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Published Version

Sillmann, J., Shepherd, T. G., van den Hurk, B., Hazeleger, W., Martius, O., Slingo, J. and Zscheischler, J. (2021) Event-based storylines to address climate risk. Earth's Future, 9 (2). ISSN 2328-4277 doi: https://doi.org/10.1029/2020EF001783 Available at http://centaur.reading.ac.uk/94766/

To link to this article DOI: http://dx.doi.org/10.1029/2020EF001783

Publisher: Wiley

AGU ADVANCING EARTH AND SPACE SCIENCE

Earth's Future

COMMENTARY
10.1029/2020EF001783

Event-Based Storylines to Address Climate Risk

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Key Points:

- Event-based storylines are a way to communicate and assess climate risk taking into account aspects of vulnerability and exposure
- Event-based storylines focus on plausibility rather than probability when looking at high-impact events
- Event-based storylines can provide climate information that feeds directly into a particular decision-making context

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Citation:

Sillmann, J., Shepherd, T. G., van den Hurk, B., Hazeleger, W., Martius, O., Slingo, J., & Zscheischler, J. (2021). Event-based storylines to address climate risk. *Earth's Future*, *9*, e2020EF001783. https://doi.org/10.1029/2020EF001783

Received 27 AUG 2020
Accepted 3 DEC 2020

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Abstract The climate science community is challenged to adopt an actionable risk perspective, which is difficult to align with the traditional focus on model-based probabilistic climate change projections. Event-based storylines can provide a way out of this conundrum by putting emphasis on plausibility rather than probability. This links directly to common practices in disaster risk management using "stress-testing" for emergency preparedness based on events that are conditional on specific and plausible assumptions. Event-based storylines allow for conditional explanations, without full attribution of every causal factor, which is crucial when some aspects of the latter are complex and highly uncertain.

Plain Language Summary One of today's major challenges is how to use insights and information from climate sciences to inform decision-making regarding managing risks from climate change, where weather and climate extremes represent a major component of climate-related risk. So far, climate science has taken a probabilistic approach producing large model ensembles and exploring likely ranges, thereby neglecting low-likelihood but potentially high-impact events that pose significant risks to society. Event-based storylines are emerging as an alternative way to explore future high-impact events while taking into account aspects of vulnerability and exposure of the considered system with an emphasis on plausibility rather than probability. This concept links directly to common practices in disaster risk management using "stress-testing" for emergency preparedness based on events that are conditional on specific, but plausible assumptions. When co-developed by climate scientists and stakeholders, event-based storylines can be informed by physical climate and impact modeling and can provide a useful way of communicating and assessing climate-related risk in a specific decision-making context.

1. Event-Based Storylines to Address Climate Risk

The traditional approach in climate science has long been to propagate information about climate change into the domain of climate risk focusing on probabilities, likelihoods, and return values, but largely avoiding discussion of low-likelihood events which are by their very nature deeply uncertain. Yet the latter could bear the highest risks. In the Chair's vision paper for the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) addressing all three Working Groups, it is emphasized that climate risk should be assessed in relation to other economic and societal risks and associated uncertainties that are relevant to decision-making (IPCC, 2017). In IPCC reports, risk is defined as the probability of occurrence of hazardous events or trends multiplied by the impacts of these events or trends (IPCC, 2014), and as the interaction of exposure, vulnerability and the (climate-related) hazard, and the likelihood of its occurrence (IPCC, 2018). Such an approach puts an emphasis on reliability of the probabilistic estimates, which from a statistical perspective requires large sample sizes. To this end, large model ensembles are produced and coordinated, most notably in the Coupled Model Intercomparison Projects (CMIP), the Coordinated Regional Downscaling Experiment (CORDEX), and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), with fairly crude process representation and coarse spatial resolution. This can overlook essential (small-scale) features of high-impact events, for which these models are not designed. There are efforts to push the models to higher spatial resolution, for example, HighResMIP (Haarsma et al., 2016), but the

