SOLVING THE PUZZLE

INNOVATING TO REDUCE RISK

Written Contributions

This publication is driven by input provided by the disaster risk community. The Global Facility of Disaster Risk and Recovery facilitated the development of the report, with funding from the UK Department of International Development.

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Preface

These written contributions are part of the *Solving the Puzzle: Where to Invest to Understand Risk* report. The report provides a community perspective on priorities for future collaboration and investment in the development and use of disaster risk information for developing countries. The focus is on high-impact activities that will promote the creation and use of risk-related data, catastrophe risk models, and platforms, and that will improve and facilitate the understanding and communication of risk assessment results.

The intended outcome of the report is twofold. First, that through the community speaking as one voice, we can encourage additional investment in the areas highlighted as priorities. Second, that the consensus embodied in the report will initiate the formation of the strong coalition of partners whose active collaboration is needed to deliver the recommendations.

The written contributions are part of the input received from the disaster risk community in response to open calls to the Understanding Risk Community and direct solicitation. The papers offer analysis around challenges that exist in disaster risk models and platforms, data, capacity building and risk communication.

SOLVING THE PUZZLE

Innovating to Reduce Risk

WRITTEN CONTRIBUTIONS

The Current State of Risk Information: Models & Platforms

Past and Future Evolution of Catastrophe Models

Karen Clark (Karen Clark & Company)

Catastrophe models were developed in the late 1980s to help insurers and reinsurers better understand and estimate potential losses from natural hazards, such as hurricanes and earthquakes. Over the past few decades, model usage has grown considerably throughout the global insurance industry, and the models are relied upon for many risk management decisions.

In short, the models have become very important tools for risk management. Now, new open loss modeling platforms are being developed to advance the current state of practice. The first generation catastrophe models are cl`sed "black box" applications, proprietary to the model vendors. Open models make more visible the key assumptions driving insurers' loss estimates, along with giving them control over those assumptions.

Market demand is driving the development of new tools because today's model users require transparency on the model components and more consistency in risk management information. Insurers are also expected to develop their own proprietary views of risk and not simply rely on the output from third-party models. The following reviews the traditional catastrophe models and their limitations and how advanced open risk models are addressing these issues. It also illustrates how other users, such as governments of developing countries, can benefit from this new technology.

Overview of catastrophe models

A catastrophe model is a robust and structured framework for assessing the risk of extreme events. For every peril region, the models have the same four components, as shown in figure 1.

FIGURE 1. **Catastrophe Model Component**

The event catalog defines the frequency and physical severity of events by geographical region. It is typically generated using random simulation techniques, in which the underlying parameter distributions are based on historical data and/or expert judgment. The reliability of the event catalog varies considerably across peril regions, depending on the quantity and quality of historical data.

For example, enough historical data exist on Florida hurricanes to estimate credibly the return periods of hurricanes of varying severity there. In contrast, nine hurricanes have made landfall in the Northeast since 1900—none of them exceeding Category 3 intensity. Model estimates of the frequency of Category 4 hurricanes in this region are, therefore, based on subjective judgments that can vary significantly between models and even between model updates from the same vendor. Because scientists don't know the "right" assumptions, they can develop very different opinions, and they can change their minds.

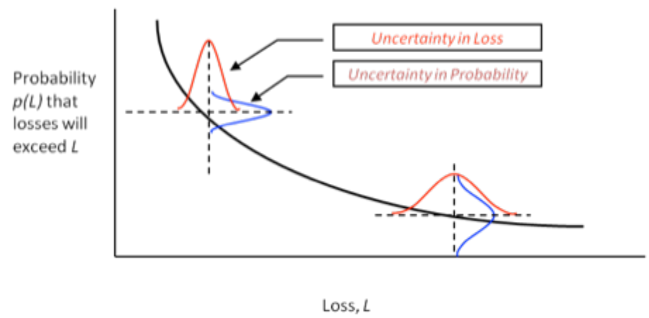
For each event in the catalog, the models estimate the intensity at affected locations using the event parameters the catalog provides, site information, and scientific formulas developed by the wider scientific community. The catastrophe models incorporate published literature and data from the public domain—usually obtained from government agencies, universities, and other scientific organizations. Scientists have collected and analyzed intensity data from past events to develop these formulas, but, again, the amount and quality of the intensity data vary significantly across perils and regions.

