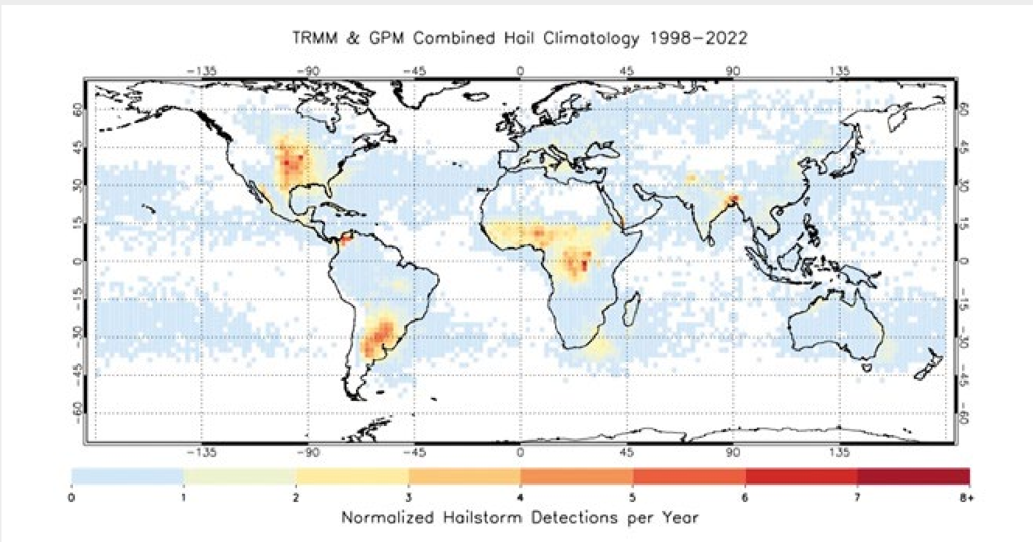
[3] Bang, S. D., & Cecil, D. J. (2019). Constructing a Multifrequency Passive Microwave Hail Retrieval and Climatology in the GPM Domain, Journal of Applied Meteorology and Climatology, 58(9), 1889-1904. https://journals.ametsoc.org/view/journals/apme/58/9/jamc-d-19-0042.1.xml

severe hail (Figure 2), even over remote, data-sparse areas, offering another view of the hail hazard beyond the regional analyses performed with geostationary imagery. Hail climatology datasets, extending over a 25-year period, have been made freely available to the public from the NASA Global Hydrometeorology Resource Center (GHRC) at ghrc.nsstc.nasa.gov/pub/hail_climatology/data.

Ongoing Work

Looking ahead, KIT and NASA will continue to apply geostationary satellite, passive microwave climatologies, and reanalysis to further study OT characteristics and convective storm parameters to better detect and constrain and hail risk (particularly over South America and Australia) while also improving our knowledge of how this hazard might evolve under climate change. Keep an eye out for future WTW Research Network insights and blogs as this exciting research continues to develop.

Fig.2: **Annual rate of severe hailstorms derived from TRMM and GPM Microwave Imagers, 1998-2022.**



Source: [3]Bang, S. D., & Cecil, D. J. (2019). Constructing a Multifrequency Passive Microwave Hail Retrieval and Climatology in the GPM Domain, Journal of Applied Meteorology and Climatology, 58(9), 1889-1904. https://journals.ametsoc.org/view/journals/apme/58/9/jamc-d-19-0042.1.xml

Karlsruhe Institute of Technology & NASA

From the first fully probabilistic hail model, through a project initiated by Karlsruhe Institute of Technology (KIT), in 2014, to today's ongoing collaborative project between KIT and NASA, our researchers at KIT (Professor Michael Kunz and Jannick Fischer) and NASA (Kristopher Bedka) are continuing to improve our understanding of hail risk.
WTW have been able to utilise such information to inform clients about the loss potential from severe hail, thus not only improving our knowledge and understanding but also helping to satisfy regulatory and portfolio optimization requirements.

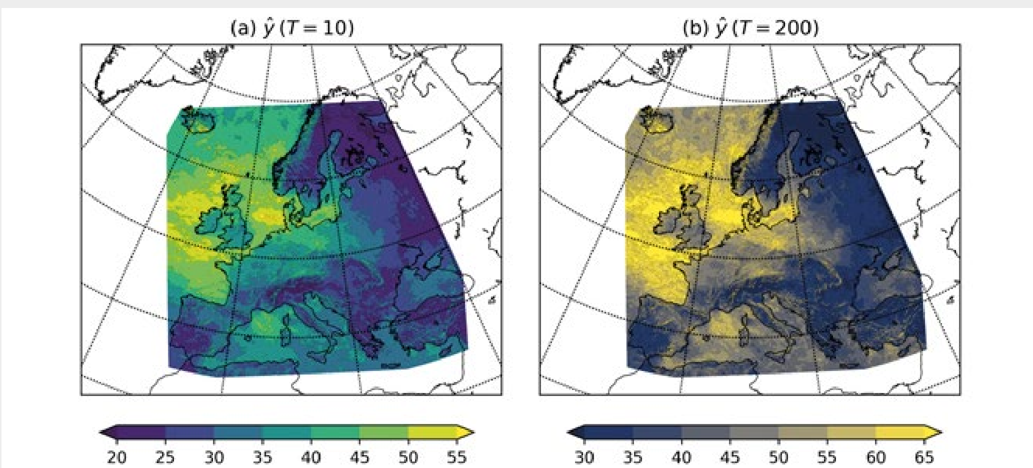
Understanding variability in European windstorm risk

Historically, climate scientists are limited to only a few decades of comprehensive observational data, which makes estimating return periods of rare events challenging.

