**Beyond Factivity: Examining Storyline-Based Understanding in Detection and Attribution of Extreme Weather and Climate Events**

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**Abstract:**

Climate scientists working in the field of detection and attribution (D&A) have developed a “storyline” approach to the analysis of extreme weather and climate events. Despite its intended complementary role to traditional “risk-based” approaches, the storyline approach has been met with scepticism and a degree of reluctance, constraining the expression of its full potential. Philosophers of scientific understanding can help articulate the unique value of storyline-based understanding, framing it as a distinct but genuine form of scientific understanding. Conversely, philosophical debates on the nature of scientific understanding, especially concerning its relation to truth and facts, can be advanced by examining risk-based and storyline approaches in the field of D&A. This paper advances both endeavours and draws two main conclusions. First, both risk-based and storyline approaches typically resort to non-veridical representations, based on counterfactuals and idealizations. However, they do so in qualitatively different ways. As a result, these approaches yield functionally distinct states of scientific understanding. Second, storyline-based understanding qualifies as genuine under the evaluative criteria of both factivist and non factivist positions in the philosophy of scientific understanding. Building on this, the paper proposes an alternative “transfactive” approach, which further supports the genuineness of storyline-based understanding in contexts marked by deep uncertainty.

Keywords: Storyline approach, scientific understanding, risk-based approach, detection and attribution, extreme weather and climate events, idealizations, counterfactuals

*“Once we come to see that many of our best theories are idealizations, we will also see why our best chance of understanding the world must be to have a plurality of ways of thinking about it” (Appiah 2017, x).*

1. Introduction: The Overarching Story

Since the early 2000s, “risk-based” or “probabilistic” approaches have dominated the field of detection and attribution (D&A) of extreme weather and climate events (Lloyd and Oreskes 2018). At their core, these approaches aim primarily to estimate the probability that a specific extreme event is caused by human-induced climate change (Allen 2003; Stott et al. 2004). In recent years, risk-based approaches have been criticised for their inadequate representations of uncertainties, both those intrinsic to the climate system and those arising from how it is represented (Herrando-Pérez et al. 2019; Hopster 2023; Stoerk et al. 2018). At the same time, researchers have expressed growing interest in a broader range of questions and problems related to extreme events, which the risk-based approach is not well equipped to address (Hazeleger et al. 2015; Kennel et al. 2016; Trenberth et al. 2015).

As a result, an alternative approach has emerged over the past decade within D&A: the “storyline” approach, also referred to as “physical climate storylines” and “event-based storylines” (Baldissera Pacchetti et al. 2024; Shepherd 2016; Sillmann et al. 2021). This method describes multiple, plausible, and physically self-consistent pathways of past or future singular, localized events, conditional on specific contributing causal factors (Shepherd et al. 2018, 557). The storyline approach is allegedly better suited than the risk-based approach to address key aspects of “deep” uncertainty surrounding extreme events (ibid., 563-4). Moreover, it appears to align more closely with a broad range of decision-making concerns (ibid., 562-3). Notably, the storyline approach helps bridge a persistent gap between scientific climate knowledge and the lived experiences of affected communities. As Shepherd and Lloyd (2021) claim, scientists are typically trained to produce quantitative, general, and abstract conclusions, whereas most people – including decision-makers – engage more readily with stories that are qualitative, contingent, and particular (2-3).

Despite its intended complementary role, the storyline approach has faced harsh criticism and even outright hostility from scientists and decision-makers who adhere to the risk-based approach (Lloyd and Oreskes 2018, 318-9). This tension is heightened by the seemingly contradictory conclusions that the two approaches often yield. Nonetheless, this conflict can be elucidated by realizing that risk-based and storyline approaches tend to address different research concerns. Broadly speaking, risk-based approaches aim to estimate the likelihood of certain classes of events, while the storyline approach seeks to describe plausible causal pathways for individual, localized events.

In this paper, I argue that one way to foster the broader adoption of the storyline approach is to characterize its epistemic contribution as a distinctive form of genuine scientific understanding under conditions of deep uncertainty. This characterization, however, must be accompanied by a more detailed description of storyline-based understanding, including a comparative analysis that clarifies how this form of understanding complements and diverges from that offered by the risk-based approach. Without such developments, the value of the storyline approach risks being overlooked, to the detriment of the scientific community, decision-makers, and civil society at large.

The philosophical literature on scientific understanding offers valuable resources for this endeavour. However, the field is still young and marked by significant disagreements over fundamental issues, such as the nature, value, and varieties of understanding. These disagreements make it difficult to simply select and apply philosophical insights to shed light upon practical cases. Part of the challenge stems from disciplinary differences: epistemologists often favour abstract conceptual analyses, while philosophers of science – especially those working in the philosophy of science in practice – tend to adopt more empirically grounded approaches. Following the latter tradition, my strategy is to engage with the ongoing controversy between proponents of risk-based and storyline approaches in D&A. By examining their practices, I aim to inform and refine philosophical accounts of scientific understanding.

In this sense, this paper addresses a twofold problem. On the one hand, the storyline approach requires legitimation, vis-à-vis the risk-based approach, as a method that affords a distinct yet genuine form of scientific understanding. On the other hand, the very notion of genuine scientific understanding requires further philosophical elaboration, informed by emerging scientific practices. This paper tackles both issues, exploring the synergies between the storyline approach and the philosophy of scientific understanding. This exploration aims to foster the legitimation and broader adoption of the storyline approach and advance internal philosophical debates in the philosophy of scientific understanding.

To these ends, the paper advances two main conclusions. First, both risk- and storyline-based understandings typically rely on non-veridical representations, using idealizations and counterfactuals, but do so in qualitatively different ways. These differences result in functionally distinct forms of scientific understanding, each suited to different scientific and decision-making contexts. Second, storyline-based understanding qualifies as genuine under the criteria of two opposing positions in the philosophical literature: factivism and non-factivism. Moreover, it also meets the criteria of a third approach I introduce here: the “transfactive” approach.

In an attempt to embrace the power of stories, this paper is structured around three of them. The first – the “climate scientists” story – can be seen, with some levity, as a coming-of-age story, one in which climate scientists confront increasing complexity and novelty in their field, navigate resistance and challenges, to eventually reach a more mature stage. The second – the “philosophers of science” story – conveys the seemingly unsolvable struggle between opposing camps in the philosophy of scientific understanding: factivism and non-factivism. The third – the “interdisciplinary” story – highlights points of encounter and mutual improvement, showcasing the interdisciplinary synergies between philosophers of scientific understanding and climate scientists working in D&A. The paper ends with some concluding remarks that serve as the morals of these stories.

1. The “Climate Scientists” Story: Facing Complexity, Novelty, and Change

For over three decades, climate scientists have engaged in two closely related endeavours: detection and attribution (D&A) of climate change. Detection involves demonstrating statistically significant changes in the climate system, while attribution seeks to identify and evaluate the relative contributions of causal factors to these changes, with a certain level of statistical confidence (Hegerl et al. 2010, 2). Since the early 1990s, D&A has developed as a research field and eventually led to a scientific consensus on global climate change. This consensus is clearly articulated – for example – in the first key finding of the IPCC’s Sixth Assessment Report: “It is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred” (IPCC 2021, 4). This statement affirms the reality of climate change (detection) and identifies humans as a cause (attribution). As a result, anthropogenic climate change (ACC) is conceived as a scientific fact.

Given the unequivocal global scope of ACC, D&A has increasingly turned to regional and local phenomena, especially extreme events such as floods, storms, heatwaves, droughts, forest fires, and various compound events. A central endeavour in D&A has become to assess whether ACC has contributed – or can contribute – to the occurrence of specific extreme events. This issue is crucial for two practical reasons (Hannart et al. 2016, 104). First, there is a backward-looking concern: D&A of extreme events helps identify liabilities and responsibilities, as in legal disputes over damage to infrastructure (e.g., Lloyd and Shepherd 2021). Second, there is a forward-looking concern: D&A of extreme events informs planning and policymaking by identifying vulnerabilities and guiding mitigation and adaptation efforts (Baldissera Pacchetti et al. 2024, Section 2.3).

