**How to provide useful attribution statements - Lessons learned from operationalising event attribution in Europe**

*Friederike E.L. Otto1,\*, Sarah Kew2, Sjoukje Philip2, Peter Stott3, Geert Jan van Oldenborgh2*

*\*corresponding author:* [*f.otto@imperial.ac.uk*](mailto:f.otto@imperial.ac.uk)

*1Grantham Institute, Imperial College London, UK.*

*2Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands.*

*3 Met Office Hadley Centre, Exeter, UK.*

*Operational attribution protocols ensure transparency of assessments, communication needs to include future changes in extremes and meteorological development of the event to add value in local decision making.*

**Introduction**

In the immediate aftermath of an extreme weather or climate-related event, the question is invariably asked whether and to what extent it was influenced by anthropogenic climate change. As a trusted source of weather information, National Meteorological Services (NMSs) in particular are facing this question and given their status as government services they are expected to answer, leading to calls for operationalising event attribution studies. Under the umbrella of Copernicus, the European climate service provider, a team of scientists and several national Met Services started a pilot project, following established frameworks (van Oldenborgh et al. 2021; Philip et al. 2020) to test whether the task of attributing individual weather extremes can now be taken over by an operational service for the simpler extremes (cold and hot extremes, large-scale precipitation extremes).

While it has long been established that the likelihood and intensity of heatwaves and heavy rainfall events is increasing in a warming climate, the degree to which they are changing is varies greatly depending on the exact temporal and geographical extent of the event (Harrington & Otto 2018; Leach et al. 2020).

In addition, anthropogenic climate change is far from being the only contributor to changing extreme weather events faced by natural and human systems. Other drivers such as population changes, water usage (Otto et al. 2015), surface roughness or land use changes (Vautard et al. 2019) can also play a role. The final risk to extreme weather is compounded by exposure and vulnerability to hazards. These factors are continuously changing and in the short-term the most amenable to protecting our society, e.g., through heat plans and updated building standards or improved water & drought management.

As such, it is important that all those aspects leading to damages and losses from extreme weather events that can be attributed and projected in a given location, like human-induced climate change, be disentangled from natural variability and other drivers in exposure and vulnerability in order to provide different European regions with the best available evidence to face global warming and give them ways to adapt to the changing nature of weather and climate extremes (van Oldenborgh et al. 2021; Stone, Rosier & Frame 2021). To ensure relevance for society and decision makers it is extremely important to involve (local) exposure and vulnerability experts.

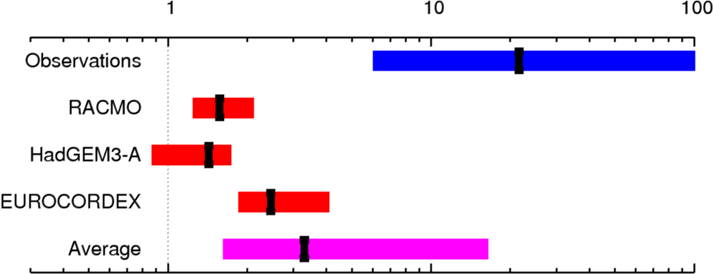
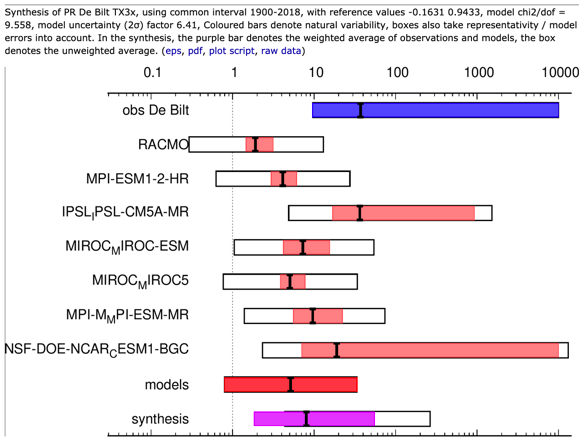
When the pilot started, the science of attributing heatwaves and large-scale heavy rainfall events had been well established in the scientific literature with a large basis of scientific papers published, in particular on European events. For example the National Academy of Science in the US assessed the “readiness” of these methods for implementation and concluded that for hot, cold and wet events methods are indeed reliable (National Academies of Sciences, Engineering 2016). Thus, the primary aim of the pilot was not to test the reliability of the scientific methodology to attribute extreme weather events but to implement a scientific methodological approach into an operational protocol that can be applied within operational services. These tests have been performed by undertaking four different event attribution studies, two slow ones reassessing previously published studies and two fast ones attributing previously unstudied events under quasi-real-time conditions.