Further complicating this is that estimates are often sensitive to the length of historical catalogue used. Through our long running partnership, the University of Exeter have developed a reliable method to estimate extreme windstorm gust speed return levels from a multi-year sample of windstorm footprints and without the complications of complex catastrophe models.

Using statistical methods, WTW Research Network Fellow Dr Matthew Priestley, guided by Professors David Stephenson and Adam Scaife, have developed a novel model for estimating wind gusts across Europe at up to the 200-year return period with a resolution of 4.4 km (Figure 1). This model uses observed windstorm footprints from the Windstorm Information Service (WISC) project as an input and is flexible to allow for varying amounts of input data to test the sensitivity of estimated return levels to catalogue length. The model requires a multi-year set of windstorm footprints, from which we deduce the intensity, their rate of occurrence, and a probability of occurrence. As the North Atlantic Oscillation (NAO) is the leading driver of weather variability across Europe, they have also been able to include historical variations of the NAO in the model, which is often not considered in risk models. This therefore allows for the return level estimates to vary with the phase of the NAO.

Fig.1: **Estimated wind gust return levels at the (a) 10-year and (b) 200-year return level derived from our statistical model using WISC footprints from 1950-2014. Units are m s^{-1}.**



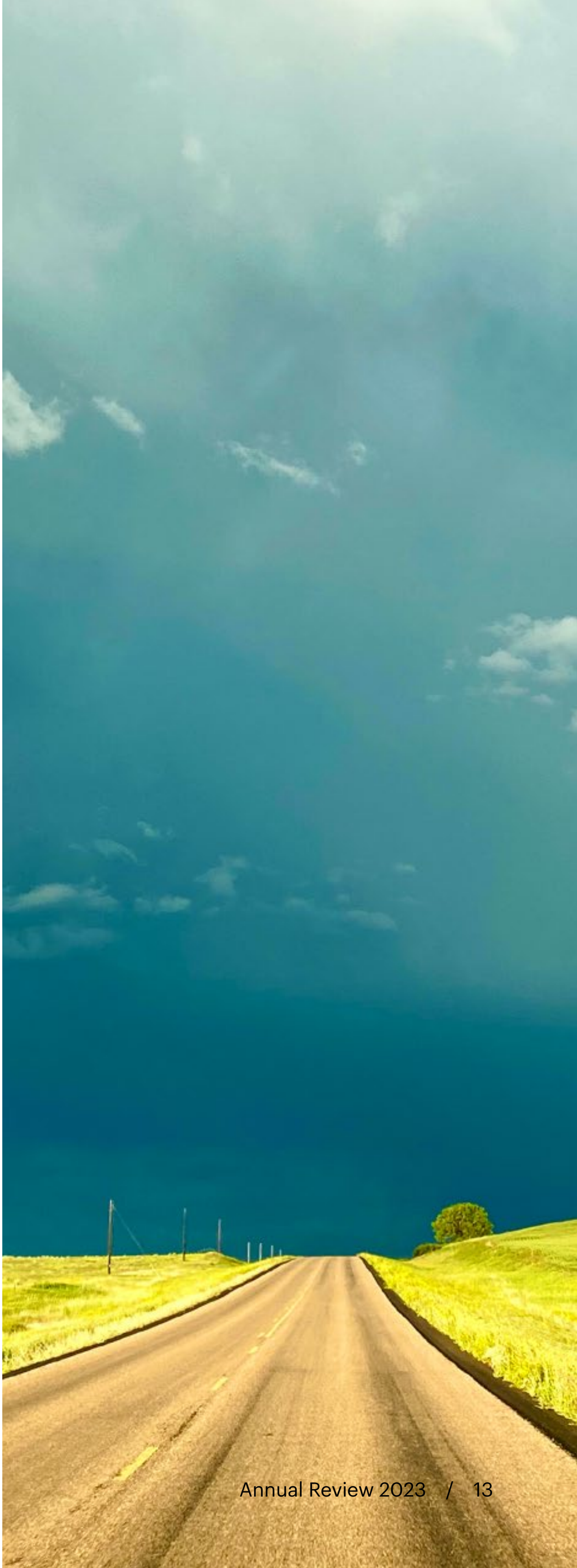
Source: Windstorm Information Service (WISC) project

Results have revealed that the NAO is very important for modulating low return period gusts and act as a pre-conditioner of the atmospheric state. In contrast, the most extreme gusts can be assumed to occur due to further stochastic processes. The University of Exeter have also been able to quantify the optimal length of historical catalogue required to generate the most accurate return level estimates for a variety of return periods. The model can generate return level estimates for several different input datasets and in the future may be applicable to other natural hazards.

The work at the University of Exeter will continue to focus on further drivers and factors affecting windstorm variability which will allow them to offer new insights into historical, and future, windstorm risk across Europe. In the meantime, watch out for this work to be published in 2023.

UNIVERSITY OF EXETER

Dr. Matthew Priestly
University of Exeter
WTW Research Network Fellow, Dr Matthew Priestley's current research is on European winter storms, with focus on constructing and evaluating present day risk. A further goal is on understanding the impact of climate change on future risk estimates. At the College of Engineering, Mathematics and Physical Sciences, he works with Professor David Stephenson, Chair in Statistical Climatology (also a founding member of the WTW Research Network) and Professor Adam Scaife, to develop new insights and views of European windstorm risks.



