Institution: University of Leeds

Unit of Assessment: 7 - Earth Systems and Environmental Sciences

Title of case study: Informing international net-zero emission targets and national legislation through physical climate model emulators

Period when the underpinning research was undertaken: 2013 - 2019

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:
Piers Forster	Professor	01/08/2005 to present
Chris Smith	Research Fellow	01/12/2015 to present

Period when the claimed impact occurred: 2018 - 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

A climate emulator developed at Leeds provided the underpinning evidence for international climate policy options in response to the Paris climate agreement, through the Intergovernmental Panel on Climate Change Special Report on 1.5°C. This evidence quantified the relationship between global temperatures and emission targets, as well as the remaining carbon budget. The report led directly to national legislation in the UK, which set net-zero target dates for the first time, and similar legislation in France and New Zealand. In response to these new legislated targets, the UK has developed and implemented policy changes, and invested extensively in creating net-zero emission pathways for multiple sectors.

2. Underpinning research (indicative maximum 500 words)

When setting climate targets under United Nations Framework Convention on Climate Change negotiations, or under the UK Climate Change Act (2008), it is essential to understand how emission reduction targets and policies affect future levels of global warming. State-of-the-art climate models are useful for understanding global climate projections but are computationally intensive; one century of model simulation can take months of computer time on the world's fastest computers.

Leeds researchers developed a new physical-climate-model emulator that can replicate the outputs produced by complicated climate models. This Finite Amplitude Impulse-Response (FaIR) emulator calculated global surface temperature projections that reproduces the temperature evolution of more complicated models in a physically consistent way but takes only a fraction of a second. The emulator does not replace the complex parent models but does provide many benefits for climate policy applications. For example, outputs allow researchers to investigate multiple emission scenarios, and to make temperature projections for a wider set of possible futures and range of uncertainties.

The FaIR v1.3 physical climate emulator [1] builds on a substantial body of Leeds' research on climate sensitivity and effective radiative forcing [2, 3], and long-term contributions to the work of the Intergovernmental Panel on Climate Change (IPCC). The relationship between aerosol emissions and forcing used in the model was derived from [3]. It incorporates a simple carbon-cycle element developed by colleagues at the University of Oxford. FaIR v1.3 employs 14 other anthropogenic emissions beyond carbon dioxide, and includes volcanic emissions, solar variations and land-use change. Simulated process uncertainty is an important part of the model, allowing an evaluation of future risk.

Professor Forster led research between 2017 and 2019 as part of the NERC Highlight project, Securing Multidisciplinary Understanding and Prediction of Hiatus and Surge Events (SMURPHS). Dr Smith was the lead Research Fellow working on the project and led the coding and the model calculations. Research with the new model specifically targeted research gaps in preparation of the IPCC Special Report on 1.5°C (SR1.5). These gaps were i) how to best to estimate a remaining carbon budget [4, 5], ii) what level of emission reduction is needed for the 1.5°C target from different greenhouses gas reductions [5], and iii) how much future warming society is committed to from past emissions [6]. This research has continued through Forster's leadership of the Horizon 2020 CONSTRAIN project.

In earlier IPCC assessment reports, another simplified model (Model for the Assessment of Greenhouse Gas Induced Climate Change - MAGICC) produced climate projections. The FaIR v1.3 model improved the IPCC assessment by using newer knowledge of physical processes compared to MAGICC, and by being more transparent in its assumptions and placing the code in an open access repository (GitHub [1]). In using both models for its assessment, SR1.5 could defend more robustly its quantitative conclusions [4, pages 3-8].

Between July 2018 and October 2018, Smith and Forster used the FaIR v1.3 model for the SR1.5 report to make estimates of the remaining carbon budget for 1.5°C and 2°C thresholds of warming [4, 6]. They then helped develop a new framework for estimating this important policy-relevant measure during January and February 2019 [5]. Figure 4 of Chapter 1 of the SR1.5 report on committed warming contributions was made with FaIR v1.3 model calculations [6].

