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| **Institution:** University of East Anglia | | |
| **Unit of Assessment:** 7 - Earth Systems and Environmental Sciences | | |
| **Title of case study:** Global Temperature Research and Data Products Underpin International Climate Negotiations | | |
| **Period when the underpinning research was undertaken:** 2001 to 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:** |
| Timothy Osborn | Professor | 1990 to present |
| Phil Jones | Professor | 1976 to present |
| David Lister | Senior Research Associate | 1995 to present |
| Ian Harris | Senior Research Associate | 1996 to present |
| **Period when the claimed impact occurred:** September 2013 to December 2020 | | |
| **Is this case study continued from a case study submitted in 2014?** No | | |

## 1. Summary of the impact

The risks from human-caused climate change are global in scope and may become unrivalled in magnitude. These complex changes in climate are often encapsulated by a single metric: the global-mean temperature change. Our research has generated one of the official sources quantifying changes in global temperature including a detailed evaluation of the uncertainties. Our global temperature record demonstrates that the current decade is 1.1±0.1 °C warmer than the pre-industrial baseline. This research has been used in all major international assessments of climate change that underpin the development of national and international climate mitigation policy. The long-term goals of the primary policy, the Paris Agreement, are defined by global temperature limits and our research has been used to track progress with respect to these goals and thus also informs critical targets for global reductions of carbon emissions. Our impact has, therefore, been on the development of public policy and evaluating the progress towards the policy goals.

## 2. Underpinning research

UEA's research into changes in Earth's global surface temperature began in the 1980s at the Climatic Research Unit (CRU, part of the School of Environmental Sciences) led by Professor **Phil Jones**, and more recently by Professor **Tim Osborn**. This research produces the *land* air temperature dataset (CRUTEM **[R1, R2]**) that, through close collaboration, is combined with *sea* surface temperature data from the Met Office. The resultant global temperature dataset (HadCRUT **[R3, R4]**) is one of three main products commonly used to monitor global warming by international organisations such as the World Meteorological Organisation (WMO) and the United Nations (UN). HadCRUT is part of the WMO's Catalogue for Climate Data, as "*a trustworthy source for climate data… assessed through an internationally agreed maturity evaluation process*" (climatedata-catalogue.wmo.int).

Estimating global temperature from raw data that were not explicitly designed for climate monitoring purposes, and that therefore suffer from time-varying biases in the measurements and from incomplete geographical coverage, is a significant research challenge that we have addressed over several decades. Having multiple independent datasets, including HadCRUT **[R3, R4]**, is essential to demonstrate that the temperature record is robust to different methodological choices. Aspects of our approach that make HadCRUT distinct from other datasets (and therefore a critical part of this multi-dataset ensemble) are: (i) it is the longest established land and sea dataset (first combined in 1986); (ii) it spans the longest time period (1850 to present) getting closer to the pre-industrial baseline chosen by policymakers **[R5]**; (iii) we utilise homogenization efforts undertaken by national or regional initiatives, which benefits from knowledge of local circumstances and additional observing stations, rather than applying statistical algorithms to identify and correct for inhomogeneities **[R2]**; and (iv) we have developed a comprehensive error

model to deal with the multiple and interacting sources of potential error **[R3, R4]**. Our research demonstrates that warming far exceeds any uncertainty in the record.

Ongoing UEA research has allowed us to: (I) incorporate newly digitized or compiled measurements (a recent expansion from 4842 to 7983 weather stations, led by **David Lister**) **[R4]**; (II) create an ensemble of 200 alternative realisations to represent the uncertainties **[R4]**; (III) address biases arising from limited sampling of the fast-warming Arctic region by first acquiring more high-latitude data **[R2]** and then interpolating to obtain a spatially complete dataset (the HadCRUT5 Analysis **[R4]**).

The Paris Agreement expressed global temperature changes relative to a *"pre-industrial baseline"* but did not define this baseline. Therefore, in collaboration with the University of Reading and others, we made a more thorough assessment of the warming since the pre-industrial baseline to provide a better estimate of our remaining headroom to the Paris Agreement goals **[R5]**. Our ongoing research has continually improved and refined our estimates of global warming. It shows that the 2011-20 decade was 1.1±0.1 °C warmer than pre-industrial.

