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Consequence-Driven Risk Framework for Uncovering Black Swans Events: Volcanic Ash in Singapore

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Both deterministic and probabilistic risk modeling techniques can result in inadvertent over-constraint of potentially sensitive variables early on in the risk modeling process, rendering some high-consequence events impossible within the framework of those models. For example, the 2016 Kaikoura, New Zealand complex fault rupture directly challenged a number of assumptions typically used in modeling earthquake ruptures. While the consequence of that specific event was limited due to the low population density in the region, this occurrence implores the evaluation of modeling assumptions which, if wrong, would miss high-consequence black swan events in potentially dense urban environments. Meanwhile, constraints on model parameters offer practical benefits from a modeling perspective, such as time and computational resources. These constraints, however, should be carefully applied, and a thorough understanding of the implication of those constraints is needed in order to achieve both a feasible, implementable and informative model, but also comprehensive. We propose to apply a consequence-driven framework in order to identify the events that could result in extreme consequences. First, we conduct sensitivity analysis to identify the events and model parameters contributing to extreme hazard. Second, we question the parameter assumptions and constraints through their systematic relaxation (e.g., increasing the parameter range) and propagation to consequence assessment. Finally, we deaggregate the model to identify the parameter space leading to consequences above a critical threshold (at this threshold, we consider to be a "black swan"). This framework would provide key information to justify or reconsider initial assumptions and constraints based on a better understanding of the consequences of being wrong about the initial inputs. Our consequence-driven framework is illustrated for the case study of airspace closure in and around Singapore due to volcanic ash presence. The Mt. Pinatubo eruption of 1991 sent ash over 2,000 km from the Philippines to Singapore. This caused noticeable changes in air quality in Singapore, and engine problems for commercial aircraft near Singapore, and yet Changi remained operational throughout the event. We explore whether this event would have been more or less consequential for Singapore under slightly different circumstances, and whether current models and analysis capture these extremes. The framework is also considered in the context of other natural hazards such as earthquakes and tropical storms.