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Enhancing public understanding of extreme weather events in a changing climate through ClimaMeter

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Abstract: *ClimaMeter is a real-time platform designed to provide rapid, science-based assessments of extreme weather events and their links to climate change. ClimaMeter's methodology relies on identifying large-scale atmospheric circulation patterns and comparing them to historical data, analysing how the intensity of extreme weather events have changed because of anthropogenic climate change or natural climate variability. By leveraging historical climate data, machine learning, and real-time weather observations, ClimaMeter delivers near-instantaneous attribution results, enabling informed decision-making in a time when media cycles and public attention are brief. This speed is crucial for climate action, as it helps policymakers, emergency responders, and the public understand the role of climate change in specific extreme events and take timely, effective measures. This allows for quicker, data-driven responses to disasters, such as the 2023 French heatwave and Storm Poly, by informing disaster response, infrastructure planning, and resilience-building efforts. ClimaMeter also plays a key role in countering climate change misinformation, offering clear, evidence-based explanations to the public and media. By bridging the gap between scientific research and policy applications, ClimaMeter supports climate action, promotes public awareness, and aids in the development of adaptation and mitigation strategies to address the growing risks posed by climate change.*

Plain Language Summary: *Climate change has led to an increase in the frequency and intensity of extreme weather events, posing significant challenges to societies worldwide. ClimaMeter is an innovative platform designed to assess and contextualize these events in near real-time, providing clear statements about their relationship with climate change. By analyzing phenomena such as heatwaves, cold spells, heavy precipitation, and windstorms, ClimaMeter serves as a crucial resource for researchers, policymakers, and the general public. This article explores ClimaMeter's methodology, its role in enhancing public understanding, and its impact on climate-related decision-making processes. Through case studies and data analysis, we demonstrate how ClimaMeter contributes to informed decision-making and fosters greater climate resilience.*

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1. Introduction

Extreme event attribution (EEA) is a rapidly advancing scientific discipline that seeks to determine the influence of climate change on individual extreme weather events (Trenberth et al. 2015, Vautard et al. 2016). By comparing observed meteorological conditions to historical climate records and model simulations, EEA enables scientists to quantify how human-induced greenhouse gas emissions have altered the probability and intensity of specific events. From the seminal work of Allen (2003) who attributed the 2003 heatwave in Europe to climate change, hundreds of studies have shown that climate change has made heatwaves more frequent and intense, increased the likelihood of extreme precipitation, and contributed to the strengthening of tropical cyclones and wildfires (Masson-Delmotte et al. 2021). These findings have provided essential scientific evidence for policymakers and the public, reinforcing the need for mitigation and adaptation strategies to address the growing risks posed by extreme weather (Newman & Noy 2023). However, while EEA has significantly improved our understanding of climate change's role in extreme weather, traditional attribution studies often take weeks or months to complete. This time lag between an event occurring and the publication of a scientific assessment is increasingly problematic in an era where news cycles and public discourse move at an unprecedented pace. The gap between the occurrence of an extreme weather event and the availability of climate attribution results creates space for speculation, misinformation, and a lack of clear guidance for decision-makers.

Recognizing this challenge, several scientific initiatives have emerged to accelerate the process of extreme event attribution. The World Weather Attribution (WWA) initiative, a collaboration between international research institutions, was among the first efforts to provide relatively rapid assessments of climate change's role in extreme weather (Otto et al. 2016, Stott et al. 2016). WWA has developed a streamlined methodology that allows for event attribution within days to weeks after an event (Philip et al 2020). Their studies have demonstrated that climate change has made extreme events more intense and frequent (see. e.g. Otto et al. 2022). Other initiatives, such as the Berkeley Earth group (Paciorek and Wehner 2016; Reed and Wehner 2023), various national or international meteorological agencies such as Copernicus Climate Services (Buontempo et al. 2022), The Climate Shift index (Pershing et al. 2024) and few others have also begun conducting climate attribution studies to inform policymakers and the public. However, despite these advancements, some of the attribution efforts remain too slow to meet the demands of modern communication and crisis response.

