Introduction and Executive Summary

The Joint Centre for Excellence in Environmental Intelligence (JCEEI) is a collaboration between the Met Office and the University of Exeter providing the expertise, skills, and capability to fully utilise artificial intelligence (AI) to address challenges facing society, including climate change. The JCEEI pioneers the use of Environmental Intelligence to provide the meaningful insight needed to inform decision-making and improve risk management, leading us towards a sustainable interaction with the natural environment and delivery of Net Zero.

The theme of this year's JCEEI conference, held remotely on 16th and 17th December 2021, was **'Beyond COP26: The Road to Net Zero'.** Across six sessions, almost 30 speakers drawn from academia, government, industry and other settings, showcased their cutting-edge work using transformative technologies to support the UK's Net Zero ambitions. They discussed barriers and enablers to the use of data science to accelerate positive change, and the importance of systemic solutions, interdisciplinary collaboration and wider stakeholder engagement in the transition. The need to inspire and support the next generation of talented environmental and data scientists was the focus of the final session. The significant technologies and themes covered included: the emerging role of digital twins; standards for building trust in the sharing of data; and the use of autonomous and semi-autonomous systems for data collection.

Open, Introduction and Keynote

The event was hosted by **Dr Kirstine Dale** and **Professor Gavin Shaddick**, Co-Directors of the JCEEI, who started with a brief introduction to the topic of environmental intelligence, and the Joint Centre, its flagship projects and a new Masters degree in Environmental Intelligence. **Professor Penny Endersby**, Chief Executive of the Met Office, and **Professor Lisa Roberts,** Vice-Chancellor and Chief Executive, University of Exeter, gave welcome addresses which set out the urgent need to achieve Net Zero and the contribution that EI could make as a key enabler.

The keynote address was given by **Professor Paul Monks**, Chief Scientific Adviser at the Department for Business, Energy and Industrial Strategy, who outlined the UK Government's policy on Net Zero, the pervasive challenges to be overcome and the role of data science and digital technologies. For Professor Monks, Net Zero is a "system of systems problem", encompassing technological innovations, such as electrification of the energy system or carbon capture, utilisation and storage (CCUS), alongside social, political and economic dimensions. For a sustainable, resilient and measurable transition, an integrated, digitally-enabled systems approach incorporating behavioural change is needed. With significantly more earth observation data now being generated, we have the opportunity to move from passively monitoring global health, to becoming a "global guardian" – using the data to drive solutions.

Session 1 - Harnessing Transformative Technologies to Achieve Net Zero

Kicking off the first session, the Met Office's Chief of Science and Technology **Professor Stephen Belcher** highlighted "the palpable appetite" at COP26 for advice, evidence and technologies to reach Net Zero. AI and analytics were, he said, vital for driving both mitigation of, and adaptation to, climate change, with the contribution of digital twins in shaping interventions of particular interest. Professor Belcher introduced CLIMAR (Climate Impacts, Mitigation, Adaption and Resilience), a pilot project spearheaded by the JCEEI, which applies the 'hazards-vulnerability-exposure' model of risk to a variety of climate hazards, including extreme weather, flooding and increased summer temperatures.

Many of those speaking at the JCEEI event, stressed the role of emerging AI techniques, including machine and deep learning, in making sense of the vast quantities of data now being generated. **Terry Makewell**, Chief Technology Officer at the UK Hydrographic Office (UKHO), offered a recent

case study of these tools in action, referencing his team's work using deep learning models and the latest satellite imagery to map the world's mangrove forests – a critically important ecosystem.

Like others, **Mark Enzer**, Head of the National Digital Twin Programme (NDTp) at Cambridge University, emphasized the importance of systemic solutions to systemic challenges, such as climate change, which simultaneously impact our economic and social infrastructure - and the natural environment. Digital twins played a vital role here as "embodiments of the information value chain", connecting physical and digital worlds with the flow of data and helping to make "better decisions faster." The National Data Twin took things to the next level, serving as an "ecosystem of connected digital twins".

The importance of a systemic solution to Net Zero, with "people, skills and culture" at its heart, was also a theme in a talk by **Dr Iain Williams**, Director of Strategic Partnerships at the Natural Environment Research Council (NERC). Dr Williams described the technologies and tools funded by NERC to collect data at multiple scales from otherwise inaccessible parts of the environment. These ranged from planes and ships to autonomous and semi-autonomous vehicles. There was also a place for smaller-scale, locally collected data, including from citizen scientists.

Session 2 - Harnessing Open Science to Achieve Net Zero

Building an open trustworthy data ecosystem is needed to solve environmental and societal challenges, argued **Lisa Allen**, Head of Consultancy for Data Programmes at the Open Data Institute (ODI). But this is threatened, she said, by "data hoarding", which sees "a few organisations treat data like oil" to be jealously guarded, or "data fearing", whereby negative publicity, such as the 2018 Facebook-Cambridge Analytica scandal, prompts individuals and groups to withdraw access to data. The "right institutional structures, and designing for fairness, could overcome these barriers.