In the remainder of this paper we discuss the two events that were re-attributed and compare them with the original attribution studies, we reflect on the functioning of the operational team, and finally we discuss several aspects that can act to strengthen attribution statements in the future.

**Re-Attributing of events**

The attribution procedure itself includes the trigger, the event definition, the trend detection in the observations, model evaluation, estimating the contribution from climate change, hazard synthesis, vulnerability and exposure analysis and writing up the results. Based on an initial draft protocol, the attribution protocol has been tested thoroughly through test attribution studies each one led by a researcher from different NMSs. Two are highlighted below, the other two led to similar conclusions.

As the first slow attribution study the project reassessed the influence of human-induced climate change on the summer heatwave 2018. The study built on an earlier World Weather Attribution assessment <https://www.worldweatherattribution.org/attribution-of-the-2018-heat-in-northern-europe/>. The scientific report can be found here <https://attribution.climate.copernicus.eu/wp-content/uploads/2018-heatwave-study-tech.pdf>.



*Fig. 1: Probability ratios depicting the change in likelihood for a 3-day 2018 heatwave (T3Xx) in DeBilt (Netherlands)as estimated in a rapid assessment in July 2018 (right-hand side) and a test-operational assessment in spring 2020 (left-hand side).*

Figure 1 shows the direct comparison of the attribution results for the station of De Bilt. The main result of the study, the attribution statement that human-induced climate change has increased the likelihood of the event to occur by a factor of at least 1.8 (2020 analysis) is within the uncertainties of the rapid assessment from July 2018 which gave an increase in the likelihood of a factor of 3.3 (1.6 … 16). The main reason for the differences is the slightly different event magnitude. For the 2020 analysis under Copernicus the summer of 2018 was over and thus the chosen event, the hottest 3-day maximum (TX3x) was estimated at a temperature of 33.7C. The rapid study in 2018 was undertaken before the end of the summer, in July 2018, so TX3x was only 33C. The difference of 0.7C changes the upper bound in in the observations based probability ratio from 500 in the 2018 analysis to infinity. In consequence, a quantitative best-estimate of the role of climate change cannot be given in the 2020 analysis and the overall probability ratio is unbounded. This means that the uncertainty range is so large that only the lower bound can be meaningfully quantified. However, due to the fact that the models considerably underestimate the trend, the estimates of the lower bounds given in both cases are very conservative, potentially dramatically underestimating the role of climate change.

Between 30th May and 2nd June 2013 intense rainfall led to flooding in many parts of Germany, most significantly in upper areas of the Danube and Elbe rivers. Though there were few casualties, the flooding caused millions of Euros of damage. An attribution study of the event had been published (Schaller et al. 2014) finding no significant role of climate change. Revisiting the analysis of the rainfall in the 4-day period in late spring 2013, including six more observational years, we still found that despite expecting the intensity of rainfall to increase on a global average as a result of climate change, there was no statistically significant increase in the likelihood of this event due to human-induced climate change.

In this second study, about half the models that were used and passed the evaluation showed a significant increase in the likelihood of the event to occur leading to an overall increase in the model result which overall leads to an inconclusive result for the Elbe, but an increase for the Danube, again not significant though.

From a very high-level perspective the results of the 2013 and 2020 studies are thus the same. However, these estimates, if presented only as inconclusive and thus no attributable change, would result in a very conservative estimate, potentially downplaying the role of climate change. We know this as in the slow study from May 2020 the same event was also assessed for a future warming level of 2 degrees, were for both basins an increase in the likelihood of a factor of 4.2 (Elbe) and 3.2 (Danube) respectively was found. A result that suggests that despite their statistical insignificance the trends towards a higher likelihood and intensity of the observed event are indeed due to climate change. This difference between models further supports the need for more process-based thinking to be included in future in operational attribution assessments in order to determine which models capture – or fail to capture – the relevant processes and thereby improve the robustness of such assessments.