The time lag in extreme event attribution presents a serious challenge for climate communication, risk assessment, and disaster preparedness. When a major heatwave, flood, or storm occurs, journalists, policymakers, and the public immediately seek answers about whether climate change played a role (Osaka & Bellamy 2020). In the absence of fast and reliable scientific assessments, discussions often become dominated by speculation, with some downplaying the influence of climate change and others making exaggerated claims without supporting evidence (Zanocco et al. 2024). This can create confusion among the

public and weaken the effectiveness of climate communication. Additionally, the delay in attribution studies limits the ability of governments and emergency responders to incorporate climate science into real-time disaster response and recovery planning. For instance, if a rapid attribution study were available immediately after an extreme event, it could help inform policy debates, emergency relief efforts, and long-term infrastructure planning. Without timely attribution, the lessons learned from a given extreme event often arrive too late to shape policy decisions or public perception effectively.

Another limitation of existing rapid attribution efforts is their reliance on computationally expensive climate model simulations, which require significant time and resources. Traditional EEA studies involve running multiple climate models under different greenhouse gas emission scenarios to compare the probability of an event in today's climate versus a world without human-induced warming (Shepherd, 2016). While this approach provides robust and scientifically rigorous results, it also means that even the fastest existing attribution efforts still take several days to weeks to complete. In contrast, media cycles and public attention spans operate on much shorter timeframes. When a major disaster occurs, initial news reports dominate headlines for generally 24 to 48 hours, after which public attention often shifts to other topics (El Khaled et al. 2019). The media attention, however, can depend on various factors such as socio-economic-political conditions and concurrent events. By the time an attribution study is released, the media narrative has often already been established, and its findings struggle to gain the visibility needed to influence public discourse.

To address these challenges, the scientific community must continue developing even faster attribution methods that can deliver credible, science-based assessments within hours or days after an extreme event occurs (Schiermeier 2018). Recent advances in artificial intelligence, machine learning, and statistical climate modeling offer promising pathways toward achieving this goal. Instead of relying solely on new climate model simulations, researchers are exploring methods that leverage precomputed model simulations, historical analogs, and statistical techniques to provide near-instantaneous assessments of whether climate change influenced a specific event. However, while some progress has been made in this area, there is still no widely accepted, fully operational system capable of producing extreme event attribution results within a time frame that matches the speed of modern news cycles. Given the growing urgency of rapid climate attribution, ClimaMeter was developed as a real-time tool designed to bridge the gap between climate science and public communication (Faranda et al. 2024a). Unlike traditional attribution studies that require days to weeks for analysis, ClimaMeter operates using precomputed climate model data, statistical methods, and real-time weather observations to provide faster assessments of extreme weather events. By leveraging historical climate data and machine learning techniques, it aims to evaluate whether human-induced climate change has influenced the probability or intensity of an extreme event almost as it unfolds. This approach is intended to provide immediate reports that can inform the public, policymakers, and media professionals at the crucial moment when public discourse on an event is at its peak.

The main objective of this article is to present ClimaMeter, explain its methodology, and discuss how it fits within the broader landscape of extreme event attribution. By comparing its capabilities with existing initiatives, we will highlight the advantages and challenges of fast attribution methods and their implications for climate communication and decision-making. The article will also examine case studies where ClimaMeter has been applied to recent extreme weather events, demonstrating its potential impact in shaping public understanding and informing policy responses. Finally, we will explore future directions for improving real-time climate attribution, including advances in data assimilation, artificial intelligence, and integration with early warning systems. To structure this discussion, the next section will provide a detailed explanation of the ClimaMeter methodology, including the datasets it uses, the statistical techniques it applies, and how it compares observed weather conditions with historical climate variability. Following this, we will present examples of past events analyzed by ClimaMeter and evaluate how its results have contributed to climate discourse. The article will then discuss the strengths and limitations of this approach, particularly in comparison to other attribution initiatives. We will conclude by outlining potential improvements and discussing the broader role of real-time attribution in climate science and policy-making.