For **Professor Sabina Leonelli,** Professor of Philosophy and History of Science at the University of Exeter, Co-Director of the Exeter Centre for the Study of the Life Sciences and Fellow of the Wissenschaftskolleg zu Berlin, open data is "a common good" but "indiscriminate openness, can hurt people and the planet." Professor Leonelli argued that open data must be managed with careful attention to its diversity in terms of sources, formats, the ways data is exchanged, and users, be they businesses, governments or NGO actors.

Theo McCaie, who is Technical Lead for Data Science at the Met Office, also heads the organisation's Informatics Lab. The latter is built on a multidisciplinary model "open to risk, open to different disciplines and open to world." This spirit of openness recently paved the way to the Met Office's partnership project, Pangeo, which now sees a diverse community of people working collaboratively to develop software and infrastructure to enable big data geoscience research and inform decisions about Net Zero.

The Centre for Environmental Data Analysis (CEDA) is part of the Science and Technologies Facilities Council within UKRI, holds a petabyte-scale archive of atmospheric and earth observation data, and operates JASMIN, a supercomputer dedicated to environmental science. **Ag Stephens**, CEDA's Head of Partnerships, detailed how those using the technologies were guided to ensure that at the end of their projects any appropriate outputs were properly stored and available for others to use.

Session 3 - Harnessing Science in Practice to Deliver Net Zero

Although science continues to reveal new things about climate change impacts, the emphasis must now shift towards *solutions*. So argued **Professor Jason A. Lowe OBE**, Principal Fellow and Head of Climate Services for Government at the Met Office. Professor Lowe, who is also Chair in Interdisciplinary Climate Research at the University of Leeds, stressed the need to bring together experts from a wide variety of specialisms, including physical science, engineering, economics and political science.

By how much must we cut carbon emissions if we are to limit the global average temperature rise to 1.5°C above pre-industrial levels? According to **Dr Andy Wiltshire**, Head of Earth System Mitigation Science at the Met Office, data science and machine learning are needed to answer this question due to the many uncertainties in our understanding of the climate system. Unknowns include the future

function of natural carbon sinks, along with the impacts of melting permafrost and wildfires, greenhouse gases other than carbon dioxide, and new technologies and policies.

Models developed by **Dr Ajay Gambhir**, Senior Research Fellow at the Imperial College London Grantham Institute for Climate Change and the Environment, suggest that the 1.5°C threshold could be breached as early as 2035, and 2°C by 2040. Efforts must be stepped up to achieve Net Zero, but a rapid transition entails its own near-term risks in the shape of stranded fossil fuel assets, energy and food price rises. Dr Gambhir presented additional research which helps policy-makers explore these trade-offs.

Amine solvent-based technologies for removing carbon from combustion plant flue gases are viewed as one way to cut industry's huge energy-related carbon footprint. But the treated gas may itself harm human and ecological health. **Professor Anna Korre**, Co-Director of the Energy Futures Lab and Professor of Environmental Engineering at Imperial College London described how her international team of researchers are using environmental intelligence to explore these impacts, considering the migration path of treated gases while integrating climate, meteorological and atmospheric influences.

Session 4 - Harnessing AI to Achieve Net Zero

Professor Gavin Shaddick, Chair of Data Science and Statistics at the University of Exeter and JCEEI Co-Director, described how the explosion in data from monitoring and sensor networks and rapid development of data science and AI techniques present a unique opportunity to understand our complex interactions with the environment. The UK's recently published National AI Strategy sets out possible applications for monitoring, forecasting and modelling complex energy and climate systems, but, said Professor Shaddick, many are yet to be attempted.

Professor Mark Girolami, Chief Scientist of the Alan Turing Institute, described how the Institute is now taking its lead from other successful "disruptors", such a Facebook and Tesla, each of whom have adopted their own "grand challenges", providing them with strategic focus and tactical guidance, while delivering great innovations along the way. For Turing, environmental sustainability is the biggest of all grand challenges, and its work in this field includes modelling climate change impacts on food security and using AI in electricity supply control rooms.

Environmental data scientist **Dr Scott Hosking**, who is Co-Leader of the British Antarctic Survey's AI Lab, as well as Senior Research Fellow at the Alan Turing Institute, discussed the IceNet tool, a deep learning neural network his team has developed to forecast and monitor the loss and gain of sea ice. The next step is to couple IceNet to a route-planning system in order to optimise data sampling by survey vehicles in Polar Regions.