The models are most widely used to estimate property damage, and their damage functions attempt to account for type of building construction, occupancy, and other characteristics, depending on the peril. The functions are used to estimate, for different intensity levels, the damage that will be experienced by different types of exposures.

The damage functions are expressed as the ratio of the repair costs to the building replacement value. Because extreme events are rare and very little claims data exist, most of these functions are based on engineering judgment. The financial module applies policy and reinsurance terms to the "ground-up" losses to estimate gross and net losses to insurers.

The input for the model consists of detailed information on insured properties, and the model output is the exceedance probability (EP) curve, which shows the estimated probabilities of exceeding various loss amounts. Unfortunately, the false precision of the model output conveys a level of certainty that does not exist with respect to catastrophe loss estimates. Model users have come to a better understanding of the uncertainty through model updates producing widely different numbers.

FIGURE 2. Representative EP Curve



Over time, the fundamental structure of the models has not changed, but faster computers have enabled the models to simulate more events and capture more detailed data on exposures and geophysical factors, such as soil type and elevation. But more events and greater detail do not mean the models now produce accurate numbers.

Model users sometimes confuse complexity with accuracy, but the catastrophe models will never be accurate due to the paucity of scientific data. In fact, since little or no reliable data underlie many of the model assumptions, adding more variables (that is, adding complexity) can increase the chances of human error and amplify model volatility without improving the loss estimates or adding any real value to the model.

Challenges and gaps with first generation models

While the traditional catastrophe models have dramatically improved the insurance industry's understanding and management of catastrophe risk, the first generation models have certain limitations and can be advanced. Insurers face five primary challenges with the current vendor models:

1. *Volatile loss estimates.* Model volatility is largely driven by modeling companies' changing the assumptions, not by new science. This volatility is highly disruptive to risk management strategies and is not fully warranted, given the current state of scientific knowledge.
2. *Lack of control over (and therefore low confidence in) model assumptions.* Because the first generation models are "secret," insurers can never be certain

about the assumptions driving their loss estimates, and they have no control over those assumptions. Loss estimates can change dramatically with model updates. Regulators put pressure on insurers to adopt the latest models, even if insurers cannot fully validate them and are not comfortable with the new estimates. In the current paradigm, insurers may feel compelled to use information they have little understanding of or confidence in.

3. *Inefficient model "validation" processes.* Because insurers cannot actually see the model components and calculations, they cannot readily determine how their loss estimates are derived and how different sets of assumptions can affect them. Insurers have to develop costly and inefficient processes around the models in attempts to infer what is inside them, using contrived analyses of model output. The process starts all over again with model updates.
4. *Significantly increasing costs of third-party model license fees.* Insurers now pay millions of dollars a year in third-party license fees. Given a duopoly of model vendors, costs continue to escalate without commensurate increases in value.
5. *Exceedence probability (EP) curve metrics, such as value at risk (VaR) and tail value at risk (TVaR), do not provide enough visibility on large loss potential.* While probabilistic output based on thousands of randomly generated events is valuable information, it doesn't give insurers a complete picture of their loss potential nor provide the best information for monitoring and managing large loss potential. VaRs in particular are not operational, intuitive, or forward looking, and they don't identify exposure concentrations that can lead to solvency-impairing losses.

Addressing the challenges and advancing catastrophe modeling technology with open models

New open loss modeling platforms address the challenges presented by the traditional models and significantly advance the current state of practice. The structure of an open model is the same as that of a traditional vendor model; the advance is model assumptions that are visible and accessible to the users, which allows insurers to do the following:

- See the model assumptions
- Understand the full range of valid assumptions for each model component
- Analyze how different credible assumptions affect their loss estimates
- Select the appropriate assumptions for their risk management decisions

Open platforms start with reference models based on the same scientific data, formulas, and expertise as the traditional vendor models. The difference is users can see clearly how this information is implemented in the model and can customize the model assumptions to reflect their specific portfolios of exposures.