Modelling the risk of climate change litigation for (re)insurers

Climate change litigation presents a unique set of risks and opportunities to (re)insurers, who face the challenge of understanding their current portfolio exposures to climate litigation risk, reserving for potential losses, and pricing new products that may be affected by climate litigation.

However, (re)insurers have struggled to assess climate litigation risk in the face of significant uncertainty, and a recent Bank of England "climate stress test"[1] suggests many insurers lack the capacity to assess their exposure to climate litigation.

Beyond their financial value, climate litigation risk assessment tools are crucial because (re)insurers are uniquely positioned to develop and propagate risk disclosure and reduction techniques. Some categories of climate litigation risk, like regulatory and governance claims, are susceptible to value-positive risk mitigation techniques. By pricing litigation risk and propagating effective governance and risk assessment processes, insurers can help their clients mitigate claims by reducing the damage underlying climate liability.

In a new partnership with the WTW Research Network, lawyers and researchers from the Sabin Center for Climate Change Law at Columbia Law School are conducting a broad assessment of (re)insurer climate change litigation risk. This research will ultimately support the development of climate change litigation models, mitigation strategies, and risk allocation products.

This collaboration has produced an internal scoping report that details the landscape of climate litigation risk assessment, informed by a combination of desk research and field interviews with specialists familiar with climate litigation risk analysis. In this report, our team of experts has:

- highlighted key dimensions of climate litigation risk and charts the impact of climate litigation risk across (re)insurers' business operations and product lines;
- assessed existing qualitative and quantitative climate litigation risk modelling frameworks and identifies key risk drivers shaping climate litigation risk; and
- reviewed key regulations, cases, and resources related to, informing, or affecting global climate litigation risk analysis.

[1] https://www.bankofengland.co.uk/stress-testing/2022/results-of-the-2021-climate-biennial-exploratory-scenario

As a next step, researchers at the Sabin Center will work with the WTW Research Network to produce a white paper that synthesizes regulatory mandates and industry best practices surrounding the assessment and reduction of climate litigation risk. We plan to release the white paper early in 2023, so please follow the WTW Research Network for more information coming soon!

Professor Michael Burger
Executive Director,
The Sabin Center for
Climate Change Law

Martin Lockman
Climate Law Fellow and
Associate Research Scholar,
The Sabin Center for
Climate Change Law

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

The Sabin Center for Climate Change Law

Since 2009, the Sabin Center for Climate Change Law at Columbia Law School has driven research in the interrelated fields of climate law, environmental regulation, energy law, and natural resources law. The Sabin Center develops legal techniques to fight climate change, trains the next generation of climate lawyers, and provides up-to-date resources on key topics in climate change law and regulation. Executive Director Michael Burger and Climate Law Fellow Martin Lockman are working with the WTW Research Network to help better understand and manage risks from climate change litigation.

La Niña and US tornado outbreaks

Severe thunderstorms accompanied by tornadoes, large hail, or damaging straight-line winds result in substantial insured losses in the US each year.

The El Niño-Southern Oscillation (ENSO) has been identified as a climate factor which modulates US severe thunderstorm activity, with La Niña being associated with increased activity in spring. The role of ENSO is crucial as severe thunderstorm activity in spring can be predicted based on the ENSO phase during the proceeding winter, and there may be correlations with other ENSO-sensitive hazards such as Atlantic hurricanes.

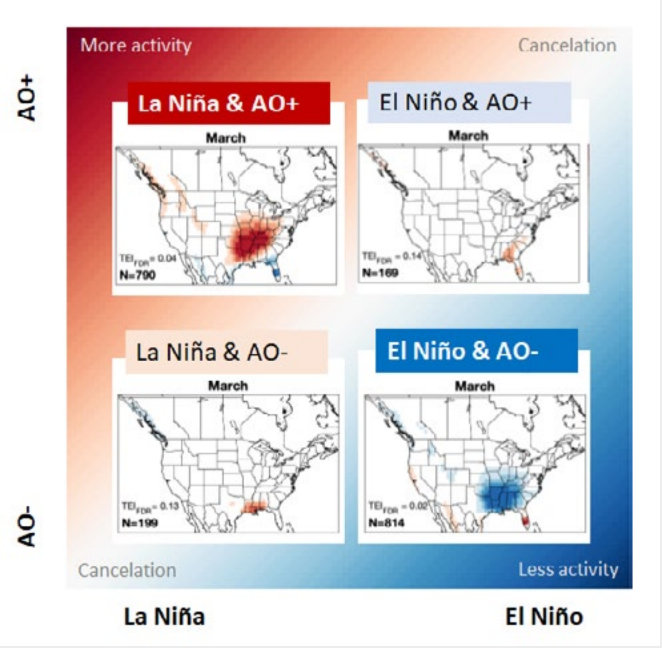
Robust estimation of the ENSO signal in US severe thunderstorm activity is challenging because of the modest number of ENSO events during the last 30 or 40 years when reliable storm reports are available. To work around that limitation, Prof. Michael Tippet and Dr. Chiara Lepore produced more than 8,000 years of synthetic data from a physics-based climate prediction model that simulates the Earth's oceans (including ENSO) and atmosphere (including weather; Tippett and Lepore, 2021). Because this model cannot directly represent tornadoes, they instead focused on those weather conditions that tend to go along with tornadoes. In a 2021 article in Geophysical Research Letters, they found the relation between ENSO and tornado weather is strongest in February and March and that more tornadoes than usual are expected during La Niña conditions but that the exact number is highly uncertain.