Yet, attributing specific extreme events to ACC is a highly contentious enterprise, fraught with uncertainty due to the complexity and variability of the climate system and ours limits in understanding it. For over two decades, these uncertainties have been addressed primarily through the “risk-based” or “probabilistic” approach (Allen 2003). The risk-based approach is widely seen as a benchmark of scientific rigour and has become normative in D&A (Shepherd and Lloyd 2021, 2). Besides its role in scientific research, this approach has played a prominent role in decision-making, providing information that (purportedly) enhances control and enables optimization.

In a nutshell, the risk-based approach estimates the probability (or range of probabilities) of an extreme event being caused by ACC, interpreted in a frequentist sense. To flesh this out, it is worth examining the general structure of the risk-based approach, which consists of three main steps (Shepherd 2016, 29-31). First, scientists define an event of concern. In practice, this involves choosing a physical variable, defining the spatial and temporal domains for averaging this variable, and establishing a threshold for the variable above which the extreme event is identified. For example, the variable might be temperature, averaged over European summers in the last decade, with a threshold set at a 1.6°C anomaly. The target extreme event is thus the set of European summers in the last decade whose temperature has risen 1.6°C above the average. The second step is the construction of a factual likelihood distribution for the event. This is typically done via computer simulations, assuming the presence of climate change as a scientific fact. The number of simulation runs in which the extreme event obtains leads to a probability p1 for the event in the factual world. The third step is the construction of a counterfactual likelihood distribution for the extreme event. This is also done with computer simulations, but in this case in a counterfactual world, one without ACC. The number of simulation runs in which the extreme event obtains leads to a probability p0 for the event in the counterfactual world. Scientists typically express the likelihood of the target event being caused by ACC as the “fraction of attributable risk” (FAR):

$$FAR=1-\frac{p\_{0}}{p\_{1}}$$

The risk-based approach faces two major challenges: aggregation and estimation. The aggregation problem arises from the need to generate statistical data about extreme events. This requires grouping events into abstract, and ultimately heterogenous, classes. In doing so, significant differences in their causal structure can be obscured, which may be crucial for attribution purposes (Lloyd and Shepherd 2023). A pedagogical analogy comes from epidemiology: a risk factor that affects a population statistically may not reliably predict outcomes for individuals within that population. Likewise, attributing (or failing to attribute) a class of extreme events to ACC does not warrant attributing (or failing to attribute) any single event in the class to ACC.

The estimation problem stems from the pretence of assigning probabilities (or a range of probabilities) to attribution claims. This is a questionable aim in domains marked by “deep” uncertainty, such as D&A. In contexts of deep uncertainty, quantitative estimates are undermined by i) inexorably insufficient or unreliable evidence to be implemented in representations of uncertainties, ii) inherent complexity and variability in the target systems; and iii) conceptual and theoretical ambiguity – or even ignorance – whether in contexts of scientific consensus or dissensus (Hopster 2023; Lempert et al. 2003, xii). D&A of extreme events face all of these challenges, firmly placing the field within the domain of deep uncertainty.

These two problems have sparked significant changes, not just in D&A, but across the climate sciences. For example, in response to the aggregation problem, there is a growing interest in singular, often unprecedented, events. This change aligns with a broader shift in emphasis from mitigation to adaptation. Mitigation relies on centralized, top-down approaches, necessitating global coordination and aggregation, whereas adaptation favours decentralized, bottom-up strategies that require disaggregation to address localized and distinctive effects of climate change (Rodrigues and Shepherd 2022). And, to address the estimation problem, qualitative and conditional approaches to handling uncertainty have emerged, most notably through the development of RCP/SSP scenarios and related narratives. These approaches have also gained prominence in science communication and transdisciplinary endeavours for decision-making and governance.

 Over the past decade, an approach has emerged in D&A to tackle the aggregation and estimation challenges: the “storyline” approach. The approach focuses on the description of multiple, plausible, and physically self-consistent pathways of past or future singular, local events, conditional on specific contributing causal factors (Shepherd et al. 2018). The storyline approach is allegedly better suited than probabilistic approaches to deal with key aspects of deep uncertainty in D&A. Unlike probabilistic methods that aggregate events across diverse populations using subjective criteria, storylines adopt a case-study approach in a forensic fashion, to identify causal factors and make attribution claims. And instead of estimating a probability for an event to be caused by ACC, the storyline approach assumes conditional settings and deterministically judges whether such settings lead to the event.

Despite its sound responses to the aggregation and estimation problems, the storyline approach has nonetheless encountered significant resistance. As Shepherd et al. (2018) admit, storylines are often seen as anecdotal and unscientific (559). Part of this resistance stems from the divergent and seemingly incompatible conclusions that the risk-based and storyline approaches often reach. For example, consider the 2013 Boulder floods in Northern Colorado, which were analysed differently in two studies. Trenberth et al. (2015), using a storyline approach, concluded that the floods were influenced by high sea surface temperatures, which had a discernible human component (725). In contrast, Hoerling et al. (2014), using a risk-based approach, found that the probability of an extreme five-day September rainfall event in Northeast Colorado, like the one in 2013 in Boulder, has likely decreased since the outset of ACC (S15).

These seemingly incompatible conclusions are actually consistent once one realizes that they answer different questions. Trenberth et al. (2015) ask whether the floods, given the specific dynamical conditions of September 2013 in Boulder, were worsened by ACC. Hoerling et al. (2014), by contrast, ask whether Boulder-like floods have become more frequent due to ACC. Their answers are compatible: the 2013 Boulder floods would have been less severe without ACC. The key storyline is based on the availability of an excess of moisture generated off the west coast of Mexico – attributed to ACC – and contingently transported to Boulder via an atmospheric river. In this sense, ACC plausibly contributed to the magnitude of the event, supporting Trenberth et al.’s conclusion. However, the floods’ actual, ACC-aggravated magnitude makes them part of a class of precipitation events that has not overall become more frequent in Colorado, aligning with Hoerling et al.’s conclusion as well.

The tensions between the storyline and risk-based approaches also reflect divergent values, particularly regarding epistemic risk (Lloyd & Oreskes 2018, 316-8). The risk-based approach prioritizes avoiding Type I errors (false positives), avoiding attributing an event to ACC without conclusive evidence. In contrast, the storyline approach seeks to avoid Type II errors (false negatives), ensuring that an event is not deemed unrelated to ACC if there are reasons to suspect it. In other words, while the risk-based approach prevents overreactions, the storyline approach prevents underreactions. Consequently, the burden of proof shifts between the two approaches: The risk-based approach requires proving that ACC is a cause of the event, whereas the storyline approach requires proving that ACC has no impact on the event.

At times, the tensions between the storyline approach and risk-based approaches have extended beyond the strictly scientific, manifesting as statements characterized by a rhetoric of failure, blame, guilt, and fear. The following are a few quotes, collected by Lloyd and Oreskes (2018), which exemplify this rhetoric: i) “We’d be *failing* in our mission to society” if we did not consider both dynamic and thermodynamic effects, “given that it is both that influence the probability and magnitude of extreme climate events” (Peter Stott in McSweeney 2015, *my emphasis*);[[1]](#footnote-1) ii) “Nothing I read in this latest paper [“proto-storylines” in Trenberth 2011] seems to provide a reason to change [the prevailing risk-based] view: Indeed, the fact that, using their approach, they seem to find a reason to *blame* all the events they consider on anthropogenic climate change, confirms my worst *fears*” (Allen 2011, *my emphasis*); iii) “Recent studies exploring the role of greenhouse gas emissions in extreme weather events tend to be conservative by working under the ‘innocent until proven guilty’ paradigm, but [Trenberth’s] paper argues it would also be useful to work under the ‘*guilty until proven innocent*’ paradigm, or something in between” (Dáithí Stone in Masters & Henson 2015, *my emphasis*); iv) “What is particularly worrying about Trenberth’s [2011] train of thought is that it highlights that some climate scientists (*alarmists*) consider that climate science is somehow different from the rest of science, believing that *in the name of precaution*, they can turn 400 years of scientific thought on its head” (Bryce & Day 2014, *my emphasis*).