Alongside Earth's surface temperature, changes and variability in other fundamental meteorological variables (precipitation, vapour pressure, cloud cover) have also been determined by research at UEA's CRU. This has enabled the creation of a complementary and higher spatial resolution dataset (CRU TS **[R6]**, led by **Ian Harris**) to better reveal regional climate changes for multiple climate variables over land, and to derive indices for monitoring drought. CRU TS is one of the most widely used datasets in climate science **[R6]**, supporting the monitoring and analysis of variability and trends in hydroclimate, critical for many climate impacts, and relied upon as input to model simulations of terrestrial carbon fluxes for tracking the fate of our $CO_2$ emissions.

All these datasets are routinely updated and disseminated via open-access data centres and Google Earth interfaces. Output citations and data download statistics demonstrate their importance and reach (Scopus citation counts on 29/1/21 were 1058 for **[R2]**, 1416 for **[R3]**, 4849 for **[R6]**). The importance of these datasets has been recognised as essential work and now receives long-term funding from the UK's National Centre for Atmospheric Science (NCAS) to sustain it.

## 3. References to the research

*Underpinning research:* The underpinning research outputs have all been published in competitive, international, peer-reviewed journals and form part of a larger body of such published work. [Citations from Google Scholar]. **UEA authors** in bold.

**[R1]** The CRUTEM4 land-surface air temperature data set: construction, previous versions and dissemination via Google Earth.
**Osborn, T.J., Jones, P.D.**
*Earth System Science Data*, **2014**, 6(1), 61-68. DOI: 10.5194/essd-6-61-2014 [136 citations]

**[R2]** Hemispheric and large-scale land surface air temperature variations: an extensive revision and an update to 2010.
**Jones, P.D., Lister, D.H., Osborn, T.J., Harpham, C., Salmon, M.**, Morice, C.P.
*Journal of Geophysical Research: Atmospheres*, **2012**, 117(D5).
DOI: 10.1029/2011JD017139 [1081 citations]

**[R3]** Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: the HadCRUT4 dataset.
Morice, C.P., Kennedy, J.J., Rayner, N.A., **Jones, P.D.**
*Journal of Geophysical Research: Atmospheres*, **2012**, 117(D8).
DOI: 10.1029/2011JD017187 [1457 citations]

**[R4]** An updated assessment of near-surface temperature change from 1850: the HadCRUT5 dataset.
Morice, C.P., Kennedy, J.J., Rayner, N.A., Winn, J.P., Hogan, E., Killick, R.E., Dunn, R.J.H., **Osborn, T.J., Jones, P.D.**, Simpson, I.R.
*Journal of Geophysical Research: Atmospheres,* **2020**, 126(3).
DOI: 10.1029/2019JD032361 [5 citations]

**[R5]** Estimating changes in global temperature since the pre-industrial period.
Hawkins, E., Ortega, P., Suckling, E., Schurer, A., Hegerl, G., **Jones, P., Joshi, M., Osborn, T.J.,** Masson-Delmotte, V., Mignot, J., Thorne, P., van Oldenburgh, G.J.
*Bulletin of the American Meteorological Society*, **2017**, 98(9), 1841-1856.
DOI: 10.1175/BAMS-D-16-0007.1 [158 citations]

**[R6]** Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 dataset.
**Harris, I., Jones, P.D., Osborn, T.J., Lister, D.H.**
*International Journal of Climatology*, **2014**, 34(3), 623-642.
DOI: 10.1002/joc.3711 [4990 citations]

## 4. Details of the impact

Our research has had impact on public policy, because it is a significant part of the science underpinning the development of national and international climate mitigation policy. Our impact is also on the engagement that is necessary for the global public to support such ambitious and far-reaching policies. The ultimate benefit of these climate mitigation policies will be reducing the adverse impacts of climate change on society and the environment.

### Impact on public policy: international climate mitigation policy

The 2015 Paris Agreement is the flagship international climate mitigation policy: all governments agreed to limit global warming to well below 2°C and to pursue efforts to limit it to 1.5°C. These goals are considered crucial to "*significantly reduce the risks and impacts of climate change*" and they are defined in terms of global-mean temperature changes relative to a pre-industrial baseline, which our research has now better defined **[R5]**.

The Paris Agreement was negotiated under the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is a science-based convention and uses the "*information in Intergovernmental Panel on Climate Change (IPCC) reports as a baseline on the state of knowledge on climate change when making science-based decisions*" **[S1, S2]**. The UNFCCC also commissioned the IPCC to assess the science related to the Paris Agreement. It is through the IPCC reports that our research has influenced the Paris Agreement and policies to implement it **[S2]**.