The damage function component is an obvious area for customization. The vendors calibrate and "tune" the model damage functions utilizing the limited loss experience of a few insurers. This subset of insurers may not be representative of the entire market or the spectrum of property business, and even within it, each insurer has different insurance-to-value assumptions, policy conditions, and claims handling practices. This means damage to a specific property will result in a different claim and loss amount depending on which insurer underwrites it, and the model damage functions will be biased to the data available to the model vendors.

Even if a modeler could correct for these biases, the damage functions in a traditional vendor model may be averaged over a small subset of companies and will not apply to any specific one. The traditional model vendors don't allow insurers access to the damage functions to test this model component against their own claims experience. New open models empower insurers to do their own damage function calibration so the loss estimates reflect their actual experience better.

Open models do not eliminate model uncertainty, but they give insurers a much more efficient platform for understanding it and the ranges of credible assumptions for the model components. Instead of subjecting their risk management decisions to volatile third-party models, insurers can test different parameters and then decide on a consistent set of assumptions for their pricing, underwriting, and portfolio management decisions.

The RiskInsight® open platform also offers new risk metrics called Characteristic Events (CEs). Insurers, rating agencies, and regulators have tended to focus on a few point estimates from the EP curves—specifically, the so-called "1-in-100-year" and "1-in-250-year" probable maximum loss (PML) studies that drive many important risk management decisions, including reinsurance purchasing and capital allocation.

Apart from the uncertainty of these numbers, PMLs do not give insurers a complete picture of large loss potential. For example, insurers writing all along the Gulf of Mexico and Florida coastlines will likely have PMLs driven by Florida events because that's where severe hurricanes and losses are most frequent. While managing the PML driven by these events, an insurer could be building up dangerous exposure concentrations in other areas along the coast. The traditional catastrophe models are not the right tools for monitoring exposure accumulations.

Exposure concentrations can be more effectively identified and managed using a scientific approach that is the flip side of the EP curve approach. In the CE methodology, the probabilities are defined by the *hazard* and the losses estimated for selected return-period *events*.

Figure 3 shows the losses for the 100-year hurricanes for a hypothetical insurer. The landfall points, spaced at ten-mile intervals along the coast, are shown on the x-axis, and the estimated losses, in millions, are shown on the y-axis. The dotted line shows the 100-year PML—also corresponding with the top of this company's reinsurance program.

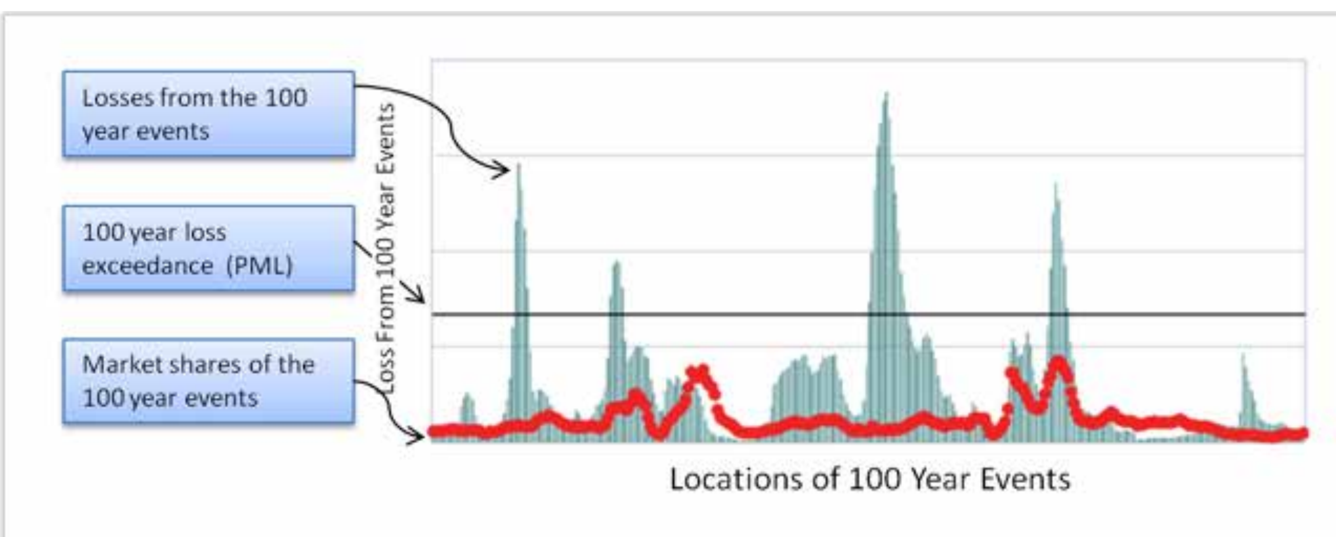
The CE chart clearly shows that, although the insurer has managed its Florida loss potential quite well, the company has built up an exposure concentration in the Gulf, and should the 100-year hurricane happen to make landfall there, this insurer will have a solvency-impairing loss well in excess of its PML and reinsurance protection.