In sum, D&A of extreme events is a field navigating significant methodological innovations. The argument for adopting the storyline approach is compelling in various research contexts, yet its broader impact is often constrained by active resistance or passive adherence to traditional methods. To be clear, the value of the storyline approach is increasingly more recognized (Baldissera Pacchetti et al. 2024; IPCC 2021). Nonetheless, tensions between the storyline and risk-based approaches persist, particularly when they yield conflicting conclusions. These tensions underscore the challenge of balancing different research questions, epistemic risks, and overall interests inherent to each method. As the D&A field develops, it is crucial for scientists to acknowledge the distinct contributions each approach offers to advancing their collective aims.

1. The “Philosophers of Science” Story: Conflict Between Opposing Forces
	1. Setting the Scene: The Factivity Debate

The philosophy of scientific understanding has gained significant traction in the fields of philosophy of science and epistemology over the past two decades (see Hannon 2021 for an overview). Yet foundational issues remain contested. Central among these is the question of what constitutes genuine scientific understanding, particularly in relation to truth and facts, as issue typically framed as the “factivity” debate. To engage properly with this debate, I briefly outline some general assumptions about truth and facts, tailored to the scope of this paper. This allows me to bracket extensive and long-standing philosophical discussions about their metaphysical, ontological, and semantical standing.

I use the term ‘facts’ to refer to either true truth-bearers – typically, true propositions – or to their corresponding truth-makers, such as obtaining states of affairs to which true propositions refer (Mulligan and Correia 2021). In doing so, I implicitly adopt a broad version of the correspondence theory of truth, in which truth consists in a certain correspondence relation to reality. In articulating this relation, I embrace Teller’s (2012) “modelling attitude”, which treats truth not as absolute but as a matter of degree, varying in precision and accuracy according to pragmatic criteria. On this view, propositions are not simply true or false, but true to some extent, depending on context or purpose. This attitude remains compatible with a correspondence theory of truth, so long as we acknowledge that the standards by which truth-makers make truth-bearers true are themselves pragmatically shaped.

The relation between facts and scientific representations warrants careful attention, given the central role representations play in scientific practices. To convey facts, scientific representations must meet a veridicality condition (de Regt and Gijsbers 2017). For propositional representations, this condition amounts to their (approximate) truth. However, the situation is less clear for non-propositional representations. Many of these rest on implicit propositional structures which, once reconstructed, allows veridicality to be assessed in terms of propositional truth (Doyle et al. 2019, 348). Yet, for representations lacking propositional structure – such as maps or diagrams – veridicality must be interpreted differently. As de Regt and Gijsbers (2017) put it, in these cases, veridicality “equals some other suitable way of spelling out that the device [i.e., representation] shows us what is really going on in the world” (51).

Wilkenfeld (2017) offers a useful account of veridicality in terms of “representational accuracy”, conceived as similarity between the actual world and the one depicted by a representation. While he does not develop an explicit theory of similarity, this omission is justifiable given the added complexity such a task would entail. Similarly, I adopt a non-committal attitude toward similarity, though I find it worth mentioning some prominent approaches. One class involves morphisms, which are mappings that reflect mathematical or structural correspondences between representation and target. Philosophers have examined the merits of isomorphisms (e.g., van Fraassen, 2008), partial isomorphisms (e.g., da Costa and French 2003), and homomorphisms (e.g., Bartels 2006). Other approaches move beyond structural matching. Weisberg (2012), for instance, proposes a similarity framework based on shared features, modulated by contextual weighting functions and background theories. In a related view, Giere (1988) argues that similarity holds between model and target only in certain respects and to a limited degree, emphasizing its context-dependence (see also “model view” in Teller 2001). Having outlined these general assumptions about facts, truth, and accuracy, I now turn to the factivity debate.

Philosophers are divided on the nature of scientific understanding. One influential view holds that understanding is factive. Proponents of this view are typically aligned with some form of scientific realism, maintaining that science affords understanding only insofar as its theories – and representations more broadly – are (approximately) true or (sufficiently) accurate depictions of reality (de Regt 2015, 3783). This view can be formulated using the two conceptions of facts discussed earlier:

1. If *x* understands that *p*, then *p* is an (approximately) true proposition.
2. If *x* understands *q*, then *q* is an obtaining state of affairs.

However, since scientific understanding is often mediated by representations, it is helpful to foreground a third formulation:

1. If *x* understands *q* as represented by *m*, then *m* is a veridical representation of *q*.

Here, the veridicality is conceived as (approximate) truth for propositional representations or (sufficient) accuracy for non-propositional ones.

Other philosophers advance a “non-factive” approach, arguing that veridicality is not necessary nor sufficient for understanding. Non-factivists often emphasize that falsehoods can play an irreducible and valuable epistemic role in advancing scientific understanding. The non-factive approach appears, *prima facie*, better suited to account for the substantial scientific understanding derived from inaccurate representations, idealized models, fictional constructs, and counterfactual settings. As Elgin (2017, 2022) argues, scientists often achieve understanding through “felicitous falsehoods”, which are representations that mischaracterize their targets yet afford epistemic access to them, not despite their inaccuracies but because of them. Felicitous falsehoods often play an irreducible role in advancing scientific understanding, considering the cognitive limitations of scientists – as humans – and the overwhelming complexity of target phenomena (Potochnik 2017). Along these lines, Doyle et al. (2019) identify four valuable cognitive goods of using falsehoods: they enable simpler calculations, highlight irrelevancies, support tractable explanations, and serve as scaffolds for developing new models. In sum, unvarnished truth and extreme accuracy may hinder – not advance – scientific understanding.

A particularly influential non-factivist account worth outlining is de Regt’s (2015) contextual approach. De Regt argues that scientific understanding is not a form of knowledge but a skill, namely the ability to use theories and models effectively within particular contexts. This view relaxes the requirement that understanding must be grounded in veridical representations, as is traditionally expected of knowledge. Importantly, de Regt does not dismiss the role of truth in understanding but rather maintains that it is context-dependent. What matters is not truth in an absolute sense, but whether a representation is true enough for the purposes at hand (ibid., 3791). An illustrative analogy is maps: good maps deliberately distort aspects of reality in order to convey information that allows users to attain specific goals, such as navigation or spatial planning. Their usefulness lies not in strict accuracy but in their functional adequacy for guiding desired tasks. Likewise, scientific representations need not be true in every respect to prompt genuine understanding. They must only be accurate to the extent that they advance specific scientific goals successfully in given contexts.

Central to this contextual approach is “intelligibility”. A representation – such as a theory or a model – is intelligible, and thus capable of inducing understanding, when it possesses features that its users value as facilitating the achievement of their epistemic or practical goals. Accordingly, intelligibility is not an intrinsic feature of a representation but relative to the skills of its users and the ends the latter pursue. While accuracy often contributes to intelligibility, it is neither necessary nor always paramount. Scientists achieve genuine understanding when they can effectively use representations to advance their goals, even if those representations do not strictly convey facts about their targets.

While non-factive approaches better account for the valuable role of falsehoods in science, they raise a key concern, namely what makes scientific understanding particularly reliable if it does not respond to the facts. This challenge prompts philosophers to reconsider factive alternatives. To be clear, factivists – particularly those interested in scientific practices – acknowledge the prevalence of falsehoods and misrepresentations in successful science. The critical issue is how to integrate these falsehoods into a coherent notion of genuine scientific understanding that remains responsive to the facts.

Three variants of factivism warrant special attention: quasi-factivism, instrumentalism, and modal factivism. First, quasi-factivism maintains that genuine understanding arises from veridical representations. However, it allows that scientists may still genuinely understand a subject while holding false beliefs. The caveat is that these falsehoods cannot be central to their belief systems (Kvanvig 2003, 2009). On this view, falsehoods degrade but not eliminate scientific understanding (Mizrahi 2012). Consequently, understanding is seen as a matter of degree, depending on the approximate truth or accuracy of underlying theories, models, and explanations.

Second, instrumentalism acknowledges that falsehoods are central to scientific practices but denies that they are part of understanding itself (e.g., Lawler 2021; Le Bihan 2021; Ross 2023). On this view, falsehoods can be a source of genuine understanding only insofar as they allow scientists to extract veridical insights. Interestingly, this view shares with Elgin the recognition that falsehoods can afford epistemic access to targets. However, the key difference is that Elgin sees such falsehoods as constitutive of understanding, while instrumentalists regard them merely as means to reach it. This way, instrumentalists are able to retain a factivist stance, even when understanding is derived from non-veridical representations.