2. Methodology

ClimaMeter employs a methodology that focuses on analyzing atmospheric circulation patterns, particularly surface-pressure configurations, to assess extreme weather events (Faranda et al. 2022). The process begins by identifying a specific surface-pressure pattern over a defined region and time frame that has led to the extreme weather conditions under investigation. This pattern is then compared to historical data, typically divided into two equal periods: an earlier “past” period and a more recent “present” period. By using physics-informed machine-learning techniques, ClimaMeter searches for analogous weather conditions in these datasets to determine how the frequency or intensity of such patterns has evolved over time. This approach allows for the assessment of whether observed changes are attributable to natural climate variability or anthropogenic influences. Notably, ClimaMeter’s methodology does not rely on numerical model simulations; instead, it leverages historical data, enabling rapid and reproducible analyses. However, this reliance on historical analogs can present challenges when encountering unprecedented extreme events, as the absence of similar past occurrences may limit the analysis.

ClimaMeter relies on analogues as a core component of its methodology to provide rapid and scientifically robust attribution of extreme weather events. The analogue approach is based on identifying past occurrences of similar large-scale atmospheric circulation patterns and comparing their frequency and intensity over different climate periods (Yiou et al 2014, Faranda et al. 2023a, Faranda et al. 2023b, Dong et al. 2024). By conditioning the analysis on circulation rather than on specific meteorological variables such as temperature or precipitation alone, ClimaMeter can directly assess how climate change has influenced the broader atmospheric conditions that drive extreme weather. This approach offers several key advantages. To account for the possible influence of low-frequency modes of natural

variability in explaining the differences between the two periods, we also consider the possible roles of the El Niño-Southern Oscillation (ENSO), the Atlantic Multidecadal Oscillation (AMO), and the Pacific Decadal Oscillation (PDO).

One of the primary reasons for using analogues is their ability to provide a direct link between climate variability and extreme events without requiring complex and computationally expensive climate model simulations. Instead of generating new model runs for each individual event, ClimaMeter searches within historical reanalysis datasets for instances of comparable atmospheric configurations. These analogs are then employed to assess whether these configurations are occurring for the first time, how rare they are, and whether associated variables like temperature, wind speed, and rainfall have intensified. This allows for a rapid assessment of how climate change may have altered the likelihood or severity of an extreme event.

An additional advantage of conditioning on circulation is that it enables the study of multiple hazards simultaneously (Jézéquel et al. 2018). Because large-scale atmospheric patterns often govern several types of extreme weather at once, the analogue approach allows ClimaMeter to analyze compound events—situations where multiple extreme weather events occur simultaneously or in close succession. For example, a persistent blocking high-pressure system over Europe might lead to concurrent heatwaves, droughts, and wildfires in southern regions while contributing to intense storms and flooding in northern areas. By examining how the intensity of such circulation patterns has changed and covering a large number of events (over 70 in only 1.5 years of activity), ClimaMeter helps understand not only individual extreme events but also their statistics, which is crucial for understanding systemic risks in a changing climate.

The use of circulation-based analogues also makes it possible to generate spatial maps of climate change impacts on extreme weather patterns. Unlike traditional attribution studies that often provide a single numerical estimate of how much climate change has influenced a specific event, ClimaMeter's approach allows for a more detailed geographical perspective. By mapping the regions where similar atmospheric patterns have historically occurred and comparing their frequency in past and present climates, ClimaMeter can illustrate how climate change is reshaping entire weather regimes across different areas. This is particularly useful for decision-makers and stakeholders who require localized information on climate risk rather than broad, generalized conclusions.

Overall, the use of analogues and circulation-based conditioning in ClimaMeter enhances the speed, scope, and spatial precision of climate attribution studies. It provides a powerful framework for understanding how climate change is modifying extreme weather patterns on a large scale while also allowing for the study of multi-hazard and compound events.

ClimaMeter employs a structured protocol to ensure that its reports on extreme weather events are both objective and scientifically rigorous. This protocol is designed to minimize personal bias and provide clear, data-driven insights into the relationship between specific weather events and climate change.