One reason for this uncertainty is that another climate factor, the Arctic Oscillation (AO), can either enhance or cancel the ENSO signal depending on its phase.

In a 2022 paper for *Weather and Climate Dynamics*, Michael Tippet and colleagues showed that when ENSO and the AO act in concert, their impact is large, and when they oppose each other, their impact is small (Figure 1). This new understanding of the combined ENSO-AO impact is relevant for understanding situations such as in early 2021 when both strongly positive and strongly negative AO events occurred during La Niña conditions.

Future work will examine the role of ENSO on tornado outbreaks. Understanding the role of ENSO is also relevant in the context of climate change. Although work led by Dr. Lepore has demonstrated that climate change will increase the frequency of conditions that are favorable for US severe thunderstorms, climate projection models appear to be biased toward El Niño conditions which means that the increase may actually be underestimated.

Fig.1: **When the El Niño-Southern Oscillation (ENSO) and the Arctic Oscillation (AO) act in concert, severe thunderstorm activity is increased (red; La Niña and AO+) or decreased (blue; El Niño and AO-). When they oppose each other, there is cancelation and near-normal activity (white) is expected.**



Source: Weather and Climate Dynamics,2022

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Michael Tippet
Columbia University

Michael Tippett is an Associate Professor in the Department of Applied Physics and Applied Mathematics at Columbia University. Tippett investigates how severe thunderstorms (those resulting in tornadoes, hail, or damaging wind) and tropical cyclones are related to climate, now and in the future. He is a co-author of the 2022 textbook *Statistics for Climate Scientists*.

On co-occurring and cascading hazards

Under the background of ongoing global climate change, we traditionally think of how the risk, vulnerability, and exposure of a society changes to individual hazards: it is well known that extreme events (like maximum day-time temperatures, rainfall, and wildfires) are projected to increase in frequency and in magnitude, and it is relatively easy to model and account for such future trends in risk management.

But what happens when natural hazards and disasters co-occur (events which occur simultaneously) or cascade (events which lead to, or are a consequence of, another)? How will climate change alter the (inter)dependency between individual and interrelated hazards? And since pricing physical climate risks is already uniquely challenging, how can we better integrate co-occurring and cascading hazards into existing and future disaster risk management and decision-making frameworks?

Nature's Complexity

Traditional risk assessment frameworks frequently use statistical methods and techniques to identify and isolate historical trends in the trigger, magnitude, or the frequency of an individual hazard, often from (patchy and discontinuous) observational datasets. While this captures the risk one hazard at a time, it does not adequately capture the risk associated with co-occurring or cascading hazards. For instance, alone, an individual but prolonged drought or heat wave can trigger significant socioeconomic effects. However, droughts and heat waves can also trigger and intensify wildfires, which in themselves further trigger other cascading hazards. The complex, interrelated nature of extreme events has the potential to turn otherwise moderate events into disasters[1].

[1] AghaKouchak, A., Huning, L.S., Chiang, F., Sadegh, M., Vahedifard, F., Mazdiyasni, O., Moftakhari, H. and Mallakpour, I., 2018. How do natural hazards cascade to cause disasters?

[2] Li, C., Handwerger, A.L., Wang, J., Yu, W., Li, X., Finnegan, N.J., Xie, Y., Buscarnera, G. and Horton, D.E., 2022. Augmentation of WRF-Hydro to simulate overlandflow-and streamflow-generated debris flow susceptibility in burn scars. Natural Hazards and Earth System Sciences, 22(7), pp.2317-2345.

Spotlight on Co-occurring and Cascading Hazard Research

To close the gap between risk management and business decision making frameworks and processes with the risks posed by complex natural hazards, we need to improve our fundamental understanding and modelling of the interrelated nature, characteristics, and trigger mechanisms of co-occurring and cascading hazards. In 2022, the WTW Research Network has supported numerous academics, across the atmospheric and geophysical hazard space, considering various angles of co-occurring and cascading hazards. These include:

- James Carruthers, Dr Selma Guerreiro, & Professor Hayley Fowler (Newcastle University): "High resolution climate modelling of extreme weather hazards and application to the analysis of risks relating to climate change" – James' PhD project will involve designing relevant metrics that capture the frequency and severity of storm and flooding hazards from high-resolution climate model outputs for global-scale diagnostic risk and impact assessment
- Dr Hannah Bloomfield (University of Bristol): "Compound wind and flood risk over Europe" – Hannah has been exploring the current and future joint risk between heavy rainfall and strong wind events when they co-occur across Europe, with her journal article published earlier this year[3]
- Dr Matt Priestley, Professor David Stephenson, & Professor Adam Scaife (University of Exeter): "Climatic drivers of extreme European windstorms" – The research at Exeter University will look at how European windstorm activity can be predicted on a seasonal to decadal timescale, and how climate change and natural variability is affecting the number, timing, and frequency of European winter storms
- Dr John Hillier (University of Loughborough): "ROBUST - Enabling better management of UK multi-hazard risk" – ROBUST builds on[4], which identified that the most damaging flooding and extreme wind events in the UK tend to occur in the same season but not necessarily during the same storm. ROBUST will further contribute to providing a better understanding of multi-hazard risk and how this may change with climate change to quantify likely future losses and impacts

In 2023, we will continue to coordinate with our existing and new academic partners (including the National University of Singapore), as well as with our clients, to develop event sets of co-occurring and cascading hazards and to define the rigorous techniques required to quantify and mitigate them.

