

Institution: University of Edinburgh		
Unit of Assessment: 7		
Title of case study: Detection of the human fingerprint in observed climate change and extremes underpins the Paris agreement on climate change and resulting policies worldwide		
Period when the underpinning research was undertaken: 2007-present		
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:
Gabriele C. Hegerl	Professor of Climate System Science	2007 – present
Simon Tett	Professor of Earth System Dynamics	2007 – present
Andrew Schurer	Senior Researcher in Climate Science	2010 – present
Debbie Polson	PDRA in Climate Analysis	2008 – 2016
Period when the claimed impact occurred: From 1 st August 2013 to 31 August 2020.		
Is this case study continued from a case study submitted in 2014? N		
<p>1. Summary of the impact (indicative maximum 100 words)</p> <p>University of Edinburgh (UoE) research on quantifying anthropogenic effects on past, present and future climates and extreme weather events, underpins climate change policies worldwide, benefiting and protecting populations across the world, particularly those most vulnerable to climate change. In particular, estimates of the human contribution to recent warming, and of the climate sensitivity (how much greenhouse gas emissions warm the climate), were key contributions to the reports of the Intergovernmental Panel on Climate Change (IPCC), which in turn had a large influence on Government commitments made in the 2015 Paris Agreement. UoE research on determining the human contribution to climate change, including to change in extreme events, influenced the 2016 report of the US National Academies on attribution of extreme weather events, which then influenced service provision on event attribution and national climate change policies in the UK and worldwide.</p>		
<p>2. Underpinning research (indicative maximum 500 words)</p> <p>UoE research has made crucial contributions to (a) estimating the human fingerprint in the climate system from observed change, and with it, the climate sensitivity (how much greenhouse gas emissions warm the climate), and (b) quantifying how changes in the frequency and/or severity of extreme weather events have already resulted from the changing climate (event attribution).</p> <p>(a) Human fingerprint and Climate sensitivity</p> <p>The UoE team has played a significant role in determining key relationships between greenhouse gas emissions and climate warming. This has been achieved by world leading analysis synthesising multiple sources of evidence, including observed warming in the pre- and post-industrial period paleoclimate and instrumental records, and physical understanding derived from worldwide modelling approaches. This led to the quantification of the Equilibrium Climate Sensitivity (ECS) ie the long-term global mean temperature increase caused by a</p>		

doubling of atmospheric CO₂ concentration from records of the observed warming [3.1] and synthesized evidence from historical warming with that from analysis of global modelling and feedback processes [3.2]. Furthermore, the human fingerprint was detected in global precipitation patterns [3.3] and in widespread intensification of extreme precipitation [3.4], confirming that human influence is changing mean and intense precipitation. These publications were used as evidence in the Intergovernmental Panel on Climate Change (IPCC) reports.

Subsequent UoE research estimated the variation in the Earth's pre-industrial climate, attributing observed variations in climate to radiative forcing and estimating detectable greenhouse gas contributions to surface temperature from across the 19th century. This research is important because it is the baseline used by the IPCC to assess climate change stabilisation targets. Analysis of the pre-industrial climate led the team to conclude that correcting this baseline reduced by up to 0.2 degrees the future further warming before the Paris Agreement targets are exceeded, with a corresponding reduction of up to 40% in the remaining future budget for carbon dioxide emissions [3.5].

(b) Event Attribution

The UoE team produced world-leading research into the crucial task of validating the hypothesis that human-caused climate change has changed both the frequency and intensity of extreme weather events. They have led the interpretation of results that found that increases in emissions of greenhouse gases have caused a 5% increase in extreme precipitation events across the globe, and have showed that human emissions have contributed to observed changes in large-scale precipitation [3.4], a finding further strengthened in recent follow-up publications [3.6]. This work underpins the attribution of recent extreme events highlighted in the National Academies report [5.5].

3. References to the research (indicative maximum of six references)

[3.1] Otto, A, Otto, FEL, Boucher, O, Church, J, **Hegerl, G**, Forster, PM, Gillett, NP, Gregory, J, Johnson, GC, Knutti, R, Lewis, N, Lohmann, U, Marotzke, J, Myhre, G, Shindell, D, Stevens, B & Allen, MR (2013). Energy budget constraints on climate response. **Nature Geoscience**, 6, pp. 415-416. doi:10.1038/ngeo1836 [197 citations]

[3.2] Knutti, R and **G. Hegerl** (2008): The equilibrium sensitivity of Earth's temperature to radiation changes. **Nature GeoScience**, 11, 735-743. doi:10.1038/ngeo337 [326 citations].

[3.3] **Polson, D., G. Hegerl, X. Zhang** (2013). Causes of robust seasonal land precipitation changes. **J Climate**, 26, 6679–6697. doi:10.1175/JCLI-D-12-00474.1. [48 citations]

[3.4] Min, S-K, Zhang, X, Zwiers, FW & **Hegerl, GC** (2011). Human contribution to more-intense precipitation extremes. **Nature**, 470, no. 7334, pp. 378-381. doi:10.1038/nature09763 [1152 citations]

[3.5] **Schurer, A**, Mann, ME, Hawkins, **E**, Tett, **S** & **Hegerl, G** (2017). Importance of the Pre-Industrial Baseline in Determining the Likelihood of Exceeding the Paris Limits. **Nature Climate Change**, 7, pp. 563-567. doi:10.1038/nclimate3345 [41 citations]

[3.6] Zhang X., Wan H., Zwiers F. W., **Hegerl G. C.** and Min S.-K. (2013) Attributing intensification of precipitation extremes to human influence. **Geophys. Res. Let** 40, 5252, doi:10.1002/grl.51010 [131 citations].