The report-writing process begins with the collection of relevant data, including meteorological measurements, scientific analyses, and pertinent news reports. To assist in compiling and interpreting this information, ClimaMeter uses conversational tools. These tools aid in synthesizing complex data into coherent narratives, ensuring that the information is both accurate and accessible. Each report follows a standardized structure to maintain consistency and clarity. This structure includes sections such as an event description, climate and data background, analysis, and conclusions. By adhering to this format, ClimaMeter ensures that all relevant aspects of an event are thoroughly examined and presented in a logical sequence. A key aspect of ClimaMeter's protocol is the emphasis on data-driven analysis. The reports focus on presenting statistical findings and empirical evidence without inferring personal opinions or speculative conclusions. This approach ensures that the assessments are grounded in observable data, enhancing their credibility and reliability. Furthermore, ClimaMeter's methodology relies on historical data and avoids the use of numerical model simulations. This reliance on observed data allows for rapid and reproducible analyses. However, it also means that in cases where extreme events are unprecedented, the lack of historical analogs can pose challenges for analysis.

By following this structured protocol, ClimaMeter aims to provide objective, transparent, and timely assessments of extreme weather events in the context of climate change. This approach not only enhances the scientific integrity of the reports but also ensures that stakeholders receive clear and unbiased information to inform decision-making. Finally, ClimaMeter's collaborative approach, involving international research teams, enhances the scientific community's capacity to understand and address the complexities of climate change (Brinkmann, R. 2020).

3. Some Examples

ClimaMeter has been used to analyze several recent extreme weather events, analysing the influence of climate change on their characteristics (see Figure 1 for an ensemble of the events analyzed since July 2023).

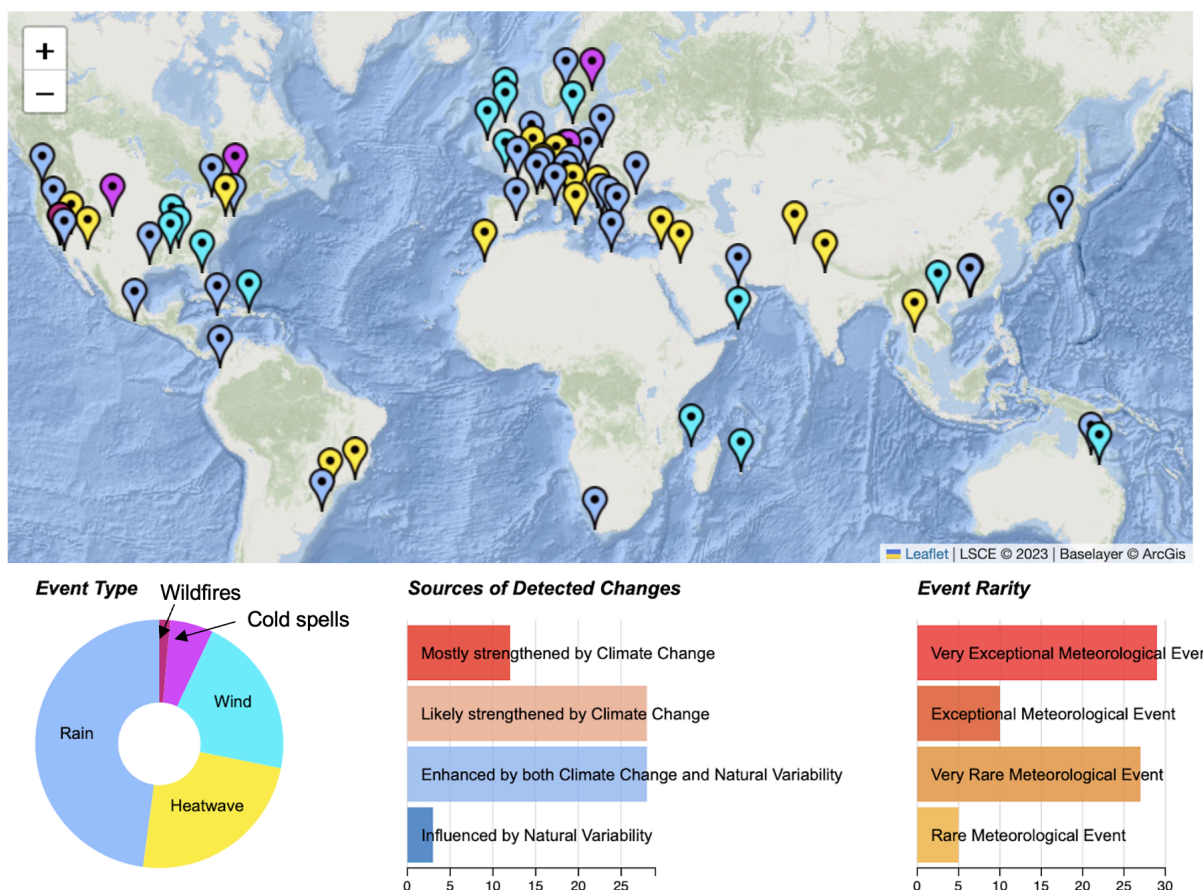


Figure 1: Events covered in ClimaMeter since July 2023.