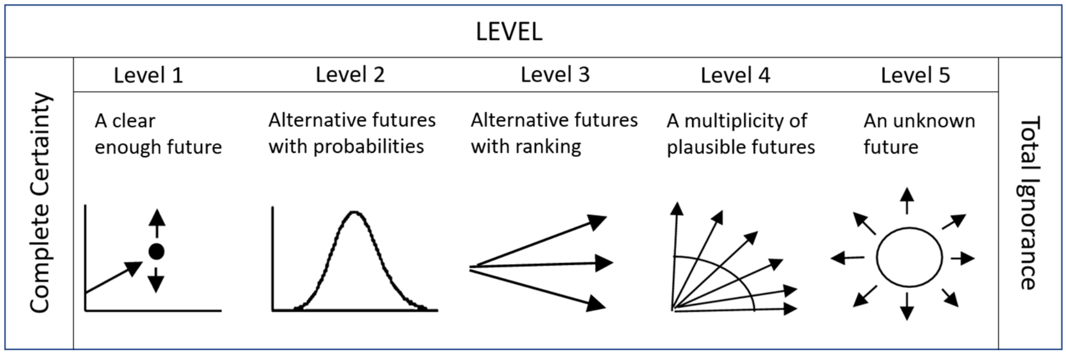


Figure 1. Representation of different levels of uncertainty in the context of decision-making under deep uncertainty. Adapted from Marchau et al. (2019).

higher resolution necessarily comes at the price of ensemble size and/or model diversity. Once the information is spatially aggregated, model projections of changes in many climate extremes are remarkably consistent (Fischer et al., 2013). However, the process of spatial aggregation blurs useful information on local extreme events that is informative for regional to local risk assessment.

Given that climate extremes represent a major component of climate risk, and 90% of natural disasters are weather- or climate-related (UNISDR, 2015), it makes sense to start from the disaster risk reduction (DRR) framework and seek to bring climate information into this framework. Indeed, in the IPCC Special Report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) the focus was put on disaster risk (see Figure 1-1 in Lavell et al., 2012). Sutton (2019) has argued that Working Group I (focusing on the Physical Science Basis) in the 5th Assessment Report (AR5) of the IPCC did not explicitly adopt a risk approach as it did not address the possibility of low-likelihood, high-impact outcomes. In so doing, it prioritized the avoidance of false positives (e.g., overstating the effects of climate change) over false negatives (e.g., missing certain changes in extremes) (Shepherd, 2019). In the coming 6th Assessment Report (AR6), IPCC strives to bridge between Working Group I and Working Group II (focusing on Impacts, Adaptation, and Vulnerability) using the risk framing developed together with the DRR community in the SREX as a vehicle. Since societal impact is central in this approach, this means that where reliable probabilities are available, more emphasis needs to be placed on the low-likelihood, high-impact part of the distribution (which entails its own challenges). But in many cases, especially in the DRR context, this is not possible, and more of an event focus in the sense of disaster forensic or "what-if" scenarios is needed (Swart et al., 2013).

Event-based storylines, which are physically self-consistent unfoldings of past events, or of plausible future events, have been proposed as a way of articulating the risk in such cases where we need to go beyond a purely probabilistic climate change perspective, with an emphasis on plausibility rather than probability (Hazeleger et al., 2015; Shepherd et al., 2018). This concept links directly to common practice in disaster risk management using "stress-testing" for emergency preparedness based on events that are conditional on specific (plausible) assumptions about the hazards and possibly aspects of exposure and vulnerability of the affected human or ecological system.