Third, modal factivism broadens the scope of facts relevant to understanding beyond the actual to include modal facts – those concerning what is possible, necessary, or impossible. For instance, Le Bihan’s (2016) notion of “modal understanding” holds that to understand a phenomenon involves the ability to navigate the various counterfactual, possible worlds in which the phenomenon could occur. Similarly, Rice’s (2021) “understanding realism” argues that scientific understanding is achieved by grasping true modal information about a target phenomenon, specifically the relations of counterfactual dependencies among its features. An adjacent approach is Reutlinger et al.’s (2018) “how-possibly understanding”. On this account, a scientist understands a phenomenon with a model if the model shows how it could possibly occur, and the scientist grasps that explanation in a given context. These modal views are epitomized by Lipton (2009): “We may improve our understanding as to why a phenomenon is as it is not just by being given a more or less accurate account of how it actually came about, but by being given even a wildly divergent account of how it could have come about” (50). He concludes: “Actual understanding may arise from being shown how something is possible” (ibid).

In many respects, factivists and non-factivists accommodate each other’s concerns, blurring a sharp boundary between their positions (Gurova 2022). Both now widely accept that representational inaccuracies – and even outright falsehoods – are pervasive in successful scientific practices. Their disagreement lies not in the recognition of these falsehoods, but in the epistemic role they play in genuine scientific understanding. Given these nuances, characterizing factivists and non-factivists as “opposing forces” may be an oversimplification. Both perspectives have developed over time, fostering greater consensus on key issues and achieving a fuller picture of scientific understanding together.

And yet, the debate persists, sustained by a terminology that casts one position as the negation of the other, thereby reinforcing a dichotomy marked by mutual exclusivity. Despite important advances, the discussion remains largely polarized, with each camp refining its arguments without ultimately bridging the divide. Participants in the debate often claim that it carries practical implications: whether scientific understanding is factive or not influences which kinds of representations – be they theories, models, explanations, etc. – are deemed as legitimate vehicles of genuine understanding. In the following section, I argue that philosophical discussions of scientific understanding should move beyond the factivity debate if they are to offer meaningful guidance to scientists navigating their own disputes.

* 1. Turning Point: Disavowing the Debate

The factivity debate has come to dominate much of the philosophical discussion on the nature of genuine scientific understanding. This is a regrettable circumstance for at least three reasons. First, the debate appears stagnant: both factivists and non-factivists have developed reasonable yet ultimately inconclusive arguments. This stagnation is especially evident whenever well-established scientific cases used to illustrate the merits of one position are reinterpreted by the other faction to support their own views (cf. Taylor 2023, 13). For example, the ideal gas law has been used to advance both non-factivist and (quasi-)factivist arguments (Doyle et al. 2019; Mizrahi 2012). As Gurova (2022) perceptively observes, this polarization conceals a deeper convergence of views. Nonetheless, as long as each faction continues to refract interpretations with their own, the result will not be a productive dialogue but a philosophical stalemate.

Second, the factivity debate has largely become a technical exercise with limited impact on the actual conduct or advancement of contemporary science, including the elucidation of scientific controversies. Consider again the ideal gas law. The understanding it affords continues to be valued and routinely applied by practicing scientists in appropriate contexts, regardless of philosophical conclusions drawn from the factivity debate. Moreover, several of these philosophical discussions rely on historical case studies examined with the benefit of hindsight. In such cases, broad scientific consensus on how to interpret the episode in question serves as a decisive factor in shaping compelling philosophical arguments (e.g., de Regt 2015). This reliance on settled episodes is telling – and somewhat troubling – as it highlights the debate’s limited relevance to advance contemporary scientific disputes, where interpretive tensions persist and philosophical analysis could offer real insight.

This brings me to the third – and arguably most pressing – reason the factivity debate should not dominate philosophical discussions of scientific understanding: it gives central stage to veridicality. I contend that there are alternative criteria not only for distinguishing genuine from illusory understanding, but also for describing and evaluating the diverse qualities of purported states of understanding. The debate tends to gloss over meaningful differences among states of understanding, many of which are often articulated by scientists themselves. Philosophers of science should aim to develop frameworks capable of capturing and analysing this diversity, rather than forcing accounts of genuine understanding into a binary opposition between factive and non-factive approaches.

Two arguments in the literature support this latter point. The first is Wilkenfeld’s (2017) theory of Multiple Understanding Dimensions (MUD), which holds that the quality of a state of understanding can be evaluated along several orthogonal dimensions, including – but not limited to – representational accuracy. In particular, Wilkenfeld argues that accuracy should be complemented by intelligibility, as construed within de Regt’s contextual approach (see Section 3.1). A direct consequence is that the representational relationship of a given state of understanding to the facts is insufficient, on its own, to determine its overall quality. Thus, the factivity debate is rendered incomplete as a framework for assessing and attributing genuine understanding. To be clear, MUD is not a non-factivism, as it allows for contexts in which veridicality may still function as the ultimate criterion. It is also worth highlighting that, while Wilkenfeld is open to considering multiple dimensions for evaluating understanding, his account ultimately centres on two: accuracy and intelligibility. This leads him to describe MUD as an evaluative “dualism” (ibid., 1288). In my view, this dualism invites further expansion, especially in light of relevant distinctions operative within the D&A case.

A complementary view is advanced by Taylor (2023), who introduces the notion of “afactivism” in the context of explanatory understanding in the cognitive sciences. At its core, this view holds that the truth or falsity of an explanation is irrelevant to whether it provides understanding. This position is motivated by the observation that the scope of idealizations in explanations of cognition is highly contested and ultimately unclear and, as a result, their veridicality cannot be definitively established. Yet this does not prevent cognitive scientists from accepting such explanations. On Taylor’s view, this acceptance marks cognitive explanations as genuine vehicles of understanding. For clarity, afactivism is distinct from non-factivity. Non-factivists identify falsehoods and recognize them as irreducible vehicles for understanding. Afactivism, by contrast, suspends judgement on veridicality altogether. I share Taylor’s motivation to decentre truth as the overriding criterion for understanding, but my stance is more equanimous. I do not discard veridicality altogether. Rather, I see it as one among several context-sensitive criteria that may contribute to genuine understanding. To be sure, Taylor limits his afactivist thesis to the cognitive sciences and refrains from postulating it as a general thesis across scientific disciplines.

Drawing on insights from both Wilkenfeld and Taylor, I develop a concrete proposal for describing and evaluating scientific understanding that moves beyond the constraints of the factivity debate. At the same time, my proposal tackles key limitations in their accounts, particularly in terms of addressing specific features of the D&A case (see Section 4.1). On one side, I extend Wilkenfeld’s evaluative dualism by introducing two additional dimensions for assessing understanding. These dimensions enable recognition of qualitatively distinct forms of understanding that serve different epistemic and practical roles in specific contexts. On the other side, unlike Taylor’s afactivism, I maintain that veridicality remains a relevant – though not overriding – consideration in the D&A case. I label this position “transfactivity”: a middle path that acknowledges veridicality’s contextual importance without granting it absolute priority. In short, Taylor’s afactivism goes too far in dismissing veridicality to be viable for the D&A case, while Wilkenfeld’s MUD theory does not go far enough in moving beyond it. I briefly outline this proposal below, deferring its application to Section 4.1.2.

* 1. The Reveal: Idealizations and Counterfactuals as Dimensions for Assessing Understanding

My proposal introduces two orthogonal dimensions for evaluating states of scientific understanding, each anchored in a key resource behind non-veridical representations: idealizations and counterfactuals. In this respect, the account does not dismiss veridicality outright. Instead, it applies contextual criteria to characterize representations in D&A as non-veridical, while allowing that in other contexts assessing veridicality may be out of reach (see Section 4.1.1). Crucially, representations in D&A can be non-veridical in significantly different and systematic ways. The central thesis is that non-veridical representations may exhibit different combinations of idealizations and counterfactuals, shaping the character and functionality of the understanding they afford. To be clear, this is not an argument suggesting that non-veridicality determines the genuineness (or lack thereof) of the ensuing states of understanding. That would simply return us to the terms of the factivity debate, which I aim to move beyond.