Armed with this additional scientific information, insurers can enhance underwriting guidelines to reduce peak exposure concentrations. Because they represent specific events, the CEs provide operational risk metrics that are consistent over time. One important lesson of recent events, such as the Northridge Earthquake and Hurricane Katrina, is that insurers require multiple lines of sight on their catastrophe loss potential and cannot rely on the traditional catastrophe model output alone.

How developing countries can benefit from open models

Because the catastrophe models were designed to estimate insured losses, vendor model coverage is more extensive for the more economically developed regions where insurance penetration is relatively high. Less

FIGURE 3. CE Profile



investment has gone into model development for the developing countries.

Open models empower developing countries to build their own models using experts of their own choosing. Open models also enable countries to be more informed about the nature of the risk and how it can be managed and mitigated versus simply giving them highly uncertain loss estimates. As governments use open models, they will become more knowledgeable risk managers. Finally, open models are more cost effective and efficient than closed third-party models.

Conclusions

The first generation catastrophe models have been invaluable tools for the insurance industry, but they were designed to let insurers put data in and get numbers out. They were not designed to enable model users to see and interact with the model assumptions so as to understand fully the model components and the drivers of the loss estimates. Insurers have had to accept the vendor model output "as is" or make rough adjustments to the EP curves.

Catastrophe models are more appropriately used as tools to understand the types of events that could occur in different peril regions and the damages that could result from those events under different sets of credible assumptions. The more open a model is, the more informative and useful it is for all parties—private companies, governments, and academic institutions. Advanced open loss modeling platforms take the powerful invention of the catastrophe model to the next level of sophistication.

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The Current State of Open Platforms and Software for Risk Modeling: Gaps, Data Issues, and Usability

James E. Daniell (Karlsruhe Institute of Technology)

A huge number of open source models (well over a hundred at last count) exist globally, with software reviews pointing to the great many programming languages, environments, locations, and data methodologies applied to different natural catastrophes. Of the makers of the open source software packages for earthquake reviewed in a 2009 study similar to this one, only a few had continued development of their models in 2014, and a few new packages were available, which indicates a large turnover of models.

As first explained by Hessel Winsemius in the Plug'n'Play workshop at the Understanding Risk (UR) Forum 2014 in London, the problem of an open source or commercial risk model is analogous to a squirrel with a nut or acorn: the squirrel will protect its nut at all costs. Similarly, in many cases, each model developer in the risk community wants to promote his or her model, retain rights to it, and, naturally, fight for funding mechanisms to improve it at all costs, often with no view to collaborating or rebuilding outside the developer's software environment.

Because of this, the concept of a unified model for risk is subject to challenges concerning usability, adaption of everyone's input and ideas, and other considerations to be detailed below. Much the same problem occurs with data and with other models. Commercial models with their black box components cannot be tested transparently, meaning platforms built for them have inherent issues in the greater scientific community. Since every developer will always want to code, adapt, change, and create new modeling capabilities, a great many models will always be available. Thus, any platform needs to have an open user/editor policy.