Event-based storylines allow for conditional explanations, without full attribution of every causal factor, which is crucial when some aspects of the latter are highly uncertain (e.g., due to unusual natural variability or limited process understanding). Event-based storylines go beyond attributing past events or their physical drivers and give the opportunity to explore plausible future events. An example is the combined role of La Niña and global warming in the record-setting 2011 Texas drought-heatwave event, for which Hoerling et al. (2013) showed that La Niña played a key factor in the drought. They argued that these anomalous conditions were the result of natural variability, based on the fact there was no sign of these conditions becoming more likely in CMIP simulations. Rupp et al. (2015) used a probabilistic approach that was conditional on the observed La Niña event, finding a clear anthropogenic signal of warming but no anthropogenic signal in either precipitation deficit or reduced soil moisture, that is, no signal in the drought components. Lloyd and Shepherd (2020) pointed out that anthropogenic changes in La Niña are uncertain.

They expanded the CMIP uncertainty space of the 2011 Texas drought-heatwave event using storylines that allowed for the possibility that La Niña conditions might become more common under climate change, and expanded the risk space by exploring biological responses to extreme environmental events. Moreover, an event-based storyline approach can be used in combination with probabilistic model assessments for addressing regional climatic impact-drivers (e.g., in terms of dynamics, extremes, compound events [Zscheischler et al., 2018]) and uncertainties related to societal factors (see example in the Box).

For the future, event-based storylines allow for the representation of multiple, mutually exclusive outcomes in situations where the uncertainty is high, or for "climate surprises." An example of the latter would be an imagined tropical cyclone landfall in Mumbai (Sobel et al., 2019). The explication of the relevant causal factors that is intrinsic to storyline development provides a means for linking different kinds of evidence (e.g., data from climate models, analog cases from the past, expert knowledge), documenting assumptions (e.g., a +2° warming), constructing physically plausible counterfactuals (e.g., by perturbing certain aspects of historical events), understanding complexity (e.g., the specific interactions between hazard, vulnerability and exposure), and facilitating an iterative process of co-development with stakeholders. This supports arguments made by Lloyd (2015) related to having both model agreement (with observations or related to a climate change signal) and causal explanations as the basis for model evaluation and assessment of model robustness.

How these aspects can come together is illustrated in the case study in the Box, where the UK Government wanted to know whether the Extreme Flood Outline that they base their risk assessment and respective policy decisions on was still fit for purpose given a major storm event in 2015. The question was stakeholder-driven, and the scientific information was put together within a prescribed timeframe (very short by normal scientific standards) to address that very specific question. Because return periods represented a regulatory metric for the UK Government, the results had to be cast within their decision-making context by providing probabilistically derived return periods, even though the storylines themselves are not associated with probabilities.

BOX. Case Study of UK Flood Risk

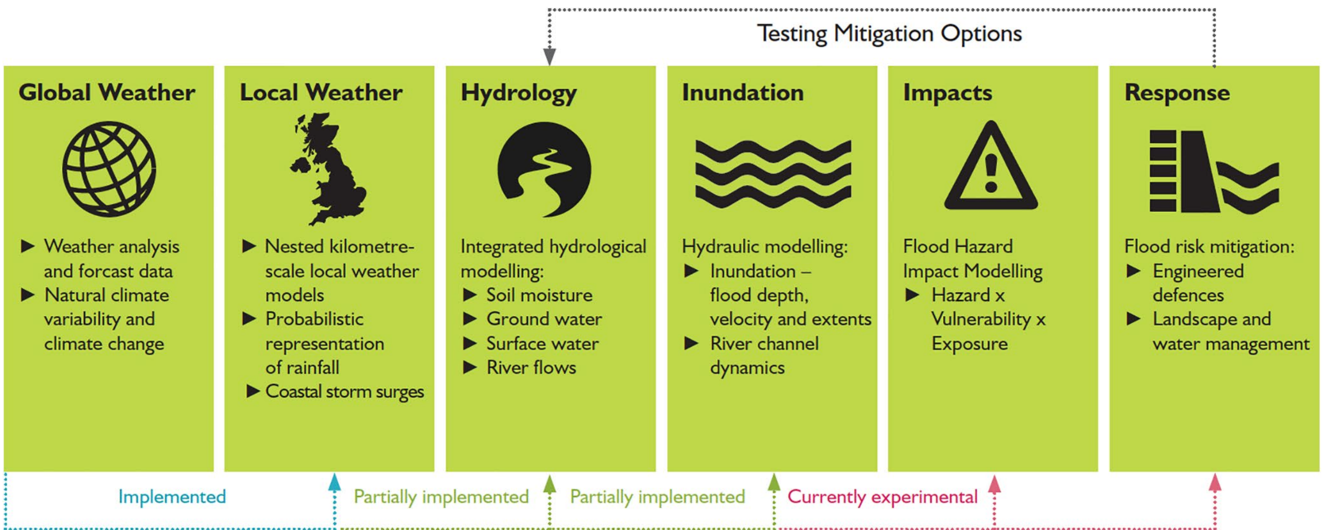
Concerned by the unprecedented rainfall and severe flooding that resulted from Storm Desmond in December 2015, the UK Government wanted to know how bad rainfall could be and whether its Extreme Flood Outline maps (which affect insurance and disaster preparation) were adequate. It asked the UK Met Office and Environment Agency to provide plausible worst case scenarios (and to do so within 6 weeks), so as to stress-test the maps as part of a major National Flood Resilience Review (NFRR, 2016).