Admittedly, the conceptual boundary between idealizations and counterfactuals is not always clear-cut. Both have undergone intricate and multifaceted developments in the philosophical literature, resulting in non-unified and context-sensitive interpretations (Elliott-Graves and Weisberg 2014, Starr 2022). Thus, the claim that idealizations and counterfactuals constitute orthogonal dimensions of scientific understanding requires clarification. My aim here is not to provide a comprehensive and settled account of these contested notions, but to clarify their respective roles and mutual independence within the context of my proposal.

Idealizations have been extensively studied, especially since the surge of interest in scientific models (e.g., Cartwright 1983; McMullin 1985; Nowak 1972; Wimsatt 1987). Given this rich scholarship, providing an account that satisfies most philosophers is no easy task. ‘Idealization’ often serves as an umbrella term encompassing a range of features in scientific representations: abstractions, simplifications, imprecisions, isolations, omissions, extractions, and approximations, among others. Despite this diversity, a common theme emerges: idealizations are distortions of reality introduced into scientific representations (Weisberg 2007, 640). Similarly, Nowakowa and Nowak (2000) describe idealizations as deformations, writing: “the ideal worlds of science are deformations of the world of ours” (9). They add: “science is about the ideal worlds and the empirical world in which we live is more or less distant from its scientific idealizations” (ibid.).

Idealizations, as distortions or deformations, yield representations that differ from their targets by selectively preserving certain features – often with alterations – while omitting others. In this sense, they stand in opposition to facts. In non-propositional representations, idealizations yield representations that are incomplete at best, inaccurate at worst. For propositional representations, idealizations lead to statements that are, strictly speaking, false, though often treated as more or less close to the truth. Thus, scientific representations can exhibit varying degrees of idealization.

Counterfactuals, by contrast, concern non-actualized possibilities: what is not, but could have been (Starr 2022). They are typically expressed propositionally as subjunctive conditional sentences with false antecedents. In the context of the storyline approach, counterfactuals are often represented as alternative, non-actual pathways in causal networks that might have led to the target extreme event or to another non-actual event. These pathways can be propositionally expressed in the form “if X, then Y”. For example, “If a jet stream had formed, then an excess of moisture from elsewhere would have been available”. Such sentences, and the causal pathways they stand for, are the primary outputs of the storyline approach; they constitute the storylines themselves. Interestingly, Ciullo et al. (2021) explicitly link storyline construction to counterfactual thinking, while Hannart et al. (2016) highlight how causal counterfactual theory fosters D&A goals.

Counterfactuals stand in opposition to facts by depicting non-actual states of affairs. Yet, they are not opposed to facts in a modal sense. Specifically, in the context of the storyline approach, counterfactuals represent facts about what is physically plausible. As such, counterfactual storylines are modally true: their antecedents are contingently false and could have been otherwise. This view aligns with Kim and Maslen’s (2006) account of counterfactuals as make-believe fictions: one imagines the antecedent as true and explores what else would follow. This prompts Kim and Maslen to describe counterfactuals as “short stories”, a characterization that evidently resonates with the storyline approach (see also Iranzo-Ribera 2022).

Now, the orthogonality between idealizations and counterfactuals is a contentious postulation. Many philosophers have emphasized their conceptual entanglement. For example, Nowak (1989, 1991) frames idealizations as counterfactual deformations; departures from actual conditions. De Donato Rodríguez and Arroyo Santos (2012) describe idealizations in biology as networks of counterfactuals and hypothetical conditionals with varying degrees of contingency. Niiniluoto (2018) treats idealizational laws as counterfactual conditionals that can be concretized (i.e., de-idealized) to increase their truthlikeness. Ibarra and Mormann (1995) propose that idealizing theories represent possible worlds where idealized entities exist. Potochnik (2017) adds that idealizations are often designed to convey counterfactual relations. These are only a few accounts that underscore a common insight: idealizations and counterfactuals are frequently conceptually intertwined.

Thus, admitting that the distinction between idealizations and counterfactuals is not always clear-cut, I propose the following way to deploy these notions as orthogonal. The motivation lies in recognizing that scientists may construct idealized representations of actual events, just as they may develop highly realistic, even detailed, representations of non-actual events. In this sense, idealizations and counterfactuals operate as mutually independent resources for generating non-veridical representations. Framing this orthogonality in terms of events is particularly apt for D&A, where the focus is on extreme weather and climate events. Of course, what counts as “idealized” or “realistic” can be quite contextual, an issue I address in Section 4.1. Broadly speaking, however, the storyline approach often yields realistic representations of non-actual events grounded in the physics of climate systems, i.e., targeting events that have not occurred, or occurred through causal pathways different from the actual ones. By contrast, the risk-based approach often yields idealized representations of actual events by subsuming them into heterogenous classes with other events that reflect causally divergent pathways.

Certainly, I do not claim that a sharp or universally valid distinction between idealizations and counterfactuals holds across all scientific contexts. Rather, I adopt a pragmatic approach: in D&A, the distinction proves useful because it tracks different representational practices that give rise to qualitatively distinct forms of understanding. Moreover, D&A scientists themselves distinguish these notions, albeit contextually. My aim is to reconstruct these distinctions in a way that remains faithful to scientific usage while rendering them philosophically tractable for evaluating understanding. By treating idealizations and counterfactuals as orthogonal dimensions, I show how different combinations of these resources – systematically patterned in the risk-based and storyline approaches – give rise to qualitatively distinct forms of understanding. In other words, the distinction matters, as each resource supports a different kind of inferential strategy and fosters a different kind of understanding (see Section 4.1.2). With this distinction in place, I now turn to how the storyline approach in D&A can inform – and be enriched by – contemporary discussions in the philosophy of scientific understanding.

1. The “Interdisciplinary” Story: Encounters and Mutual Benefits

Philosophers of science have much to offer – and much to gain – by engaging with scientific controversies as they unfold. When new methods emerge, such as the storyline approach in D&A, philosophers can help clarify their epistemic status and provide conceptual tools for their assessment. But this engagement should be reciprocal: philosophical frameworks must remain responsive to evolving scientific practices. The task is twofold, then: philosophers should contribute meaningfully to scientific debates, while also letting those debates shape and refine their own accounts. This section explores such synergies, focusing on methodological developments in D&A – particularly the storyline approach – and the philosophy of scientific understanding (Fig. 1). The first subsection examines how practices in D&A provide empirical grounding for philosophical reflection on the nature of genuine scientific understanding. The second subsection considers how philosophical criteria for genuine understanding can, in turn, lend theoretical support for the storyline approach as a legitimate alternative to the risk-based approach.



Fig. 1: Synergies between the storyline approach and the philosophy of scientific understanding.

* 1. The Voyage: From Scientific Practice to Philosophy of Science

D&A offers a rich and instructive case for philosophers of scientific understanding. Proponents of the storyline approach, in particular, have highlighted the centrality of understanding to their endeavours. As Baldissera-Pacchetti et al. (2024) observe, storylines are often developed to improve understanding of the processes underlying relevant phenomena (4). Similarly, Shepherd et al. (2018) claim that the storyline approach aims for understanding of driving factors and their plausibility (557). They add: “*Scientific understanding* is used to push out the boundaries of plausible futures by proposing mechanisms through which outcomes not currently seen in GCMs [i.e., Global Climate Models], either because of missing physics or because of insufficient sampling, could arise” (565, my emphasis).

Having said this, not all aspects of the philosophy of scientific understanding stand to be equally advanced by the D&A case. The following discussion primarily concerns one form of understanding directly implicated in both the risk-based and storyline approaches: explanatory understanding. At its core, D&A is an explanatory enterprise. Scientists working in D&A seek to identify anomalies in climate phenomena – extreme events – and assess whether, and to what extent, these can be attributed to specific causes, particularly ACC. When they ask, “Can we attribute this detected extreme event to ACC?”, they are pursuing an explanatory endeavour, seeking to understand why the event occurred and how it unfolded. In the risk-based approach, explanatory understanding is pursued by assessing whether ACC has increased the frequency of such events. In contrast, the storyline approach seeks it by evaluating how ACC can influence the magnitude and causal unfolding of specific events under particular conditions. With this clarification in place, the remainder of this section can be read as drawing on insights from the D&A controversy to advance philosophical discussions of scientific understanding, with particular bearings on its explanatory type.