[3] Bloomfield, H., Hillier, J., Griffin, A., Kay, A., Shaffrey, L., Pianosi, F., James, R., Kumar, D., Champion, A. and Bates, P., 2022. Co-Occurring Wintertime Flooding and Extreme Wind Over Europe, from Daily to Seasonal Timescales. Available at SSRN 4174051.

[4] Hillier, J.K., Macdonald, N., Leckebusch, G.C. and Stavrinides, A., 2015. Interactions between apparently 'primary' weather-driven hazards and their cost. Environmental Research Letters, 10(10), p.104003.

The WTW Research Network also supports projects on interconnecting risks and how physical hazards impact critical infrastructure and organisational systems. For instance, a project with Mitiga Solutions ("Volcanic Ash Risk Transfer in Aviation (VOLARISK)") aims on providing a global, high-resolution probabilistic view of volcanic ash risk for the aviation industry to understand how this individual hazard has the potential to disrupt infrastructure (e.g., aircraft maintenance and safety), organisational (e.g., supply and procurement chains), and technological (e.g., flight operations) systems. Such work can provide a better understanding of how the co-occurrence or cascading nature of two or more hazards also intersects the human and socioeconomic systems.

Thinking Ahead

Climate scientists understand that individual extreme events are increasing (in terms of their magnitude and frequency) due to climate change. While the risk posed by individual hazards will increase in a warmer world, so too will the associated risks of co-occurring and cascading hazards.

Therefore, it is apparent that there is a clear gap in research, and in the application into disaster risk management, in how one extreme event may alter all other interrelated hazards (whether that is via co-occurring and cascading, simultaneous or asynchronous, occurrence) and how this further disrupts socioeconomic systems.

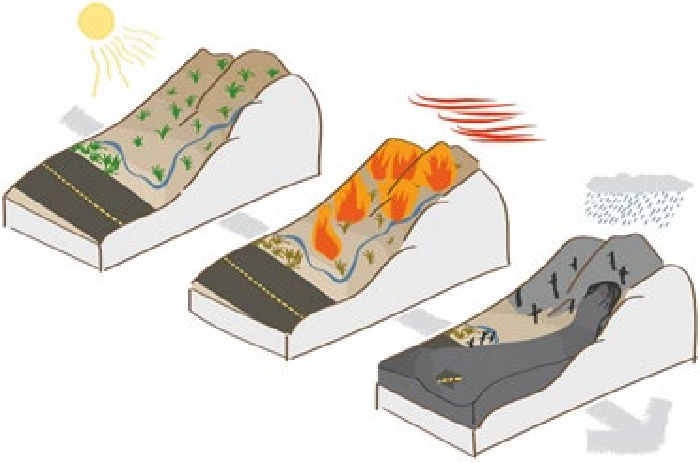
The research the WTW Research Network supports on the nature and dependencies of these events enables the community to identify appropriate datasets, methodologies, and technical approaches to analyse, simulate, and estimate the risk, vulnerability, and exposure of a society for accurate and decisive risk management and insurance purposes.

Case study:

Landslides: A Cascading Hazard

Landslides are a major hazard that have the potential to cost millions of dollars in damage, and cause thousands of fatalities, across the world every year. While the primary trigger for a landslide is usually heavy rainfall or seismic activity, they are also frequently a consequence of two or more consecutive hazards, such as extreme rainfall over a burned area, see Figure 1[2].

Fig.1: **Schematic diagram depicting events leading to a landslide: drought, followed by wildfires, followed by intense precipitation.**



Source: Tierney Acott/Institute of Sustainability and Energy at Northwestern.

A recent example of this is the mudslides in Southern California in September 2022. The remnants of Tropical Storm Kay brought heavy rainfall to a region that had been scorched by a wildfire two years prior, leading to a mudslide which destroyed and damaged buildings, infrastructure, and vehicles. Since climate change has the potential to increase the likelihood of both wildfires and heavy rainfall events, how can we more accurately capture the co-occurrence in the trigger, magnitude, and frequency of both these hazards to better constrain immediate and future landslide risk? An added complexity to this question is also how individual but consecutive wildfires and individual but consecutive storms will also change in the future: are consecutive wildfires correlated and does one wildfire precondition the environment for subsequent wildfires, and how does climate change and natural climate variability influence storm clustering?

Such examples emphasise how the non-linear (spatial and temporal) dependency and causal sequences between superficially individual extreme events makes them challenging not only to study but also to model in existing disaster risk management frameworks. This leaves society ill-prepared for co-occurring and cascading hazards.

Global event sets of dangerous heat

In partnership with the National Center for Atmospheric Research and as part of the WTW Challenge Fund, we are creating new views of global trends in heat dangerous to human health.