Our HadCRUT global temperature record **[R3]** has appeared in the Summary for Policy Makers and Synthesis Report of all five IPCC assessments, most recently in the fifth assessment report (AR5, **[S3]**). HadCRUT4 data features in the overall Synthesis Report **[S3]** and the Summary for Policy Makers of the Working Group I (WGI) report **[S4]**. Our research on global **[R3]** and land **[R2]** temperature is cited in Chapter 2 of the accompanying WGI report **[S4]**. The co-chair of IPCC WGI (2008 to 2015) confirms the importance of our global temperature record to the IPCC: "*UEA's research led to important improvements in this record, especially in the better quantification of its uncertainties and biases, which enabled a more robust IPCC assessment of climate system warming*" **[S2]**.

Our temperature record together with our new quantification of its uncertainty **[R3]** were central lines of evidence for two of IPCC's most important findings **[S4]**. IPCC WGI co-chair confirms the impact of our global temperature research and data thus: "*Their global temperature record… was a significant line of evidence for key IPCC AR5 statements… «Warming of the climate system is unequivocal» and «Human influence has been the dominant cause of the observed warming»*" **[S2]**. These are both catalysts for urgent climate mitigation policy.

Climate mitigation policy is even more urgent because climate change is already being seen at regional scales and in ways that directly affect social and natural systems. Our CRU TS3.10 dataset **[R6]** was used as evidence in IPCC AR5 **[S4]** that such changes are underway, particularly that the hydrological cycle has already changed. Specifically, it was used in Chapter 2, with headline findings about precipitation change reported in the WGI Technical Summary (TFE.1 Fig. 2) and Summary for Policymakers **[S4]**. IPCC WGI co-chair confirms that CRU TS3.10 "*was a significant line of evidence underpinning the IPCC assessment of changes to the hydrological cycle… for example, that precipitation in the mid-latitudes of the Northern Hemisphere has increased*" **[S2]**.

The importance of the IPCC scientific assessment, including the contribution from our research, to development of the Paris Agreement is expressed by IPCC WGI co-chair: "*The Fifth Assessment Report of IPCC, especially the WGI SPM and the overall Synthesis Report, which both featured the HadCRUT global temperature record, was an important step towards the development of international climate mitigation policy embodied in the UNFCCC Paris Agreement… This importance arises because the UNFCCC is a science-based convention which uses IPCC reports as a baseline on the state of knowledge on climate change*" **[S2]**.

While the IPCC assessments synthesize the underpinning science for these policy negotiations, the temperature targets themselves were agreed following a parallel science-policy process: the "Structured Expert Dialogue" (SED) during 2013–2015. The SED led directly to the strengthening of the previous 2°C target **[S5]** and its final report **[S6]** used our HadCRUT4 record as evidence in its assessment that warming to date had reached 0.85°C (the source is given as IPCC 2013 **[S4]** which cites our underpinning research **[R2, R3]**). IPCC WGI co-chair confirms the link to policy development: "*the SED was the main science-policy process underpinning the development of the Paris Agreement and it relied entirely on the IPCC fifth assessment report for its scientific baseline*" **[S2]**.

As well as providing a catalyst for the development of stronger climate mitigation policy, our research provides a measure of progress towards meeting the policy goals (which are framed as global temperature change limits) and it critically also provides an observational constraint on the future carbon budget required to meet the temperature target. These were important considerations in the IPCC Special Report on 1.5°C (SR1.5 **[S7a]**), which was the first major assessment of the Paris Agreement goals. Our work to better define the pre-industrial baseline **[R5]** was used and cited in this report **[S7a]**. Our temperature record **[R3]** featured in its Summary for Policymakers to quantify how close historical warming has already come to the 1.5°C goal and to estimate the remaining carbon budget **[S7a]**. The UNFCCC welcomed this report and encouraged countries to use it to strengthen their scientific understanding (decisions 24-29 of the UNFCCC COP24 **[S7b]**). Thus, our research is now forming part of the science basis for the implementation of the Paris Agreement.

The impact is "near-universal" and truly global as 190 parties have ratified the Paris Climate Agreement, so almost the entire globe.

**Impact on public policy: national UK climate mitigation policy**

Our evidence of the amount and rate of global and regional European warming **[R2, R3]** also underpinned the development of UK climate policy **[S8]**. UK government policy on international action for climate change from 2010 to 2015 stated that *"The Earth's surface has consequently warmed by about 0.8°C since around 1900, with much of this warming occurring in the past 50 years"* **[S8a]**. The scientific evidence for this statement comes from our HadCRUT temperature record **[R3]** **[S8]**.