The standard risk assessment for flooding looks at 1-in-100-year risk (1% chance). Probabilistic estimates of that risk level from observations alone, for example, based on extreme value analysis, have too large an uncertainty to be useful, because of the shortness of the observational record. Instead, the question was addressed through the construction of a storyline based on Storm Desmond, namely an event-based storyline.

All extreme flooding events are linked to specific weather patterns that arise primarily from natural variability. Using large ensembles of global climate simulations, which are regularly produced in seasonal and decadal forecasting, it is possible to sample a much larger number (1,000s) of meteorologically plausible weather events for the current climate that may result in more extreme rainfall than has been seen in the short observational record—so called black swans (Thompson et al., 2017). This approach allowed a much more robust identification of plausible extremes and identified a 1% risk of regional rainfall being 20%–30% higher than the most extreme rainfall observed so far. To test the plausibility of these model weather events, the simulated weather charts were given to Met Office operational forecasters, who were unable to distinguish them from real weather charts, and confirmed that they would likely lead to heavy rainfall and serious flooding.

The problem was then how to take this information from the global models, working at the regional weather scale, down to the local scale of flood risk. Ideally this would be achieved through dynamical downscaling with the kilometer-scale UK forecast model, but this was not feasible in the time available. Instead, using an event-based storyline approach, the kilometer-scale UK forecast model was used to create a counterfactual "black swan" version of Storm Desmond by artificially increasing its precipitation, using a uniform uplift factor of 20%–30% based on the global model results without violating physical constraints. Thus, probabilistic information was used as part of the storyline approach, to meet user requirements in terms of 100-year return levels.

The output from the counter-factual Storm Desmond was used to drive a local flood model in a range of catchments, including the center of Carlisle which was badly affected. In this way, an auditable chain of evidence was built (NFRR, 2016). For example, the results showed that even with a 20% increase in precipitation, the flooded areas in Carlisle would only have exceeded those observed in Storm Desmond by a small amount (because of the particular shape of the flood plain in this area), and more importantly would have stayed within the Extreme Flood Outline. Similar results were obtained for other high-risk cities and coastal communities. This allowed the UK Government to conclude that the Extreme Flood Outline was still fit for purpose as a policy tool, and to adjust their risk register accordingly. A major recommendation of the NFRR was the development of an end-to-end, event-based storyline approach using simulations for identifying extreme flood risk and assessing effective adaptation and mitigation options at the local level (see Box figure).



Box Figure. Example of a seamless modeling pathway for assessing flood risk that allows storylines and exploration of the options for reducing risk (based on NFRR, 2016).