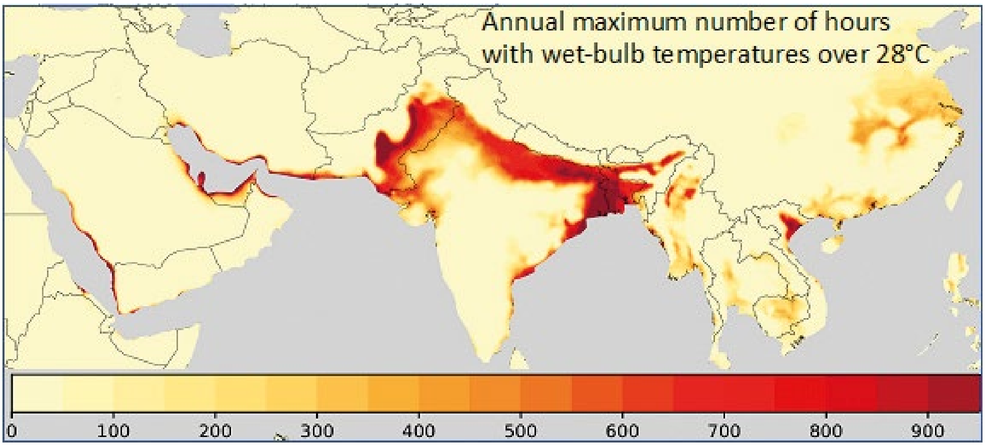
Heat can severely impact human health and cause ripple effects across societal systems such as the health sector, the global labor force, and national defense. Human heat stress is strongly related to air temperature and moisture content. Once air temperature exceeds 35°C, the human body can only cool through sweating and evaporative cooling. If humidity also increases, we reach an upper limit of survivability where sweat no longer evaporates and the body temperature rises. A measure of how well sweating cools us is obtained by wrapping a thermometer in a wet cloth. Like our skin, the thermometer cools through evaporation. Once this 'wet-bulb thermometer' reaches 35°C the body can no longer cool, and humans can only survive for a few hours. However, impacts on population health can start at much lower wet-bulb temperatures of 28°C.

Some regions, such as the Arabian Peninsula, are already reaching critical points for human survival. Of particular concern are coastal locations where onshore moist flow off warm seas can combine with hot inland air to create deadly humid heat. Historically, the geographic pattern of deadly heat has been concentrated in places where warm, moist air moves directly onto land (Figure 7). In low latitudes, this danger is most common in coastal areas and inland regions that experience strong monsoons.

Under climate change, the air warms and can hold more moisture. The combined increase in temperature and moisture has already driven a doubling in the frequency of extreme wet-bulb temperatures in some locations. And the global population exposure to humid heat has increased faster than exposure to dry heat. Looking ahead, even under the most optimistic future warming scenarios, deadly heat exposure will increase markedly. It is therefore imperative to understand the potential human health impacts.

This project uses a new object-tracking algorithm to identify and track humid heat objects geographically and through time. Collectively, these objects comprise a historical event set suitable for statistical analysis of event locations, timing, trajectories, intensities, and trends. Of particular interest are objects expanding into new territories and new seasons. The objects will also be used to calculate recent historical trends of heat metrics for key global cities including Los Angeles, Mexico City, London, Paris, Cairo, Sharm El-Sheikh, Dubai, Manila, and Sydney.

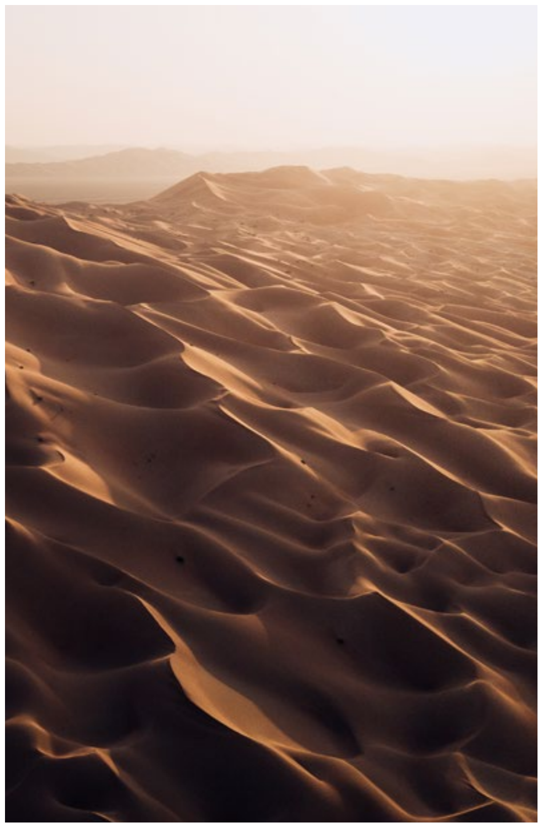
Fig.7: **Map showing the annual maximum number of hours where wet-bulb temperatures have exceeded 28 ºC in the Middle East, south and southeast Asia, and China.**



Source: National Centre for Atmospheric Research

Dr. James Done,
National Centre for
Atmospheric Research

Dr. James Done is the director of the Capacity Center for Climate and Weather Extremes at the National Center for Atmospheric Research. He is a Senior Academic Fellow of the WTW Research Network. His research extends across a range of extreme weather and climate phenomena and connects with risk managers to strengthen the science and ensure business relevance. In recognition of his scientific leadership his scientific leadership, he testified before the U.S. Congress on extreme weather in a changing climate. Dr. Done received his Ph.D. in Meteorology from the University of Reading, U.K. in 2003.