The underpinning research listed was published in highly ranked academic journals (Scopus citations as of December 2020 shown above), and supported by peer-reviewed grants. Examples include:

PI, Hegerl G. (2010-2013). Causes of changes in European mean and extreme climate over the last 500 years. [NE/G019819/1] *NERC* [GBP385,682]

PI, Hegerl G. (2013 – 2019). Transition Into The ANthropocene (TITAN). [320691] *ERC advanced grant*, [EUR2,445,545]

PI, Hegerl G. (2011-2014). PAGODA: Understanding via process-based global detection attribution and prediction. [NE/I006141/1] *NERC* [GBP352,956]

Hegerl was awarded fellowship of the American Geophysical Union “For world-leading research in understanding the drivers of historical climate change and communicating these results clearly to policy makers” (2016), and the American Meteorological Society (2019), and was awarded the Hans Sigrist Prize given by the University of Bern (2016) for work on the human fingerprint in the climate system.

She was elected Fellow of the Royal Society (2017), the Royal Society of Edinburgh (2013) and of the Leopoldina (German National Academy of Sciences, 2018).

4. Details of the impact (indicative maximum 750 words)

Informing the Paris Agreement

UoE research on the effect of increasing greenhouse gases on past and future climates and precipitation patterns has made vital contributions to reports of the Intergovernmental Panel on Climate Change (IPCC) since August 2013, with the team’s “*contribution to the IPCC and public policy*” judged “*substantial and a very good example of innovative and policy relevant research*” [5.1]. The IPCC reports directly informed the international climate change negotiations which resulted in the 2015 United Nations Paris Agreement treaty on climate change. The Paris Agreement is the overarching global framework for addressing climate change, with 194 states and the European Union (EU) as signatories in 2015. Of these, 187 states and the EU, representing about 79% of global greenhouse gas emissions, have now ratified or acceded to the Agreement.

Professor Hegerl was a lead author of the IPCC’s Working Group 1 Report on *Climate Change 2014 - the Physical Science Basis*, published in June 2014 [5.2]. This report provides a comprehensive assessment of the physical science basis of climate change since 2007 when the Fourth Assessment Report (AR4) was released. She was selected for her role based on her scientific output on the causes of climate change. Among the IPCC authors she was selected for the author team of the AR5 Synthesis Report: *Climate Change 2014* [5.2], and led the section on observed emissions and changes in the climate in that report. The AR5 Synthesis Report (approved in the IPCC plenary meeting in October 2014), is the overarching and top-level document of the IPCC 5th Assessment Report, which “*was the scientific foundation for the Paris Agreement of the United Nations Framework Convention on Climate Change*” [5.3]. The Working Group 1 co-chair describes her “*seminal work that has transformed our field... you have pioneered the method to detect fingerprints of anthropogenic climate change combining observations and climate model simulations..this [method] has become one of the central pillars of climate science*” [5.3]. Altogether the IPCC 5th Assessment Report [5.2] contains 18 citations of Professor Hegerl, 2 of Professor Tett, 3 of Dr Polson and 1 of Dr Schurer (allocated to first author listed only to avoid duplication), and the Edinburgh team has provided 3 figures. In particular, an update to [3.2] provided a key figure in the IPCC 5th Assessment Report, which was also reproduced in the Technical Summary as figure TFE6.1, and [3.1- 3.6] are all cited in IPCC 5th Assessment Report, or the 1.5 degree special report [5.2].

Professor Hegerl also led the Guidance Paper on attribution of observed climate change and impacts to causes for use across the IPCC’s working groups, which was widely used and cited in the overarching IPCC 5th Assessment Report. At the approval plenary for the report involving all the United Nations country delegations she presented the keynote presentation on climate sensitivity. This was one of only four key science presentations given to directly communicate the report’s findings to full plenary session of Government representatives [5.2, 5.3]. Professor Tett was selected to be an expert review editor for the 2014 IPCC 5th Assessment Report,

Working Group I. The former Head of Science at the Department of Energy and Climate Change describes the two key issues that the UoE team highlighted – climate sensitivity [3.1,3.2] and event attribution [5.5], as “*key policy issues which affect both the scale and urgency required of the response to climate change internationally... the agreement that was reached to limit the global temperature rise to 2C above pre-industrial levels (and to aim for as close to 1.5C as possible) and achieve net zero emissions in the second part of the 21st Century, drew directly on this and similar work*” [5.1].