* + 1. Two Key Characters: Contextuality and Transfactivity

In my view, the developments in D&A yield two key insights into scientific understanding: (i) its contextual character and (ii) the value of a “transfactive” approach. The first insight underscores that scientists pursue different ends and apply different standards to attain them. While this may seem a philosophical truism, the D&A case vividly illustrates how such divergence occurs even within a single research program ostensibly unified by the shared aims of detection and attribution. Even when studying the same events, researchers may adopt differing commitments, pose conceptually distinct – yet often complementary – questions, and apply divergent criteria for evaluating answers. In D&A, the risk-based approach investigates how ACC influences the frequency of classes of extreme events, whereas the storyline approach examines whether ACC may intensify single events under particular conditions.

A robust philosophical account of scientific understanding must be attuned to the plurality of ends and standards that guide scientific practices. The controversy between risk-based and storyline approaches highlights that genuine understanding cannot be ascribed based on absolute criteria. Instead, it must be evaluated relative to the aims, practices, and standards operative within a specific scientific enterprise. Put bluntly, there is no genuine scientific understanding *simpliciter*, only understanding relative to what scientists are trying to achieve and what their practices afford. This insight reinforces the contextual character of scientific understanding, echoing de Regt’s (2015) account (Section 3.1). However, recognizing this contextuality does not, by itself, entail a commitment to de Regt’s non-factivism, a point I return to in the discussion on transfactivity below.

An instructive example of the contextual character of scientific understanding is the case of the 2013 Boulder floods (Section 2). Both Hoerling et al. (2014) and Trenberth et al. (2015) investigate the same event with the shared aims of understanding whether it can be attributed to ACC. Yet, their analyses and ensuing states of understanding differ markedly, leading to seemingly conflicting attribution claims. Trenberth et al. treat the Boulder floods as a singular, contingent event and argue that ACC amplified its magnitude. In contrast, Hoerling et al. construe the Boulder floods as part of a broader class of comparable events and find no detectable influence of ACC on their frequency. Crucially, both groups may be said to attain understanding of the Boulder floods and their relation to ACC, insofar they manage to successfully answer to their well-posed questions according to their own epistemic standards. Still, their states of understanding can only be deemed genuine relative to their respective construals of the event (individual occurrence vs. class member) and inquiry foci (magnitude vs. frequency).[[2]](#footnote-2)

The second key insight is a particular instantiation of the contextual character of understanding. Yet, it deserves distinct emphasis for its critical implications in the factivity debate: scientists relate to facts and veridicality in diverse, context-sensitive ways. This is particularly evident in fields like D&A, where researchers work under conditions of deep uncertainty. I refer to this insight as the need for a “transfactive” approach to understanding. Its main philosophical import lies in challenging the assumption that the quality of a state of understanding must be tethered to the veridicality (or lack thereof) of its content and to a particular relation to facts. As argued in Section 3.2, understanding is an epistemic achievement evaluable along multiple dimensions. Veridicality may be relevant in several contexts, but it is neither universally necessary nor always decisive.

Importantly, transfactivity is not a form of non-factivity. Non-factivity holds that genuine understanding can arise from non-veridical representations, not despite their falsehoods, but because of them. While this is a legitimate position – one that is often applicable to D&A – transfactivity accommodates situations in which the veridicality of representations may not be decisively established. This may be due to epistemic limitations that hinder conclusive assessments of veridicality, or to divergent, context-sensitive conceptions of what constitutes a fact. In this respect, transfactivity is a distinctive consequence of the contextual character of scientific understanding.

This view bears some affinity with Taylor’s afactivism, which holds that judgements of explanatory understanding should not hinge on veridicality assessments, given the lack of consensus on the scope of idealizations in cognitive explanations. Likewise, in the D&A case, the veridicality of representations may remain indeterminate, and the operative notion of ‘facts’ may vary across contexts. However, unlike afactivism, transfactivity leaves room for the possibility that veridicality judgements can be meaningfully made, albeit relative to the standards and aims of specific contexts. Transfactivity is thus more flexible: it admits that judgements of veridicality are not always viable, but nonetheless acknowledges their justified existence relative to a given practice.

To substantiate the need for a transfactive approach, I identify four contexts within D&A in which the veridicality of representations, and their relationship to facts, is either tangential, ambiguous, polysemous, or indeterminate in ways that do not univocally determine the quality of a state of understanding. First, scientists do not always aim for their outputs to convey or rest upon established facts. Instead, they may engage in speculative modes of inquiry, formulating conjectures and hypotheses that are explicitly provisional and exploratory. In such cases, the veridicality of representations remains deliberately open-ended or underspecified. This attitude is especially prevalent in the storyline approach, where scientists often construct and examine storylines with no pretence of establishing their truth or factual accuracy. This speculative attitude is openly acknowledged in the literature. For example, Hazeleger et al. (2015) describe storylines as hypothetical conditions intended to explore uncertainties about future climate (108). Similarly, Shepherd (2021) characterizes scientific claims about climate change as hypotheses that cannot be tested using traditional methods (2). In the same vein, Hegdahl et al.’s (2020) paper is described as an exploration of a range of storylines under different conditions, showing possible impacts under hypothetical conditions (Baldissera-Pacchetti et al. 2024, 6).

Second, even when scientists aim to assert facts, the nature of these facts can vary considerably. Scientists routinely engage with diverse types of facts, including different varieties of modal facts (e.g., concerning what is possibly the case) and probabilistic or statistical facts (e.g., concerning how likely something is the case).[[3]](#footnote-3) Crucially, no single type of fact holds absolute priority in sanctioning genuine understanding; this is a context-sensitive, non-neutral matter. To illustrate, climate scientists working with the risk-based approach typically seek to establish probabilistic or statistical facts. As Shepherd (2016) explains, this approach addresses attribution questions probabilistically, using simulations to estimate quantitative changes in the likelihood of a class of events occurring in a world with ACC versus one without it. By contrast, scientists adopting the storyline approach are more often concerned with modal facts, offering qualitative claims through counterfactual thinking about what is physically plausible under specified conditions (Baldissera-Pacchetti et al. 2024, 6; Sillmann et al. 2021, 1; see also “possibilist view” in Katzav 2014). As Shepherd et al. (2018) emphasise, the storyline approach prioritizes “qualitative understanding rather than quantitative precision”, and accepts that its outputs “are not probabilistic.” (557). Thus, risk- and storyline-based states of understandings differ in the types of facts they invoke, yet neither is inherently superior. Whether a given type of fact contributes to genuine understanding depends on context, relative to guiding research questions and the standards internal to the scientific practice.

Third, the need for a transfactive approach becomes especially salient when scientists operate without consensus on evidential thresholds, making it unfeasible for a single, context-independent standard of veridicality to adjudicate the quality of scientific understanding. This is illustrated in D&A, where climate scientists assert facts while accepting divergent degrees of epistemic risk. Lloyd and Oreskes (2018) insightfully explore this issue, noting that scientists employing the risk-based approach tend to adopt more conservative evidential thresholds, thereby minimizing the risk of Type I errors (false positives) but increasing the chances of Type II errors (false negatives). By contrast, scientists using the storyline approach often show a greater willingness to tolerate Type I errors in order to avoid missing plausible influences of ACC on extreme events. This divergence is rooted in differing null hypotheses: while the risk-based approach typically begins with a presumption of no influence from ACC, the storyline approach tends to presuppose such influence. As a result, the burden of proof shifts between the approaches, leading to different standards for asserting attribution claims as facts, whether probabilistic, modal, or otherwise.