Can we reduce infant hunger? The Guatemalan case

Food security remains a major challenge worldwide

For countries like Guatemala, the situation for children under five years old has become extremely alarming, with figures reaching almost fifty per cent for acute undernutrition in certain departments (primary administrative divisions) of the country, as per the IV National Survey of Infant and Maternal Health in Guatemala (ENSMI in Spanish).

Columbia University's International Research Institute for Climate and Society (IRI) has been working with the Secretariat of Food Security and Nutrition in Guatemala (SESAN) to help Guatemala achieve food security by co-developing climate services to support SESAN's decision-making process. Both institutions have been working together to co-develop an objective and reliable next-generation forecast system to predict the number of cases of acute undernutrition for children under five years old in each of the country's 22 departments. Starting with SESAN's conceptual model of drivers of food insecurity for children, the team developed a hierarchical probabilistic set of models using climate and socio-economic variables.

Thanks to the WTW Research Network, both institutions have been able to continue with the collaboration and develop an interactive online tool to be used by SESAN in their decision-making process to fight acute undernutrition in children in Guatemala. The tool has the capacity to visualize which departments in the country present a higher risk of undernutrition in the target population using an objective, state-of-the-art forecast methodology. In addition, this collaboration allowed for the development and delivery by SESAN of NextGenNut, the interactive online tool mentioned above, in the form of regularly updated, actionable forecast products.

NextGenNut offers an accessible and intuitive way for decision-makers to monitor, in real-time, infant cases of acute undernutrition.

Moreover, NextGenNut gives SESAN and its partners early warning of expected hunger three to five months ahead of the actual impact, helping the country fight hunger department by department, and focus on those places where undernutrition is most acute.

IRI and SESAN had several meetings to discuss the conceptual model and to develop an interactive online tool to support SESAN's decision-making process. In this image are Gabriel José Pérez Tuna, Juan Roberto Mendoza Silvestre, Ana Gabriela Rosas García (SESAN) and Carmen Gonzalez Romero and Zain Alabweh (IRI). Photo credit: Ángel G. Muñoz.

NextGenNut enables SESAN and international partners, like the Pan American Health Organization and the World Food Program in Guatemala, to plan for food and nutrition interventions in advance and protect children's health. It will also allow SESAN and other organizations to allocate resources and target their interventions to areas with the greatest needs. Furthermore, early interventions, social programs and other anticipatory mechanisms could reduce the impact of food insecurity in children through a combination of SESAN's undernutrition monitoring system and this new forecast system developed with the support of WTW Research Network.

NextGenNut has the potential to be upscaled across Central America via IRI's long-term relationships, especially the Central American Regional Commission for Hydrological Resources. NextGenNut can become a tool for humanitarian relief agencies such as USAID and the World Food Program, much like USAID's Famine Early Warning System is a mainstay of food insecurity planning. NextGenNut will increase Guatemala's capacity to develop more effective, anticipatory actions to fight the impact of food insecurity on particularly vulnerable populations.

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Carmen González Romero
Carmen González Romero is presently Staff Associate III at Columbia University's International Research Institute of Climate and Society and PhD candidate at the University of Bologna. She has a multidisciplinary background with more than five years of experience in developing climate services for developing and developed countries. Starting in January 2023, she will serve as Social Scientist on Climate and Earth Quality Services at the Barcelona Supercomputing Center in Spain.

Ángel G. Muñoz
Ángel G. Muñoz is presently an Associate Research Scientist at Columbia University's International Research Institute of Climate and Society, focusing on climate variations and prediction at multiple timescales. Muñoz works on the development of climate services, especially those related to food security (involving models for undernutrition and human migration), vector-borne diseases and lightning activity. Starting in January 2023, he will serve as Senior Research Scientist for Climate Services at the Barcelona Supercomputing Center in Spain.

The sky's the limit: sustainable aviation

The path to net zero for the aviation sector is a complex yet necessary challenge that no single stakeholder can solve on their own.

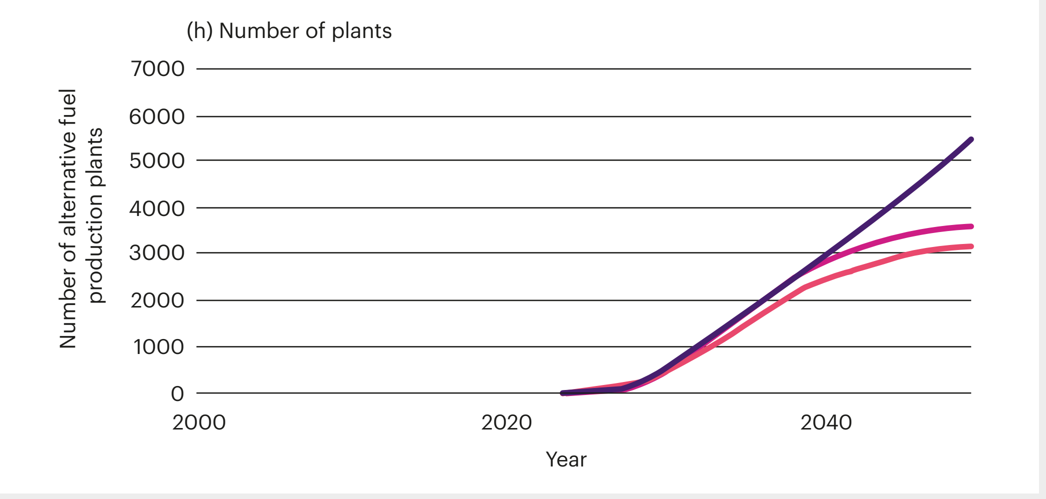
Direct aircraft emissions alone, globally, account for approximately 3% of all anthropogenic carbon dioxide (CO2) emissions, and while regulators and consumers have raised ambition within the sector, a rapid lift off is needed to meet the goals of the Paris Agreement. A whole host of different measures are required to overhaul both the direct and indirect emissions produced by the entire aviation system (aircraft manufactures, airlines, and airports). With changes needed to: aircraft design, development, testing, and certification, airport vehicular operations and waste management, sustainable clothing for aircraft crew and airport staff, and more.