As with scenario storylines (IPCC, 2014), event-based storylines are, by design, not assigned probabilities. The emphasis is rather on their plausibility, salience, and relevance from a vulnerability perspective. However, as shown with the case study of UK flood risk in the Box, event-based storylines can be fully quantitative in the sense of producing a quantification of impact (i.e., whether existing flood risk maps are fit for purpose), and the construction of the counter-factual will in general be guided by probabilistic information. While entirely probabilistic estimates of risk are appropriate within a decision framework of cost-benefit analysis, event-based storylines recognize the presence of deep uncertainty and are well suited for robust or scenario-neutral decision-making (e.g., Marchau et al., 2019). The latter is the more natural context from a preparedness perspective and better aligns with DRR community practices and language (e.g., Doyle et al., 2019). Figure 1 depicts the spectrum of qualitative levels of uncertainty lying between complete certainty and total ignorance. IPCC Working Group I has generally framed its findings according to Level 1 or 2, or with a statement being "likely" (a limited form of Level 3). Working Groups II and III have dealt with their comparatively high levels of uncertainty by expressing their findings in a conditional manner (Mastrandrea et al., 2011). Event-based storylines are similarly conditional, and are informative when the likelihood of a cause is uncertain, but the effect it would have is more certain (e.g., like the uncertainty around future La Niña conditions, but the more certain impacts of an associated drought in Texas when it happens). In this way, event-based storylines can span uncertainty Levels 3 and 4 as illustrated in Figure 1. This information, if taken together (i.e., considered in a similar manner in a decision-making process) with the probabilistic information derived from multimodel exercises, can widen the information space as a basis for decision-making and for facilitating action. Isolation of individual events from the probability space and zooming in on them with high resolution simulations via event-based storylines can provide additional insights (e.g., Schaller et al., 2020), expose hidden or unexpected features and allow for a detailed mapping of consequences. They can also be used to explore the efficacy of possible adaptation and mitigation actions by considering the residual risk within a "what if" framework.

To conclude, event-based storylines are a complementary way of articulating the risk perspective with an emphasis on plausibility, rather than the probabilistic emphasis that has been the primary focus in climate science so far. A key aspect of designing an event-based storyline should be to use a modeling chain (see Box figure), from climate models (including global and regional climate models) to impact models or assessments, so they can provide climate information that feeds directly into a particular decision-making context (e.g., Hegdahl et al., 2020). There are different ways in which physical modeling can support such event-based storyline approaches which offer a promising avenue to better connect with decision-makers, and to incorporate aspects of vulnerability and exposure in the risk assessment (Sillmann et al. 2019). An engaged co-development or co-production process (Vincent et al., 2018) including the scientific community and stakeholders (as for instance elaborated in the UK flood risk example; see Box) can make event-based storylines a credible, useful, and salient method for providing climate information to decision-makers, particularly in the context of low-likelihood high-impact events.

Data Availability Statement

There was no actual data collected or used for writing this commentary.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Acknowledgments
The authors acknowledge the insightful discussions and presentations held at the Workshop on "Physical modeling supporting a storyline approach" in Oslo, Norway (April 2019, https://www.cicero.oslo.no/en/publications-and-events_twex/workshop-on-physical-modeling-supporting-a-storyline-approach) and the Workshop on Correlated Extremes in New York, USA (May 2019, http://extremeweather.columbia.edu/workshop-on-correlated-extremes/), both supported by the European COST Action DAMOCLES (CA17109) and the WCRP Grand Challenge on Weather and Climate Extremes. J. Sillmann particularly acknowledges the discussion with Kate White (US Army Corps of Engineers) that helped consolidating thoughts for this commentary. J. Sillmann was supported through the TWEX (grant #255037) and TWEX-film (grant nr. 304551) projects funded by the Research Council of Norway. J. Zscheischler acknowledges the Swiss National Science Foundation (grant nr. 179876), O. Martius acknowledges the Swiss National Science Foundation (grant nr. 178751). T. G. Shepherd acknowledges the European Research Council (grant 339390). We further acknowledge the comments of two reviewers that helped to improve this Commentary.

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