**Discussion**

Both events were performed by operational teams from the NMSs following a detailed protocol, and at the end of the four events the teams could do these attributions without guidance from scientists experienced in this established attribution framework. Whilst a large team size ensures the use of multiple models and a wider public support, a larger team becomes more ponderous, with more decisions required and a higher level of detail in the protocol, yet still with need of expert judgment.

Both test studies showed that employing the published attribution methodology provides quantitative results that are robust against changes in models and datasets and, to a degree that this is expected in a non-stationary climate, also time. In that respect the protocols have been shown to be fit for purpose and do not overplay the role of climate change (Bellprat & Doblas-Reyes 2016). However, the test studies have also shown that, especially when also taking the projected changes in the respective extreme events into account the quantitative estimates are conservative.

It has been argued that this by Diffenbaugh (2020) (Lloyd & Oreskes 2018; Lloyd & Shepherd 2020; Mann, Lloyd & Oreskes 2017), that current practice is too conservative in emphasizing the robustness of the attribution assessment and focusing on lower bounds when these are least ill-defined and thus underestimating the role of anthropogenic climate change and consequently misinforming the public.

And while these arguments might indeed be very valid, if the only purpose of an attribution study would be to answer a polar question of whether climate change played a role, we argue that this is not the main added value of an individual attribution study. The answer to that question could mostly be gained from a general understanding of how extremes are changing in a warming climate as undertaking most recently again by the IPCC (Seneviratne et al. 2021).

Both studies summaries above and all studies undertaken following the protocols include a detailed description of the event, as well as the role of vulnerabilities and exposure and thus the local context in a globally changing climate. This purpose could be strengthened by incorporating for example assessments of future changes in the likelihood of the event directly into the uncertainty assessment to calculate the synthesis result or approach this issue within the communication of the results only. The former will however only be meaningful if the climate change signal has simply not emerge from the noise, if however drivers other than greenhouse gases, e.g. aerosols mask the effects (van Oldenborgh et al. 2018) errors would be introduced. In any case systematically assessing the reasons for discrepancies between present and future changes will improve the usefulness of attribution studies.

Communications needs to be very clear on what the limitations of an individual event attribution study are, i.e. that they present a snapshot of the role of climate change on a very specific event at a point in time. This is also a strength, in that all factors of that event are taken into account, e.g., circulation change, possible other drivers that give a trend that deviates from the global mean one.

Having tested the developed protocols for operational attribution in two instances the performance of the protocol and reliability of the results from a scientific point of view has been very successful and for the purpose of scientific appropriateness the attribution protocol advocating the multi-method approach and maximum transparency is the best currently available approach to event attribution. Towards the future development of operationalising event attribution a conscious decision on where the service stands between risking to overstate the role of climate change and underestimating it by issuing too conservative statements needs to be undertaken. In the evolution of the service these findings need to be taken into account when developing communication strategies.

**References**

Bellprat, O. & Doblas-Reyes, F. 2016, ‘Attribution of extreme weather and climate events overestimated by unreliable climate simulations’, *Geophysical Research Letters*, vol. 43, no. 5, pp. 2158–64.

Diffenbaugh, N.S. 2020, ‘Verification of extreme event attribution: Using out-of-sample observations to assess changes in probabilities of unprecedented events’, *Science Advances*, vol. 6, no. 12, p. eaay2368.

Harrington, L.J. & Otto, F.E. 2018, ‘Adapting attribution science to the climate extremes of tomorrow’, *Environmental Research Letters*.

Leach, N., Li, S., Sparrow, S., van Oldenborgh, G.J., Lott, F.C., Weisheimer, A. & Allen, M.R. 2020, ‘Anthropogenic influence on the 2018 summer warm spell in Europe: the impact of different spatio-temporal scales’, *Bulletin of the American Meteorological Society*.