For **Professor David Topping**, a Reader at the School of Earth and Environmental Science, University of Manchester and a Fellow of the Alan Turing Institute, cities are "theatres where environmental and societal problems play out." He reflected on various 'smart city' initiatives over the years, ranging from the use of AI and modelling to forecast air pollution to the automated detection and monitoring of airborne pollen. As Professor Topping argued, for data science projects to succeed, they must engage diverse stakeholders – to improve accuracy and win trust.

Session 5 - Building Interdisciplinary Communities to Deliver Net Zero

Dr Kirstine Dale, Principal Fellow for Data Sciences and JCEEI Co-Director, reported that current teams working on Net Zero are not sufficiently diverse either in terms of academic specialism or in their gender and other demographic characteristics. This is a problem because diverse, interdisciplinary communities – which can, for instance, be built from communities of practice or hackathons – are more effective, creative and harmonious. They're also necessary to address the multiple dimensions of climate risk and to reflect the societies they represent.

Dr Kaveh Jahanshahi, Lead Data Scientist at the Office for National Statistics' Data Science Campus, argued that the multidisciplinary approach is vital for delivering the UK's ambitious climate strategy because policies will have multiple and interacting impacts on different sectors, including electricity, land use, infrastructure, mobility and aviation. Outcomes are further affected by human behaviour and socio-economic factors. Developing a digital twin, informed by varied specialisms, allows us to test Net Zero policies before actually applying them.

Professor Robert Nicholls, Director of the Tyndall Centre, University of East Anglia, introduced OpenCLIM. This multi-partner data science project, funded by the UK Climate Resilience Programme, assesses climate risks and supports adaptation across the UK. It does this by developing and applying an integrated assessment model that couples existing models with a community of developers and users. According to Professor Nicholls the tool's many applications include predicting how trends in urbanisation and agriculture might modify the impacts of climate change.

Professor Icarus Allen, Chief Executive of Plymouth Marine Laboratory and PML Applications, believes advances in environmental intelligence offer a great opportunity to transform our ability to study the ocean, including answering "big questions" around the structure and function of marine ecosystems, anthropogenic impacts and solutions to support sustainability. Among exciting recent developments referenced by Professor Allen is the new Smart Sound Plymouth initiative, a UK platform for proving, validating and demonstrating advanced marine autonomy, technology and digitalisation.

Session 6 - Working with EI Next Generation to deliver Net Zero

Felicity Liggins, the Met Office's Education Outreach Manager introduced the final session of the conference, noting that young people around the world are increasingly worried – and vocal – about climate change impacts, and want to get engaged in the solutions to these real-world environmental challenges. She described some of the opportunities provided by the Met Office for school and university students to get hands-on with the science and data alongside her organisation's wider education outreach activities, such as discussing with young people the sorts of skills they might need should they wish to enter academia or industry.

What is the human impact on climate change? This was the question that Exeter Maths School students **Matthew Butts, Louie Bond** and **Joshua Smart** recently set out to answer, with support from their teacher **Stuart Allen**. Using data from Met Office simulations and working alongside scientific experts, they explored the likelihood of extreme temperature variance in the Mediterranean and western North America regions, pinpointing where the impacts were likely to be caused by human activity. The students said the exercise opened their eyes to the realities of statistical analysis, and inspired further extra-curricular and personal projects.

Aerosols are minute solid or liquid particles suspended in our atmosphere, and are generated from many natural and anthropogenic (human-made) sources. They interact with the climate – and each other - in extremely complex ways. **Eliza Duncan**, Postgraduate Researcher, UKRI CDT in Environmental Intelligence at the University of Exeter, described her work to untangle natural aerosol processes using novel machine learning techniques to model historical trajectories of specific aerosol datapoints.

Dan Pritchard is Co-Founder of Tech South West, a cluster organisation which supports, connects and showcases the region's fast-growing tech sector, with many companies working on sustainable and green tech. He closed this year's JCEEI conference with results of a survey showing recruitment as the main challenge for his members. With nearly 20,000 students in tech across the South West, this is not for want of regional talent. "Tech South West can help," said Mr Pritchard, "but it also needs tech companies to come out and explore what's on the doorstep, forming partnerships, and showcasing what they're doing."

Conclusions

In conclusion, the 2021 JCEEI conference demonstrated the wide variety of data science research now being undertaken across the UK and beyond to deliver the Net Zero challenge. An important overall theme to emerge was the vital importance of interdisciplinary working, bringing together varied teams encompassing data and environmental scientists, engineers, social scientists, behavioural researchers and other experts. As Professor Monks highlighted in his keynote address, Net Zero is a system of systems problem – which makes it both highly complex and necessarily inclusive. No single academic discipline alone can solve it: those applying EI approaches will need to draw on a truly diverse community of practitioners bringing other forms of knowledge, experience and skills.