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

1. Smith, C.J., Forster, P.M., Allen, M., Leach, N., Millar, R.J., Passerello, G.A., Regayre. L.A., 2018. FaIR v1.3: A simple emissions-based impulse response and carbon cycle model. *Geoscientific Model Development*, 11, pp. 2273-2297. https://doi.org/10.5194/gmd-11-2273-2018. Model code available on GitHub https://github.com/OMS-NetZero/FaIR
2. Forster, P., Richardson, T., Maycock, A.C., Smith, C., Samset, B.H., Myhre, G., Andrews, T., Pincus, R., Schulz, M., 2016. Recommendations for diagnosing effective radiative forcing from climate models for CMIP6. *Journal of Geophysical Research: Atmospheres*, 121, pp. 12460-12475. http://dx.doi.org/10.1002/2016JD025320.
3. Carslaw, K.S., Lee, L.A., Reddington, C.L., Pringle, K.J., Rap, A., Forster, P.M., Mann, G.W., Spracklen, D.V., Woodhouse, M.T., Regayre, L.A., Pierce, J.R., 2013. Large contribution of natural aerosols to uncertainty in indirect forcing. *Nature*, 503, pp. 67-71. https://doi.org/10.1038/nature12674
4. Forster, P., Huppmann, D., Kriegler, E., Mundaca, L., Smith, C., Rogelj, J., Séférian, R., 2018. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development Supplementary Material. 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, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Supplementary material to Chapter 2. Available from https://www.ipcc.ch/sr15
5. Rogelj, J., Forster, P.M., Kriegler, E., Smith, C.J., Séférian, R., 2019. Estimating and tracking the remaining carbon budget for stringent climate targets. *Nature*, 571, pp. 335-342. https://doi.org/10.1038/s41586-019-1368-z
6. Smith, C.J., Forster, P.M., Allen, M., Fuglestvedt, J., Millar, R.J., Rogelj, J., Zickfeld, K., 2019. Current fossil fuel infrastructure does not yet commit us to 1.5 °C warming. *Nature Communications*, 10, 101. https://doi.org/10.1038/s41467-018-07999-w

Research Funding

- NERC, Securing Multidisciplinary Understanding and Prediction of Hiatus and Surge Events (2015 - 2020), GBP3million (GBP804K to Leeds)

- European Union, Constraining Uncertainty of Multi-Decadal Climate Projections (CONSTRAIN, 2019 - 2023), EUR8million (EUR1.9million to Leeds)

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

Influencing the implementation of the Paris international climate agreement

In December 2015, the Paris agreement (signed by 196 nations) called for a Special Report on Global Warming of 1.5°C in order to address policy options and solutions in response to the agreement. The publication of the SR1.5 in October 2018 employed extensive calculations made by Leeds researchers using the FaIR v1.3 model for Chapters 1 and 2 of the report, which fed directly into statements within the Summary for Policy Makers (SPM) [A]. Smith performed calculations for SPM Figure 1, and Forster acted as a drafting author of the SPM. The calculations undertaken with the FaIR v1.3 model at Leeds contributed essential quantitative information within the SPM. Specifically, this was the committed warming level from current emissions, the estimated time left before temperatures exceed 1.5°C warming, the estimated time when emissions would need to decline to zero, and the remaining carbon budget (Headlines A1, A2.2, C1 C1.3, Figures SPM1 and SPM2) [A, B]. Forster played an important role in presenting the remaining carbon budget and the underpinning methodology to international delegates, at a meeting in South Korea in October 2018, an important step in securing SPM approval [B].

The IPCC Co-Chair stated that *"…new methodologies and knowledge developed by the University of Leeds (Forster and Smith) has provided major contributions to the IPCC Special Report on Global Warming of 1.5°C (2018)."…"The new FaIR simple emission- based impulse response and carbon cycle model (developed by Leeds) has been used systematically in Chapter 2 of this report to develop a classification of mitigation pathways building on estimates of atmospheric composition, radiative forcing and global temperature outcomes until 2100. Compared to the method used in the IPCC AR5 report, and which relied on only one such model (MAGICC), the approach used in the SR1.5 allowed us to explore the robustness of the findings with a different representation of the relationship between emissions and effective radiative forcing in FaIR, and to evaluate the associated uncertainty. The FaIR model was also used to estimate the remaining carbon budget associated with the goals of the Paris Agreement, limiting global warming at 2°C or 1.5°C."… "Leeds' FaIR model was also used to develop a conceptual representation of emission pathways related to climate stabilization, clearly identifying the relationship between the timing of net zero CO2 emissions and future peak warming, due to the major effect of cumulative past, present and future CO2 emissions on climate, separated from the requirement to reduce the net radiative forcing of non- CO2 drivers. The corresponding figure from the Chapter 1 of this report has been used as one of the four figures in the Summary for Policy Makers, and has also been made available online, as an interactive tool"* [B].

The published report had a transformative global response as it set out the timetable and actions needed to limit warming to well below 2°C. It reported that zero carbon emissions should be achieved by mid-century, informed by evidence on the remaining carbon budget. The publication of the report in October 2018, led to immediate reaction from the media, public and governments around the world, focusing on the need to meet ambitious net-zero targets.

