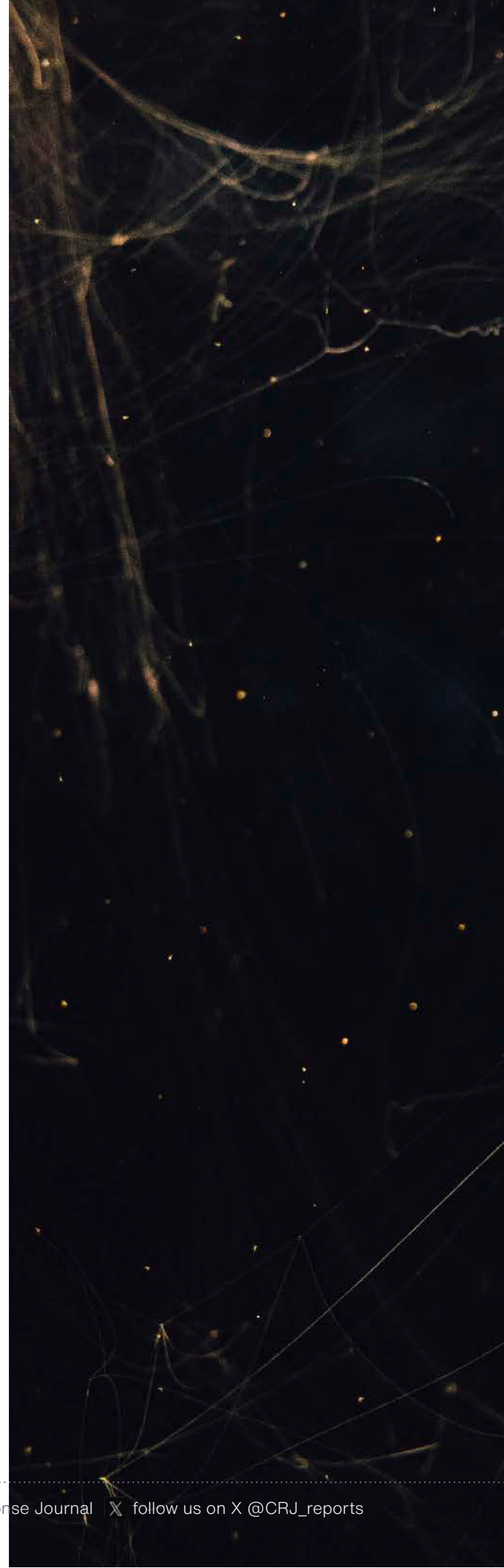
Embracing the jellyfish: HILP events, risk agnosticism, and stress-testing resilience

What do we call events that defy expectations, overwhelm systems, and leave little time to react? **Gianluca Pescaroli** takes a look



Three years ago, I was in Hamburg attending a meeting with a group of partners who would later form the Horizon AGnostic risk management for high-impact low-probability events (AGILE) project consortium. We were discussing how to develop a proposal on HILP events, also known as outliers, typically defined as events that are difficult to predict, hard to model, and often fall outside the thresholds used in traditional risk assessments.

I remember someone asking me: "What's your idea for dealing with this problem?" I turned the question back to the room: "What could cause a common failure in power plants in Israel, Scotland, and Sweden?"

The answers covered a gamut: Cyberattacks, extreme weather, and equipment failure. Then I pulled up a map from CyberSquirrel1.com, which documents real-world power outages and infrastructure disruptions caused by animals, particularly squirrels, as a counterpoint to the common fears of cyberwarfare. It features a map and a catalogue of incidents that can be used to build scenarios. If you explore it, you will discover that the answer to my question may be quite unexpected: Jellyfish.

These gelatinous creatures have previously caused shutdowns costing millions. Their unpredictable mass appearances, sometimes described in the media as invasions, pose a persistent threat to coastal energy infrastructure. Power plants are often located near the coast to access cooling water, but without it, reactors risk overheating. The issue is well known, and researchers are exploring innovative solutions, such as using drones and acoustic monitoring, to detect jellyfish blooms before they reach critical infrastructure (D'Agostino, 2021). This moment captured the essence of what we were trying to understand: how seemingly unrelated, low-probability events can trigger major disruptions in systems assumed to be secure and resilient. More importantly, it highlighted how our assumptions about risk often fail to account for the unexpected: What we perceive as unpredictable may, in fact, be rooted in overlooked or ignored precursors.

If you think more carefully, the cooling system of a power plant is a single point of failure vulnerable to multiple threats. The most famous example is the Fukushima Daiichi

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disaster in Japan. On March 11, 2011, an earthquake damaged the external power lines supplying electricity. Landslides and a massive tsunami interacted with pre-existing vulnerabilities, disabling the plant's backup power and causing the cooling systems to fail. This, and all other factors, interacted together leading to reactor meltdowns, hydrogen explosions, and a major nuclear crisis.

What we know for certain is that disruption is no longer the exception; it is the new normal. As our societies become more interconnected and dependent on critical infrastructure, the operational context is increasingly shaped by cascading and compounding events and environmental shifts. The risks we face are evolving faster than our ability to predict them.