Following the Paris Agreement, the United Nations Framework Convention on Climate Change requested advice from the IPCC on the target of limiting climate warming to 1.5 degrees C. The resulting 2018 landmark IPCC special report on *Global Warming of 1.5 degrees C* (1.5C Report), arguably one of the most important and influential reports in the IPCC’s history, cited four papers from UoE climate researchers, with findings from [3.5] applied directly in the calculation of the future emissions allowable without exceeding 1.5C warming. The 1.5C report has guided climate change policies across the globe including, via assessment by the UK Committee on Climate Change, the UK Parliament strengthening its climate target in June 2019 by passing legislation requiring the government to reduce the UK’s net emissions of greenhouse gases by 100% relative to 1990 levels by 2050. This was described as the ‘*defining decision of this generation in fulfilling our responsibility to the next*’ by Prime Minister Theresa May. [5.4].

Contribution to national policymaking

The UoE team’s research identifying human influence in extreme weather events has successfully engaged policymakers in the immediate risks and damages resulting from climate change. Professor Hegerl was on the committee (one of ten) that produced the 2016 US National Academies review on extreme weather event attribution [5.5], which cites 10 of her papers (5 as first author or principal supervisor; incl. [3.6]) as well as the IPCC guidance document [5.2]. This report reached the major conclusion that it is now possible to identify the role of climate change in individual extreme events. The report is “*by all metrics, [...] among the most impactful contributions of the National Academies in the past decade*” and was widely reported and communicated to US agencies and policymakers. It was downloaded more than 27,000 times by October 2020, ranking it as the most downloaded Earth Science report, and in the top 1% of all National Academies’ products. It was also covered by 300 news outlets, with “*multiple mentions by leading outlets including the New York Times, Washington Post, Forbes and CNN*”. It was briefed to numerous audiences, including multiple US government agencies, staff from House and Senate committees, and the White House Office of Science and Technology Policy. [5.6]. The report also underpinned the international development of an operational event attribution capability that can rapidly assess the factors contributing to extreme events. This “*enables analyses to be completed quickly after an event, leading to more direct connection to climate change*” in media communication about an extreme event. The work was named as one of the top ten breakthrough technologies by the MIT Tech Review in 2020 [5.6]. Professor Hegerl also wrote the section on changes in climate extremes of the Climate Updates report by the Royal Society. This was used to inform policymakers ahead of the 2017 Bonn COP23 on scientific developments in the understanding and prediction of climate change since the 2014 IPCC 5th Assessment Report [5.7].

The team’s research into extreme events and climate sensitivity has further contributed to international reports (eg Figure 10.11 in the 5th IPCC Report [5.2] is adapted from [3.3]. Professor Hegerl chaired the scientific review group for the UK Met Office Hadley Centre 2014-2017 (review group member from 2008) [5.1], and was a review group member for the recently released UK climate predictions 2018 (UKCP18) [5.8] which provide quantitative climate change predictions for UK policymakers and stakeholders informing major decisions on climate change adaptation e.g. managing flood risk and rising sea levels.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Former Head of Science *Department of Energy and Climate Change* (testimonial letter 21/04/2020)

[5.2] **a)** the overarching 5th IPCC Assessment Report- *Climate Change 2014* is at <https://www.ipcc.ch/assessment-report/ar5/>; **b)** the AR5 Synthesis report on *Climate Change 2014* is at https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf; **c)** the IPCC's Working Group 1 Report on *Climate Change 2013 - the Physical Science Basis* (approved September 2013) is at https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf; **d)** the guidance document on attribution is at <https://www.ipcc.ch/event/wgi-wgii-expert-meeting-on-detection-and-attribution-related-to-anthropogenic-climate-change/> and the IPCC special report on global warming of 1.5C is available from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

[5.3] Former co-chair of *IPCC WG1* (testimonial letter 14/06/2020)

[5.4] **a)** Explanatory Memorandum to The Climate Change Act 2008 (2050 Target Amendment) Order 2019 http://www.legislation.gov.uk/ukxi/2019/1056/pdfs/ukxiem_20191056_en.pdf section 7.2 - 7.7. ; **b)** UK Climate Change Committee Net-zero report <https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf> p.8 "We have reviewed the latest scientific evidence on climate change, including last year's IPCC Special Report on Global Warming of 1.5°C, and considered the appropriate role of the UK in the global challenge to limit future temperature increases." ; **c)** UK The Climate Change Act 2008 (2050 Target Amendment) Order 2019 <http://www.legislation.gov.uk/ukxi/2019/1056/introduction/made> "obtained and took into account the advice of the Committee on Climate Change" (see also explanatory memorandum); **d)** https://twitter.com/theresa_may/status/11387307272211138 (12 June 2019)

[5.5] Attribution of Extreme Weather Events in the Context of Climate Change. Washington DC: National Academies Press <https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change> ; Hegerl on Committee

[5.6] Senior Director, Board on Atmospheric Sciences and Climate, *The National Academies of Science, Engineering and Medicine* (testimonial letter 09/10/2020)

[5.7] <https://royalsociety.org/topics-policy/publications/2017/climate-updates/> Royal society updates on climate science, Hegerl author of section on climate extremes.

[5.8] Hegerl member of UKCP18 Peer Review Panel <https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-peer-review-panel-description.pdf>