Among the first events analysed is the late-summer French heatwave on 21–23 August 2023. For this event, the analysis indicated that such heatwaves have become more frequent and intense in recent years, consistent with trends attributed to anthropogenic climate change.

Similarly, ClimaMeter evaluated Storm Poly, which occurred in July 2023. By analyzing the storm’s surface-pressure configurations and comparing them to past records, the platform found that windstorms of similar magnitude have increased in intensity, suggesting a possible link to human-induced climate alterations.

In October 2024, Storm Kirk brought record rainfall across France, leading to widespread flooding and power outages. ClimaMeter’s analysis indicated that climate change intensified the storm’s rainfall by 20% and increased wind speeds by 12%, highlighting the role of human-induced warming in exacerbating such events.

In January 2025, Storm Éowyn impacted parts of Ireland and France with significant wind and precipitation. ClimaMeter’s assessment found that storms similar to Éowyn are now up to 4 hPa deeper, 10% windier, and up to 15% wetter compared to historical records, suggesting a notable influence of climate change on the storm’s intensity and moisture content.

Many other examples are available on the ClimaMeter platforms but these illustrate the variety of the results that can be obtained with the ClimaMeter approach.

4. First implications of ClimaMeter for Climate Action

ClimaMeter plays an essential role in countering misinformation on climate change by providing scientifically grounded explanations for extreme weather patterns. In an era where climate-related misinformation can spread rapidly, the platform serves as a reliable source of information, distinguishing between natural variability and climate change-driven trends. By engaging with journalists, educators, and the general public, ClimaMeter helps foster a nuanced and fact-based understanding of extreme weather attribution, reducing the risk of misinterpretation or politicization of climate science. ClimaMeter has been cited in various press articles across multiple countries, highlighting its contributions to understanding the connection between extreme weather events and climate change. Some of the key countries involved in this media coverage include Australia, the United States, France, Spain, the United Kingdom, Italy, Germany, Colombia, India, Brazil, Turkey, and Mexico. Key media outlets citing ClimaMeter include prominent news outlets such as *The Independent*, *BBC News*, *France 24*, *Le Monde*, *Futura-Sciences*, *NBC News*, *Al Jazeera*, *Reuteurs*, *AP*, *El Pais*, *La Vanguardia*. Additionally, various local media outlets, such as *Mediapart*, *RTS*, and *El Espectador*, have also reported on ClimaMeter's contribution in extreme weather analysis (for an overview please visit <https://www.climameter.org/media-coverage>). This widespread media coverage reflects the growing recognition of ClimaMeter's impact in both scientific and public discourse on climate change and its effects on extreme weather events. Part of this success is due to the platform's standardized reports, the use of a single, clear figure to present the results, and the fact that the reports avoid overstating their findings or the implications of the analyses. This cautious approach helps maintain the platform's credibility while effectively contributing to discussions around climate change and its impacts.

ClimaMeter's real-time analyses offer several benefits for climate political action. By providing rapid assessments of extreme weather events, it enables policymakers to make timely and informed decisions regarding disaster response and mitigation strategies (Adams et al. 2020). Indeed ClimaMeter's impact goes beyond media attention, as the platform plays an active role in collaborating with the scientific community and policymakers to enhance climate event attribution methods. For instance, the ClimaMeter report on the 2023 floods in France (Faranda et al. 2024b) was instrumental in compiling a report for the Prefect of the Hauts-de-France region, aimed at strengthening the resilience of flood-affected territories (Palhol et al. 2024). This request for ClimaMeter analyses came directly from the Inspection Générale de l'Environnement et du Développement Durable (the French Ministry for Ecological Transition) after the minister's office saw the study featured in the media. Through these collaborations, ClimaMeter not only enhances public understanding but also contributes to the refinement of climate attribution science, bridging the gap between research and policy applications.