From volcanic ash grounding flights across Europe, to pandemics colliding with supply chain disruptions during winter storms, the 21st century has shown us that crises rarely occur in isolation. They cascade, interact, and recombine in ways that challenge even the most robust emergency and continuity plans (Pescaroli and Alexander, 2018). As we suggested in the *United Nations Global Assessment Report 2022*, to address growing uncertainties and interdependencies in systemic risk, emergency management must evolve beyond traditional tools like risk registers. Innovative approaches, such as scenario planning and adaptation pathways, are needed to identify critical vulnerabilities and ensure societal resilience in the face of complex, cascading disruptions (Pescaroli *et al*, 2022).

The research from our projects is helping define a new dimension in how operations and preparedness are evolving. In the earth observation for high-impact multi-hazards science (EO4Multihazard), we are advancing the understanding of how high-impact, cascading, and compounding multi-hazard events interact, as we explore their drivers and dynamics, and translate these insights into operational tools that incorporate Earth observation technologies. Meanwhile, projects like AGILE and community and infrastructure resilience to climate-geological long-term effects (Circle) indicate a pressing need to move beyond traditional, hazard-specific approaches, advocating for more flexible, system-wide strategies that can adapt to uncertainty and complexity. But is this just academic blue-sky thinking, or can it lead to practical improvements in organisational resilience? What answers can we offer to colleagues struggling to engage their line managers or teams in preparing for the unexpected?

Yet another buzzword?

Before joining University College London, my last job was preparing bread in a bakery. That experience taught me to be sceptical when things get more complicated than necessary. The owner used to tell me that the secret to good bread was not about measuring flour and yeast to the gram, but about understanding the specific conditions of the day and adapting the recipe accordingly.

So, when we began working on HILPs in the AGILE project, my first question was: "Do we really need this concept, or are we just reinventing the wheel?" Before I knew it, at the request of our project officer, I was working full-time on developing yet another definition. To be clear, this is a task I have undertaken before, and it is not one I appreciate (see Pescaroli and Alexander, 2015). It can feel petty, and nothing excites some of my academic colleagues more than spending an afternoon debating the spine of a definition, especially when it involves choosing between 'black swans,' 'grey rhinos,' and, my personal favourite, 'dragon kings.'

I started informally testing the concept with some readers of this journal in December 2023. To my surprise, it became clear that the idea could be genuinely useful. The new reality in which organisations operate requires planning based on the assumption that disruptions will happen. Recent history has shown that there is a category of events that has not been fully understood yet is far from irrelevant. There was a clear appetite for something that could help practitioners and policymakers better identify and prepare for these events, particularly tools that could support training, exercises, and stress testing.

So, our project officer was right. We needed to draw a new line. We developed a pilot definition, tested it with our consortium, added a taxonomy to support scenario development, and went through a long validation process. The result was published in May of this year (Pescaroli *et al*, 2025).

We now have a validated academic definition, standing at around 300 words long, which emphasises context, uncertainty, and the role of dynamic vulnerabilities. Blood, sweat, and tears went into every comma. But during testing, a couple of very senior colleagues from the private sector brought me back to the bakery. One said: "This is conceptually bulletproof, I fully agree with it. But seriously, how am I supposed to present this to my CEO or include it in a report?" So, we created a complementary practical, operational definition tailored for real-world use that may be close:

"HILPs are rare events which may potentially result in catastrophic impacts on people, infrastructure, utilities, critical services, and wider societal function. They are characterised by a lack of precedence and high levels of uncertainty in their predictability and combinations of effects, often coming as surprises or shocks."

This explanation may not meet academic standards, like those found in scholarly papers, but it is sufficient for understanding. To support this, we developed a taxonomy, which is a structured checklist to help determine whether an event qualifies as a HILP. It includes indicators such as:

- Lack of historical precedent or long return periods
- Recombination of known risks in new ways
- Disruption of critical services or cascading failures
- High uncertainty in impact or response

This helps shift the focus from 'what might happen' to 'what could break.' This is a subtle yet powerful change in how we think about preparedness. It is unrealistic to expect every organisation to persuade its senior management to invest heavily in HILPs. These events often fall below traditional risk thresholds and are excluded from planning owing to their perceived improbability or high mitigation costs.

However, this approach allows us to acknowledge that HILPs exist, that they can happen, and that we can use them to test for single points of failure across scenarios, even if we cannot justify investing in each one individually.

■ **Stress Testing and Risk Agnosticism in Practice:** If HILP events challenge our assumptions, then stress testing challenges our methods. By considering practical issues of capacity and capability, stress testing offers new operational tools to integrate what we have learnt about

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systemic risk (Pescaroli *et al*, 2022; Linkov *et al*, 2022). As we argued years ago, when exploring systemic risk (Pescaroli and Alexander, 2018), instead of only asking what could go wrong based on past events, we should also ask what could fail, regardless of the trigger. This is the essence of risk agnosticism (Trump *et al*, 2025).

Risk agnosticism is not about ignoring hazards, and this is not to suggest that we abandon investment in detection, mitigation, or intelligence gathering. It is about preparing systems to function even when the hazard is unknown. It focuses on identifying common points of failure across different types of disruptions, whether they stem from cyberattacks, climate extremes, or geopolitical shocks.

Our project has shown that this thinking can be operationalised through stress testing, which is a structured method for simulating how systems respond under pressure. By applying this approach, we can identify vulnerabilities shared across scenarios, such as over-reliance on centralised infrastructure, lack of redundancy, or gaps in co-ordination. Ultimately, risk agnosticism is about building resilience by design, and being ready to challenge the way we think. It is a way to future-proof systems in a world where the next crisis may not look like the last. And it is not only possible, but also necessary.CRJ

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