Fourth, a transfactive approach is prompted to address the evidential asymmetry in establishing the veridicality of attribution claims about past and future events. While claims about past events can, in principle, be assessed for veridicality – even if only modally, probabilistically, or approximately – claims about the future typically resist such assessment. This is because decisive evidence for future-oriented claims does not yet exist. Under conditions of deep uncertainty, scientists are rarely in a position to make assertive predictions with veridical aspirations. Instead, they often develop projections that are conditional on specified assumptions. This forward-looking practice reflects a distinctive epistemic attitude, one that resist veridicality judgements in favour of conditional reasoning. As Shepherd (2016) observes, this attitude aligns with the pursuit of understanding over prediction: “It has therefore been argued that the quest for more accurate climate model predictions is illusory and that instead we need to be using models for understanding, not prediction” (36).

Having motivated the need for a contextual and transfactive approach to understanding in D&A, I now turn to implement the proposal outlined in Section 3.3, which is designed to meet these desiderata.

* + 1. The Message: Understanding Differently

At times, the factivity debate misrepresents how scientific understanding is pursued in practice. In several contexts, scientists do not seek to partition the space of representations neatly into those that can or cannot afford genuine understanding. Rather, they often adopt a more pragmatic and open-ended stance, recognizing that different representations may simply advance understanding in different directions, to varying degrees, relative to the aims and background assumptions of specific enterprises. Moreover, scientists routinely engage with representations whose veridicality cannot be conclusively established and may remain undecidable. Consequently, a philosophical framework that treats veridicality – or its absence – as the central criterion for evaluating understanding risks misalignment with (some) actual scientific practices and remains, therefore, incomplete.

This is particularly evident in contexts like D&A. Drawing on this case, I argue that scientists often adopt contextual – and sometimes provisional – standards for assessing veridicality. Yet they do not necessarily treat veridicality, or its absence, as the sole or primary criterion for evaluating the understanding afforded by a representation. In many instances, assessments of veridicality may be unwarranted, either because they exceed what the available evidence allows, or because there is no consensus on what counts as a fact in that context. In general, representations in both the risk-based and storyline approaches rely on idealizations and counterfactuals – according to descriptions delivered by their own proponents – and are thus non-veridical. Still, there are cases where veridicality is not readily assessable (e.g., claims about future events) or is tied to divergent conceptions of facts (e.g., modal vs. statistical).

My aim is not to catalogue instances of idealizations and counterfactuals in D&A, but to highlight qualitative differences in how the risk-based and storyline approaches engage with them in representations, leading to qualitatively different states of understanding. Broadly speaking, risk-based understanding typically relies on a coarse-grained counterfactual assumption, while accommodating a wide range of idealizations. By contrast, storyline-based understanding deploys multiple finer-grained counterfactuals and foregrounds situated, physically realistic reasoning, typically involving lower degrees of idealization.

The distancing that proponents of the risk-based approach assert from the storyline approach – framing the former as more firmly grounded in facts – is misleading. In practice, the risk-based approach relies on non-veridical representations in at least three significant respects. First, it depends on climate models that incorporate simplifying and idealizing assumptions to run simulations and generate outputs. While such idealizations are pragmatically justified, their use – especially under conditions of deep uncertainty – often leads to a version of the estimation problem (see Section 2). Second, to estimate probabilities, simulated extreme events are grouped – based on subjective criteria – under the assumption that they form a causally homogenous class suitable for attribution purposes. This strategy bring about an aggregation problem (see Section 2), as it risks distorting or obscuring the distinct causal pathways of individual events.[[4]](#footnote-4) Third, the risk-based approach requires comparing simulation results under both factual and counterfactual assumptions. Crucially, the representation of a coarse-grained counterfactual – a world without ACC – constitutes a central non-veridical representation underpinning attribution claims in this approach.

The storyline approach also relies on non-veridical representations, particularly through its systematic use of counterfactuals. It explores a range of fine-grained, non-actual assumptions, especially concerning counterfactual atmospheric dynamics. This exploration engages with what Sjölin Wirling and Grüne-Yanoff (2021) term “epistemic” and “objective” possibilities. Epistemic possibilities are consistent with what is currently known to be true and could be actual (cf. “physical conceivability” in Massimi 2019). In contrast, objective possibilities are not actual, but could have been; they are only contingently non-actual. When analysing past events, the storyline approach typically explores causal pathways that are physically plausible though not necessarily actual, thus often engaging with objective possibilities. When focused on future events, the approach surveys plausible causal pathways consistent with current physical knowledge, thereby engaging with epistemic possibilities.

With respect to idealizations, the storyline approach employs them much like any attempt to represent the physics of complex natural systems. As Baldissera Pacchetti et al. (2024, 4) observe, storylines draw on outputs from global and regional climate models, numerical weather prediction models, and societal and climate impact models, all of which include idealizations. In this regard, both the risk-based and storyline approaches share a fundamental reliance on idealizations. However, they diverge in a key respect: the storyline approach adopts a forensic perspective, examining the causal structure of individual events rather than aggregating them into broader classes for attribution. This focus helps preserve the integrity of the event’s causal structure, avoiding the aggregation problem. Accordingly, the storyline approach allows for a slightly more realistic – and often detailed – causal analysis.

Thus, the risk-based and storyline approaches – through their distinct uses of idealizations and counterfactuals – give rise to qualitatively different states of understanding (see Fig. 2). Crucially, these differences are prompted by divergent concerns and attitudes. Drawing on Stirling’s (2010) distinction, echoed by Shepherd (2021), the risk-based approach promotes a “single-definitive” understanding, driven by the assumption that decision-makers need a single, univocal answer to their concerns. By contrast, the storyline approach more directly addresses the constraints of deep uncertainty, fostering a “plural-conditional” understanding (Shepherd & Truong 2023). This way, it conveys a space of possibilities – both epistemic and objective – accommodating the varied concerns and perspectives of decision-makers and stakeholders.



Fig. 2: Qualitative differences in the states of understanding afforded by risk-based and storyline approaches.

In sum, the storyline approach affords a qualitatively different state of understanding from the risk-based approach. Still, it remains to be shown that this constitutes genuine understanding. In the next section, I defend the storyline approach as fostering genuine understanding by engaging with the two dominant positions in the philosophical literature: factivism and non-factivism. I then introduce a third view – transfactivity – and explain what it means for understanding to be genuine within this framework.

* 1. And Return: From Philosophy of Science to Scientific Practice

As discussed in Section 3, philosophers of science remain divided over whether genuine scientific understanding should be assessed according to factivist or non-factivist criteria. I have argued that this debate should not dominate discussions about the nature of scientific understanding, for at least three reasons: (i) it has become a largely intractable dispute; (ii) it has limited impact on actual scientific practices; and (iii) the genuineness of understanding involves more than simply meeting – or failing to meet – veridicality. Nonetheless, the debate continues to shape the philosophical literature. In response, I propose a conciliatory strategy: to evaluate storyline-based understanding through both factivist and non-factivist lenses. If it can be shown to meet the criteria for genuine understanding on both accounts, this would confer it broader legitimacy. Beyond this, I introduce a third alternative: a transfactive criterion for assigning genuine understanding.

I begin by examining how the storyline approach can afford genuine understanding from a non-factivist perspective. This is a timely task, as one of the main criticisms levelled against the approach is its alleged failure to faithfully represent actual causal pathways of extreme events, thereby undermining the credibility of its attribution claims. This objection stems from a factivist assumption: that genuine understanding requires veridical representations that track the facts of an event’s unfolding. Non-factivists, however, demur.

Drawing on a particular non-factivist approach, namely de Regt’s (2015) contextual account (Section 3.1), the storyline approach affords genuine understanding of extreme events insofar as it enables scientists to successfully accomplish a number of epistemic and practical aims. Crucially, this holds even when the storylines do not represent the actual causal unfolding of the target events and, in that sense, the ensuing understanding is based on non-veridical representations. To substantiate this point, I offer four core achievements advanced by the storyline approach (Shepherd et al. 2018). First, it improves risk awareness by framing it in an event-oriented manner (as opposed to a fact-oriented way), which aligns more closely with how people perceive and respond to risk. Second, it strengthens decision-making by allowing one to work backward from a particular vulnerability or decision point and looking at the various causal pathways that affect it, including those involving compound events. Third, it enables the partitioning of uncertainty between thermodynamic and dynamic components of the climate system, allowing more credible use of regional models in a conditioned manner. Fourth, it shifts attention from probabilities to plausibilities, bringing attention to unlikely but still plausible high-impact events. In turn, exploring the scope of physical plausibility helps guard decision-makers against false precision and unexpected outcomes.