Interoperability issues between models

Any effort to produce a multirisk software or system approach needs to maintain interoperability between models and hazards. If the system is to be adopted or integrated with other approaches, a highly adaptive solution is needed. In a modeling Utopia, the following would prevail among all software packages:

- Standards licensing for intellectual property (IP)
- A marketplace for modeling software
- No licensing required for access
- Open taxonomy
- Standards for delivery of results, return periods, and hazard intensity
- Standards for mapping, reporting, and animations
- Examples of output metrics and case studies
- Connection among models to allow adjustments and provide users with many options
- Metadata (self-describing documentation) and model standards for these metadata
- Development of a validation checklist that is usable and flexible.
- Standardized delivery of information (simple to accomplish)
- Unification of hazard description (quite complex)
- Transmission of units of uncertainty and translation of vulnerability and hazard metrics (complex)

- Standards between models created from crowd-sourced empirical, and analytical data
- Quality ratings of approval, moderation, or a peer review process
- Defined acceptance requirements

A number of challenges come with this. One key example is the adoption of standard modeling parameters and taxonomies that have often not been reused across different models. Engaging in this process would mean dealing with the following:

- Establishing standard modeling formats (codes and so on)
- Defining who comprises the modeling community (risk management firms, the insurance industry, academic institutions, and so on)
- The languages spoken and how they relate
- Determining the expected standard output of a software package
- Determining what basic modeling metadata are needed
- Establishing a data format that enables easier access to loss data (barriers such as privacy considerations need to be overcome)
- The complexity of adherence (easy, medium, hard?)
- Whether the OASIS framework (a platform for testing models associated with risk, including insurance models) fits into the global approach
- Using holistic community engagement as a metric

If, however, the models were supported on a platform that showed their applicability and data sources, all the modelers would have an incentive to have their models on it, without problems concerning rights. As more open datasets became available, the platform would also be a useful place to go as a first check for new ones.

To make this happen, the following are needed:

- A lead international organization (such as the World Bank or other international group, with international coverage provided), with no commercial company affiliations but a general mandate from the public and the risk community
- Focused working groups
- An email list
- Government support
- International data sharing, with interoperability but not hard-wired standards
- Connection with data agencies globally
- Common contract terms (for example, INCO-Terms, GPL, creative commons)
- Movement outside the black box system by creating credibility through case studies and communication (through prob, prob 3D, and so on)
- Beneficiaries from the public and private sectors, with a call for technical support and communication
- Definition of key incentives

Encouragement for modelers and existing platforms to contribute to a one-stop shop

Providing incentive to the model developers, data providers, users, funders, institutions, and agencies is key to driving any process of integrating software platforms. Companies often help create or disrupt the creation of standards or platforms—consider, for example, the developers of proprietary document file types that have become common standards, such as Google (KML), Adobe (PDF, PS), ESRI (Shapefile), and GDAL (JSON, XML). The providers and builders, as opposed to the users and distributors, often drive the process for setting the design criteria. Among the incentives for using an open standard and/or open system are that the model gets used more, it meets a design criterion, and it is usable across different users. Disincentives for companies and developers, however, include the loss of commercial advantage, profits, and proprietary value (as in the case, for example, of Microsoft Word documents and their market share). This leads to a need for constant encouragement for interoperability, which can be accomplished by setting a standard of acceptability—either through an international standards organization (ISO) system or an Open Geospatial Consortium (OGC) style system providing the ability to plug and play; these allow creativity and flexibility while not interfering with potential innovation.

To get developers to sign on to such an interoperable or standard approach, reward mechanisms must be provided, such as giving appropriate credit where it is due. Referencing of the developer's work in any subsequent works and accountability need to be shown and some assurance of standard relevance provided to give confidence to the entire community. The approach should also allow for some kind of rating system for models going into the platform/standard/interoperable format. This can be achieved by providing quality assurance in adhering to criteria (through transparency on the part of companies and developers), as well as by the commercial developers' retaining IP (intellectual property) rights. The approach needs to be robust and simple enough for developers to adhere to it and provide documentation and disclosure, while also being accountable.