The IPCC Co-Chair stated*, "It is very clear that this report* [A] *has changed mitigation conversations from «reducing emissions» to «how to reach net zero CO2 emissions». The small margin of action identified in the assessment of remaining carbon budgets has also triggered numerous reactions, including by youth movements using this information to call for urgent climate action. Recent mitigation ambitions from cities, companies, governments are increasingly formulated with respect to the timing of reaching net zero CO_2. This highlights the importance of the contributions of University of Leeds to these aspects of the SR15 report to climate action."* [B]

In her address to the US congress, on 19 September 2019, prominent climate activist Greta Thunberg began with one science fact to illustrate the importance of climate change, by directly pointing to SR1.5 page 108, and a table of the remaining carbon budget numbers computed by the Leeds team with the FaIR v1.3 model [C].

National legislative responses

The report, and especially its negotiated summary, has led to governments introducing legislated net-zero carbon emissions targets and ambitious emission reduction plans. As a direct result of the publication of SR1.5, the UK government tasked its Committee on Climate Change to apply the emission reduction pathways of SR1.5 to national emission targets. Forster was appointed to the CCC in 2018 for his specific expertise [D] and the CCC delivered its net-zero report in May 2019, recommending a 2050 net-zero target for all greenhouse gas emissions for the UK. The report cites use of the FaIR v1.3 results directly in its technical assessment of the 2050 net zero greenhouse gases target date [E].

"The SR1.5 assessment of net-zero emission pathways played a crucial role in the instigation of the CCC's Net Zero Report."…"The University of Leeds' researchers, their development of the FaIR model and their experience of SR1.5 supported the CCC Net Zero analyses. In particular, Professor Piers Forster was appointed to the committee in December 2018 in part for his role in the SR1.5 report." [F]

The UK government responded to the Committee's direct recommendations and amended the 2008 Climate Change Act to set the 2050 net-zero target into legislation on 26 June 2019 [G], becoming the first major global economy to pass a net-zero emissions law.

"The SR1.5 assessment of net-zero emission pathways and remaining carbon budgets produced by the FaIR model were important lines of evidence in the CCC recommendation of a 2050 net-zero date for the UK." [F]

In November 2018, immediately after the publication of SR1.5, The President of France established the Haut Conseil pour le Climat, modelled on the UK CCC. Using the same evidence and science from the SR1.5 report, citing the CCC Net Zero report [E] as key evidence (43), the Conseil published a report setting a 2050 zero-emission target date [H]. This was signed into law on 29 June 2019, a few days later than in the UK.

New Zealand legislated for a net zero target in November 2019, following the SR1.5 and CCC evidence, setting up a Climate Change Commission, modelled on the CCC [I], as confirmed by [F] *"Other country governments, such as New Zealand and France, have also worked directly with the CCC to understand and replicate the analytical approach taken in the UK."*

UK policy implementation

In its advice on the net zero target, the UK CCC recommended that the Treasury undertake a funding review. The resulting Net Zero Review Interim Report was published in December 2020, as the first of its kind from a finance ministry to set out the steps toward transition to net-zero by 2050 [J], with reference to [E] and [G]. The report outlines the UK government response to date including investments across multiple sectors announced in the UK budget of March 2020. These included GBP1,130,000,000 for a Carbon Capture and Storage (CCS) Infrastructure Fund to help establish four CCS clusters by 2030, a GBP240,000,000 Net Zero Hydrogen Fund, GBP2,400,000,000 for transport decarbonisation, and GBP640,000,000 for tree planting and peatland restoration.

During 2020, NHS England established an expert panel, including Forster, to chart a practical route map to enable the NHS to respond to Net Zero targets. The outcome was a report [K] published in October 2020 to guide this process of action for the NHS, which is the UK's largest employer, and responsible for 4% of the nation's carbon emissions.

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

A. Report. 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, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp. Headlines A1, A2.2, C1, C1.3, Figures SPM1 and SPM2.
B. Letter from Co-Chair of the IPCC Working Group 1.
C. News Article. Greta Thunberg's speech to the US congress printed in the Independent newspaper, 19 September 2019. Refers to the carbon budget computed at Leeds in Chapter 2 (p. 108) of SR1.5.
D. Press Release. UK Committee on Climate Change. 3 December 2018.
E. Report. UK Committee on Climate Change. *Net Zero – The UK's contribution to stopping global warming*. May 2019. Chapter 2 (p. 68-69)
F. Letter from the Chief Executive of the UK Committee on Climate Change
G. UK Legislation. Amendment to the Climate Change Act (2008). June 2019.
H. Report - Haut Conseil Climat, France. Annual Report 2019. p. 22.
I. New Zealand Legislation. Climate Change Response (Zero Carbon) Amendment Act 2019. New Zealand Ministry for the Environment summary of the details of the amendment and actions.
J. Report. HM Treasury Interim Net Zero Review, 17 December 2020. Box 1A P14-16 sets out the UK government's work on the transition to Net Zero and references E and G.
K. Report. NHS England. *Delivering a 'Net-Zero' National Health Service*. October 2020. Expert panel members are listed in Annex A, p .52. Forward explains the role of the NHS in meeting the net-zero targets.