In 2019, the UK's 2008 Climate Change Act was strengthened to mandate net-zero carbon emissions by 2050. The Committee on Climate Change's "Net Zero" report (May 2019, **[S9a]**) was used as the basis for the 2019 amendment. It begins its presentation of the climate science with the warming already seen as evidenced by our global temperature record **[R3]**. The "Net Zero" report **[S9a]**, formally requested by the UK Government in 2018 to provide guidance on the timing of UK's reduction to net-zero carbon emissions, states as a "key conclusion" that "*Human activity has already led to 1°C of global warming from pre-industrial levels which has resulted in damaging impacts on lives, infrastructure and ecosystems that are apparent today*" based on our contribution to the IPCC SR1.5 report **[S7a]**. The 2019 amendment to the Climate Change Act "broadly puts into effect" the "Net Zero" recommendation from the Climate Change Committee (House of Commons Briefing Paper, Dec 2019; **[S9b]**). This chain of evidence corroborates the UK policy impact of our research.

**Impact on public understanding and engagement: societal awareness of climate change and the need for mitigation policy**

Our global temperature record **[R3]** was centre stage in what has been described as "probably the most watched broadcast about the climate ever" **[S10a]** – a segment on climate change in the

opening ceremony of the Rio 2016 Summer Olympics. This featured an animated spiral using UEA's HadCRUT4 dataset showing the rise in temperatures from 1850 to the present, originally created and popularised by Ed Hawkins (University of Reading). The International Olympic Committee estimated that 342 million people watched this opening ceremony (Reuters, **[S10b]**).

The climate mitigation policy needed to achieve the aims of the Paris Climate Agreement is so-wide reaching that it requires the engagement and support of all communities worldwide. Reaching an audience of over a third of a billion people is a significant milestone in raising public understanding of ongoing climate change.

**5. Sources to corroborate the impact**


**[S1]** Lynn J, Zabula W (2016) Outcomes of COP21 and the IPCC. World Meteorological Organisation Bulletin 65(2).

**[S2]** Testimonial letter from the co-chair of IPCC Working Group I (2008-2015) during the preparation of the IPCC AR5 report, 02.12.2020.

**[S3]** IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pp. (**HadCRUT4 [R3] features in Fig. 1a**).

**[S4]** Held on file at UEA: IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 1535 pp. **(the only global temperature uncertainty ranges shown in Fig. SPM.1 are those from our research [R3]).**

**[S5]** UNFCCC Decision 10/CP.21 links the decision to strengthen the climate mitigation policy targets directly to the Structured Expert Dialogue (points 1 and 4 of Decision 10/CP.21).

**[S6]** UNFCCC/SBSTA Report on the Structured Expert Dialogue on the 2013–2015. **Our global temperature record and confidence intervals [R3] used in Fig. 2 (black line/grey shading).**

**[S7]** a) IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways… World Meteorological Organization, Geneva, Switzerland, 32 pp. **Fig. SPM.1 is based partly on HadCRUT4 [R3]; as is Fig. 2.3 of Chapter 2 which leads to the remaining carbon budget in Table 2.2; underpinning research [R3, R5] is cited in Chapter 1**.
b) United Nations Framework Convention on Climate Change (UNFCCC) Report of COP24, December 2018.

**[S8]** a) UK government policy on international action for climate change (updated 8/5/15). First section titled "Issue" and Appendix 5.
b) Underpinning evidence from the 'climate change explained page'.
c) Met Office 2017 temperature announcement.
**Our global temperature record is used in the underpinning evidence, directly and via its reliance on the IPCC reports.**

**[S9]** a) The Climate Change Committee "Net Zero" report (May 2019). **It uses the HadCRUT4 temperature record in Fig. 2.1 from our underpinning research [R3].**
b) Net zero in the UK, House of Commons Briefing Paper Number CBP8590, December 2019

**[S10]** a) Hawkins E et al. (2019) The climate spiral demonstrates the power of sharing creative ideas. Bull. Amer. Meteorol. Soc. 100, 753-756. **This cites [R3] and confirms its appearance in the Rio opening ceremony.**
b) "Half the world watching Games, opening ceremony ratings flat: IOC", Reuters, 2016.