Towards Zero Carbon Aviation

To support the industry with this challenge – and bringing our clients perspectives to the table – the WTW Research Network have been supporting the 3-year Towards Zero Carbon Aviation (TOZCA) project led by Professor Andreas Schäfer at the Air Transportation Systems Lab, University College London. In last year's review, we shared details on TOZCA, which will examine how the sector can realistically move towards a net zero climate impact global aviation system by 2050, and the costs and emissions trajectories associated with such transitions, looking at changes in technology, fuels, operations, competition, and consumer behaviour that can lead to drastic CO2 emission reductions.

One year on, the team has provided an insightful update of their progress in a peer-reviewed article in Nature Climate Change: "Cost and emissions pathways towards net-zero climate impacts in aviation"[1]. The key finding from the paper is that while demand for aviation will increase by as much as 3-fold by 2050, 90% decarbonization can still be achieved through continued efficiency gains in aircraft and operations, and using ultra-green fuels derived from biomass or clean electricity. This is encouraging, and yet, the challenge is immense, requiring much coordination and investment (e.g., Figure 1).

Fig.1: **Middle demand scenario projections of the number of alternative fuel (biofuel-only, purple; biofuel as a bridging fuel to power-to-liquids, yellow; biofuel as a bridging fuel to liquid hydrogen, red) production plants required to achieve net-zero climate impacts in 2050. See Dray et al. (2022) for further details.**



Source: [1]Cost and emissions pathways towards net-zero climate impacts in aviation. Nature Climate Change, 12(10), 956-962. 2022

[1] Dray, L., Schäfer, A. W., Grobler, C., Falter, C., Allroggen, F., Stettler, M. E., & Barrett, S. R. (2022). Cost and emissions pathways towards net-zero climate impacts in aviation. Nature Climate Change, 12(10), 956-962. https://www.nature.com/articles/s41558-022-01485-4

Enabling Discussion to Accelerate Action

By design, the TOZCA project has the active support of several industrial partners in the aviation sector. In this group, WTW brings insights on risk management, insurance, and finance. In addition to joining the TOZCA advisory board, the WTW Research Network has organised a series of roundtables for a growing community of aviation and aerospace executives.

In March 2022, the first roundtable focussed on the opportunities and risks in transitioning to a net zero-carbon aviation system. This was the first opportunity for a community, led by the science developed under the TOZCA project, to focus and discuss the ambitious, yet realistic, action plans needed for this industry to undergo an orderly transition.

In November 2022, a second roundtable with over 30 experts and leaders from across the industry (insurance, finance, services, public sector, energy, legal, airlines, airports, and academia) focused on how to overcome to hurdles to the transition, and the relative contributions of science, policy, and markets to support the transition to a net-zero aviation system.

Three key areas, vital in driving and advancing change, emerged from the discussion:

1 More meaningful collaboration within the sector and across sectors (e.g., academia, policies)

2 Improved communication on the sector's endeavours to reach its Paris-aligned emission goals and targets

3 Additional support in the investment and development of methods and technology to deliver such changes.

While there is no silver bullet or one-size-fits-all solution that can switch aircraft manufactures, airlines, and airports to net zero within the next 10 years, the time for planning is disappearing and the industry will need to instigate take-off on decisions. Figure 1 helps to demonstrate the scale of the energy transition and required infrastructure for commercial-scale synthetic-fuel plants and the underlying renewable-power-generation system – the next 10 years are critical in driving this transition. In 2023 WTW will be doing our part to support the industry in making decisions on investing in the right technologies and understanding factors such as changing consumer behaviours. These decisions as necessary and open the door to some of the most exciting transformation opportunities for the industry – the sky's the limit for those bold enough to embrace risk and turn it into opportunity.

University College London

WTW Research Network is supporting Professor Andreas Schäfer and his team, at the Air Transportation Systems Laboratory (University College London), for the EPSRC funded project TOZCA (Towards Zero Carbon Aviation). The Air Transportation Systems Laboratory explores the interaction between air transportation, the economy, and the environment. Their work is data-driven, using physical science, econometric, and operations research-based methods. The integrating mechanism is the Aviation Integrated Model (AIM), a unique tool, consisting of interlinked modules simulating current and future levels of global airport-to airport demand, flight schedules, arrival delay, technology uptake, aircraft performance, local and global emissions, aircraft noise, and the related environmental costs and economic benefits under a wide range of policy conditions.

About WTW

At WTW (NASDAQ: WTW), we provide data-driven, insight-led solutions in the areas of people, risk and capital. Leveraging the global view and local expertise of our colleagues serving 140 countries and markets, we help you sharpen your strategy, enhance organisational resilience, motivate your workforce and maximise performance. Working shoulder to shoulder with you, we uncover opportunities for sustainable success — and provide perspective that moves you. Learn more at wtwco.com.

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