From a factivist viewpoint, defending the genuineness of storyline-based understanding is not straightforward, since it typically relies on non-veridical representations. However, as noted in Section 3.1, factivists have developed strategies to reconcile genuine understanding with non-veridicality. Among these, the modal variant of factivism arguably offers the most promising route. On this view, storylines can afford genuine understanding insofar as they convey modal facts – specifically, facts about what is physically plausible in relation to extreme events. More precisely, scientists may achieve genuine understanding when storylines offer how-possibly explanations of extreme events (*à la* Reutlinger et al. 2018) or enable the navigation of counterfactual pathways (*à la* Le Bihan 2016 or Rice 2021). In this sense, while storylines may not be veridical in a strict actualist sense, they can nonetheless represent the counterfactual structure of extreme events. Accordingly, they may support genuine understanding by factivist standards, through a modal approach.

Storyline-based understanding meets both factivist and non-factivists criteria for genuineness. This is good news for proponents of the storyline approach. However, it underscores a challenge for philosophers of scientific understanding: the factivity debate appears ill-equipped to adjudicate cases or offer resolution in controversial cases, like the one in D&A. As I have argued, contexts marked by deep uncertainty, may call for a transfactive approach, one in which veridicality is neither central nor necessary for evaluating understanding. In this spirit, I propose a context-sensitive revision of Taylor’s (2023) afactivist intuition, tailored to the D&A case:

[Transfactivity in D&A]: A representation affords genuine understanding of extreme events in context C if it is accepted and effectively used by domain experts in C, irrespective of its veridicality or its veridicality-aptness.

Transfactivity differs from Taylor’s afactivism in four key respects. First, while Taylor focuses on understanding afforded by explanations, transfactivity extends to representations more broadly. Second, it acknowledges that the inaccessibility to veridicality judgements stems not only from idealizations (Taylor’s focus), but from the four reasons discussed above in Section 4.1: (i) speculative motivations; (ii) lack of consensus on the types of fact at stake; (iii) divergence in attitudes toward evidential thresholds and epistemic risk; and (iv) future-oriented claims under deep uncertainty. Third, transfactivity allows for veridicality to be assessed in some contexts (as opposed to Taylor’s afactivism) but does not treat it as a necessary criterion to adjudicate genuine understanding. Fourth, it adds the requirement of effective use alongside acceptance, highlighting its pragmatic character. On this view, understanding is meaningful insofar as it enables scientists to achieve further epistemic or practical goals (cf. de Regt 2015). Finally, note that the formulation of [Transfactivity in D&A] uses ‘if’ rather than ‘iff’, deliberately leaving room for alternative accounts – such as factivism and non-factivism – to remain applicable in some contexts within D&A.

I anticipate a critical objection to the transfactive view, namely that it appears unable to adjudicate scientific controversies, such as the one in D&A. If genuine understanding hinges on acceptance and effective use, then different research groups might each claim genuine understanding, even when their insights conflict. I suggest, however, that this is not a weakness but a strength of the transfactive approach, particularly in contexts marked by deep uncertainty and ongoing scientific developments. In such cases, it is neither realistic nor desirable to evaluate understanding by the standards of a single group. Scientists may adopt divergent assumptions – especially regarding truth and facts – and reach different, yet legitimate, forms of understanding through distinct methodologies. Admittedly, this view amounts to a form of relativism. But in the face of deep uncertainty, I argue that such relativism is not only defensible but advisable. Whether this position is appropriate in scientific domains dealing with more certainty remains an open question.

According to the transfactive view, storyline-based understanding qualifies as genuine insofar as it is accepted by a community of experts and effectively used to generate attribution claims, thereby contributing to meaningful scientific discussions. The risk-based approach, by the same standard, is equally entitled to this claim. The transfactive perspective improves upon factivist and non-factivist positions by recognizing the contextual relevance of veridicality without treating it as a necessary criterion. Such flexibility is crucial in contexts of deep uncertainty, where veridicality may not be assessable, or where its meaning is ambiguous or contested. Importantly, transfactivity is not an anything-goes position. A representation supports genuine understanding only if it remains accepted and productively employed within its expert community. Research programs can, and do, get abandoned when they cease to meet these criteria. While the storyline approach remains active and valued in various corners, it could be abandoned should its community come to judge it ineffective. As of now, however, there are no indications of such decline.

1. Morals: Concluding Remarks and Further Research

The “stories” examined above leave us with at least two main morals. First, for climate scientists: contextuality about scientific understanding is crucial for addressing the diverse, yet complementary, questions within a field like D&A, where different research groups may operate under distinct standards. In particular, this contextuality must encompass differing attitudes toward veridicality. In a domain marked by deep uncertainty, veridicality may be difficult to assess, not assessable at all, or interpreted in divergent ways. Second, for philosophers of science: accounts of scientific understanding must better reflect scientific practices, in particular those within D&A. This means moving away from making veridicality a necessary criterion for evaluating understanding or at least allowing for a spectrum of attitudes toward it. This includes the attitudes and inclinations of storyline researchers, who often aim for advancing plural and conditional forms of understanding.

This paper raises several unresolved questions that merit further exploration. Three particularly promising lines of research stand out. First, insights from the philosophical literature on narrative explanations may shed light on how the presence, absence, or inaccessibility of veridicality can be part of accounts of genuine understanding (e.g., Morgan et al. 2022). Narrative explanations often prioritize coherence and plausibility over strict factual accuracy, making them a particularly suitable notion to approach storyline-based understanding in D&A. Second, engaging with research on single-case, actual causation could offer a critical approach to improve the storyline approach. Most prominently, Cartwright’s (2022) suggestion that single causation claims might rest on direct evidence – rather than counterfactual reasoning – is worth exploring.

Third, and finally, it is important to explore other notions in opposition to facts, beyond idealizations and counterfactuals, that could serve as additional dimensions for evaluating understanding. In particular, values and opinions warrant closer examination. Unlike facts, opinions are mind-dependent and shaped by the values and interests of those who hold them. These factors can significantly shape scientific representations, especially in fields like D&A, where stakeholder perspectives and societal concerns often play a central role. To motivate this line of inquiry, consider Baldissera Pacchetti et al. (2024), who identify different types of storylines and emphasize how some are explicitly shaped by stakeholder values and interests. This raises the possibility of introducing a third axis in Fig. 2, capturing the extent to which the mix of idealizations and counterfactuals in storylines is informed by normative commitments. Such an axis would allow us to more fully represent the plural and value-laden nature of understanding in D&A.

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1. This statement not only criticizes the storyline approach but also misconstrues it as failing to consider both the dynamic and thermodynamic components of the climate system in its representations of uncertainty. This is not the case. As Shepherd et al. (2018) explain, the storyline approach does not exclude either component. Rather, it enables scientists to treat them separately, acknowledging the qualitatively distinct forms of uncertainty each introduces to the study of attribution. [↑](#footnote-ref-1)
2. A similar point is emphasised by Otto et al. (2012) in their effort to reconcile two seemingly contradictory studies on the attribution of the 2010 Russian heat wave. They write: “The difference in conclusion between these two papers illustrates the importance of specifying precisely what question is being asked in addressing the issue of attribution of individual weather events to external drivers of climate” (1). Otto et al. show that these studies are not contradictory because they address different aspects of the same event, namely its magnitude and its frequency. [↑](#footnote-ref-2)
3. It is worth highlighting that the storyline approach reflects a sustained interest in modal modelling and modal knowledge, an area of growing recognition in contemporary philosophy of science (Dohrn 2020, 2023; Gelfert 2019; Godfrey-Smith 2020; Gregory 2017; Massimi 2019; Sjölin Wirling and Grüne-Yanoff 2021). [↑](#footnote-ref-3)
4. Aggregation is a form of Galilean idealization: distinct extreme events are grouped into classes to enable statistical analysis, rendering complex climatic phenomena more tractable. As Lloyd and Shepherd (2023) observe, however, there are cases where disaggregation is necessary: effectively a move toward de-idealization. [↑](#footnote-ref-4)