Beyond its role in media and scientific communication, ClimaMeter also serves as a valuable educational tool. The platform's results have been utilized to engage PhD students in attribution studies and to provide rapid reports on past phenomena. For example, during the TROPICANA (Tropical Cyclones in the Anthropocene: Physics, Simulations, and

Attribution) program held at Paris-Saclay in June 2024 (Faranda et al., 2024c), participants and students collaborated to produce a report on Medicane Ianos (Gonzalez Aleman et al, 2024). They also explored best practices for communicating findings and motivating climate action to mitigate the impact of Mediterranean cyclones. These efforts have contributed to widespread recognition, including mentions in public platforms like Wikipedia (see e.g. the Wikipedia citation on California wildfires: https://en.wikipedia.org/wiki/2025_California_wildfires). ClimaMeter's open-access reports and interactive analyses are widely used by educators, students, and researchers, providing valuable resources for understanding the complexities of climate change attribution. By making climate science more accessible to a broader audience, ClimaMeter empowers individuals and communities to engage more deeply with climate action, fostering awareness and advocacy grounded in scientific evidence.

5. Limitations

While ClimaMeter and similar initiatives provide valuable tools for understanding the relationship between extreme weather events and climate change, there are several limitations that need to be considered. One of the primary challenges is the complexity of accurately attributing specific weather events to climate change (Van Oldenborgh et al. 2021). Despite advancements in modeling and data collection, the chaotic nature of weather systems means that it is often difficult to pinpoint a direct cause-and-effect relationship between climate change and any individual event.

Another limitation is the availability and quality of data. All attribution efforts rely on methods, models and datasets, the accuracy of their conclusions depends heavily on the quality of the input data. In regions where data is sparse or unreliable, the assessments may be less robust. Furthermore, there are still gaps in understanding how various climate drivers interact at different scales, which can affect the precision of attribution analyses (Slater et al. 2021, Clarke et al. 2022). Additionally, the time scales involved in climate change and extreme weather events are vastly different. Climate change occurs gradually over decades or centuries, while extreme weather events happen on shorter time scales, sometimes within a matter of hours or days (Fan et al. 2021). This mismatch in time frames can make it challenging to link specific events directly to long-term climate trends, even with advanced attribution techniques (Clarke et al. 2023).

Finally, while national attribution services are expected to provide more localized analyses, they also face challenges related to computational resources, expertise, and political or institutional constraints (Lahsen & Ribot 2022). These factors can limit their capacity to deliver timely or comprehensive assessments, especially in countries with fewer resources to dedicate to climate research.

6. Conclusions

ClimaMeter represents a significant advancement in the field of climate attribution, particularly through its ability to provide near-instantaneous assessments of extreme weather

events and their links to climate change. By leveraging historical data and machine learning techniques, ClimaMeter offers a faster alternative to traditional attribution methods, which often require weeks or months to produce results. This real-time approach has the potential to improve public understanding and support more timely decision-making by policymakers, emergency responders, and the general public. However, despite these advantages, ClimaMeter and similar initiatives face several challenges. The complex nature of extreme weather events, combined with data limitations and the inherent difficulty of attributing individual events to long-term climate trends, presents ongoing hurdles (Callaghan et al. 2021). Indeed while ClimaMeter contributes to more efficient climate action, the need for broader collaboration and continued methodological improvements remains.

A possible direction for ClimaMeter's future development includes expanding its focus to model not only the attribution of extreme weather events but also their impacts, exposure, and vulnerability (Drakes & Tate, 2022), thereby providing a more comprehensive understanding of how climate change affects different regions and communities as outlined in Faranda et al. (2023b) and Jezequel et al. (2024). This would allow for a better assessment of the broader consequences of climate change and support more targeted adaptation and mitigation strategies. The work of ClimaMeter highlights the importance of making climate science more accessible and actionable, with the aim of fostering better preparedness and response to the growing risks posed by climate change. As more national attribution services come online and other initiatives like WWA and Copernicus continue to develop, a more integrated and comprehensive approach to climate event attribution can and should be achieved.

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