Lloyd, E.A. & Oreskes, N. 2018, ‘Climate Change Attribution: When Is It Appropriate to Accept New Methods?’, *Earth’s Future*, vol. 6, no. 3, pp. 311–25.

Lloyd, E.A. & Shepherd, T.G. 2020, ‘Environmental catastrophes, climate change, and attribution’, *Annals of the New York Academy of Sciences*, vol. n/a, no. n/a.

Mann, M.E., Lloyd, E.A. & Oreskes, N. 2017, ‘Assessing climate change impacts on extreme weather events: the case for an alternative (Bayesian) approach’, *Climatic Change*, vol. 144, no. 2, pp. 131–42.

National Academies of Sciences, Engineering, and M. 2016, *Attribution of Extreme Weather Events in the Context of Climate Change*, National Academies Press, Washington, D.C.

van Oldenborgh, G.J., Philip, S., Kew, S., van Weele, M., Uhe, P., Otto, F., Singh, R., Pai, I., Cullen, H. & AchutaRao, K. 2018, ‘Extreme heat in India and anthropogenic climate change’, *Natural Hazards and Earth System Sciences*, vol. 18, no. 1, pp. 365–81, viewed 2 July 2018, <https://www.nat-hazards-earth-syst-sci.net/18/365/2018/>.

van Oldenborgh, G.J., van der Wiel, K., Kew, S., Philip, S., Otto, F., Vautard, R., King, A., Lott, F., Arrighi, J., Singh, R. & van Aalst, M. 2021, ‘Pathways and pitfalls in extreme event attribution’, *Climatic Change*, vol. 166, no. 1, p. 13.

Otto, F.E.L., Coelho, C.A.S., King, A., Coughlan de Perez, E., Wada, Y., van Oldenborgh, G.J., Haarsma, R., Haustein, K., Uhe, P., van Aalst, M., Aravequia, J.A., Almeida, W. & Cullen, H. 2015, ‘Water shortage in southeast Brazil’, *Bull. Amer. Meteor. Soc.*, vol. 96, pp. 35–44.

Philip, S., Kew, S., van Oldenborgh, G.J., Otto, F., Vautard, R., van der Wiel, K., King, A., Lott, F., Arrighi, J., Singh, R. & van Aalst, M. 2020, ‘A protocol for probabilistic extreme event attribution analyses’, *Advances in Statistical Climatology, Meteorology and Oceanography*, vol. 6, pp. 177–203.

Schaller, N., Otto, F.E.L., van Oldenborgh, G.J., Massey, N.R., Sparrow, S. & Allen, M.R. 2014, ‘The heavy precipitation event of {May--June} 2013 in the upper {Danube} and {Elbe} basins’, *Bull.\ Amer.\ Met.\ Soc.*, vol. 95, no. 9, pp. S69–72.

Seneviratne, S.I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S., Wehner, M., Zhou, B., 51 O. Yelekçi, R.Y. and B.Z. (eds. )]. . I.P., 52, 54, 53 Date: August 2021, 55 This document is subject to copy-editing, corrigenda and trickle backs. & 345, 11-1 Total pages: 2021, ‘Weather and Climate Extreme Events in a Changing Climate.’, in V. Masson-Delmotte, P. Zhai, A. Pirani, S. Connors, C. Péan, S. Berger, N. Caud, L. Chen, L. Goldfarb, M. Gomis, M. Huang, K. Leitzell, E. Lonnoy, R. Matthews, T. Maycock, T. Waterfield, O. Yelekçi, R. Yu & B. Zhou (eds),*Climate Change 2021: The Physical Science Climate, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Change*, Cambridge University Press.

Stone, D.A., Rosier, S.M. & Frame, D.J. 2021, ‘The question of life, the universe and event attribution’, *Nature Climate Change*.

Vautard, R., Jan Van Oldenborgh, G., Otto, F.E.L., Yiou, P., De Vries, H., Van Meijgaard, E., Stepek, A., Soubeyroux, J.M., Philip, S., Kew, S.F., Costella, C., Singh, R. & Tebaldi, C. 2019, ‘Human influence on European winter wind storms such as those of January 2018’, *Earth System Dynamics*.