There is a great need to create consensus by inviting modelers and decision makers to contribute without taking losses or having to adapt; they can then see a benefit in participating. A number of issues have arisen with many existing contributions from projects with major funding and commercial interests: overambitious work packages and deadlines; a separation between those selected and not selected for contracts and workshops; locations where models are being developed; and models with the same methodologies (for example, the Global Earthquake Model and other major funded software packages). The shortcomings of such approaches often create an immediate disconnection within the risk community between the selected and not selected partners. They tend not to arise, however, with approaches such as holding a forum (like Understanding Risk) where everyone can attend and give their opinions, which inspires participation.

User perspectives of risk platforms: Advanced risk modelers versus decision makers

There is never one perfect model that will suit all developers and all decision makers. Building typologies, for instance, feature over fifty different methods globally—for earthquake, EMS, HAZUS, GEM, RISK-UE, MMI, NEXIS, various census definitions, and so on. Similarly, for earthquake intensity parameters, more than a hundred scales have been used historically. No one perfect platform has all of these options integrated, and ten more scales might be produced by the time one is integrated.

Different models by developers are built for different purposes, and different programming structures are used for different methodologies. A very complex model can be useful at high resolution, but the uncertainties often increase with resolution in total losses. A very robust model, such as a rapid global earthquake economic loss model, can give good quality results at province-level resolution but not be used for very detailed analysis. The need for a global solution often presents an insurmountable obstacle to attempting robustness, accuracy, and precision.

Similarly, decision makers require different levels of complexity, depending on the user. With more knowledge of a subject often comes more uncertainty and realization of the complexities of decision making. A compromise is needed between simplicity or simple explanation methods on the one hand and getting the right outputs and information to the user on the other.

Data issues (global, regional, local) and the ability of governments to provide completely open data

Global, regional, and local datasets of differing quality are produced constantly around the world, in different formats and languages, using different methods and systems, and providing different levels of manipulation by the creators of the surveys. A global repository of any such data for use within models (such as a Gripweb system for disaster loss databases) cannot contain all data. A repository containing many datasets is often good enough, however, to start the "crowd-sourcing" effect of contributors (again, with incentives). Having a login system (or guest accounts) is often good, with contributor scores assigned (that is, with one point awarded for each contribution), as is done in forums for programming solutions (such as Matlab Central and MrExcel) or chatting platforms.

As a result of issues such as digital elevation models (DEMs) in Australia and other parts of the world not being free (and the resolution being too low for meaningful flood/storm surge modeling) or being unavailable, or the removal earlier this year of the National Computing Infrastructure for TsuDAT, online calculations now cannot be performed. These are constant concerns with regard to the dependability of "funded" software packages. Such issues with the use of data globally will remain no matter what, with decisions about census methods and global politics playing a major role in funding for research and data collection.

Similarly, the remote running of models through computer infrastructure, although sometimes useful via "cloud" systems, runs into issues of incompatible data, inability to change parameters, and other obstacles. In parts of the developing world, this sometimes leads to models' not being used. Models that are too complex, difficult to install, or very large (such as Oats, Telemac, parts of CAPRA, and flood models) have also presented problems in the past for basic users.

Commercial packages do not provide, as yet, a transparent view of what data sources they use; and closed running on a marketplace model system, such as OASIS, has drawbacks as well as benefits. Many portfolios are not open to the public, yet models are still needed. Similarly, councils may examine a risk model before investing in data collection. For true global collaboration, a completely open and impartial management system is needed from outside the commercial, insurance, or private financial hemispheres.

Toward a solution

Currently, a fully open source, impartial platform for risk modeling does not exist, although there is no shortage of risk models in general. A repository containing free and possibly commercial datasets and integrated results (such as an HDX, SOPAC, or census websites) is needed, and the twenty-four-hour nature of disasters should be looked at and taken into account. Around the world, entities such as Earthquake-report.com provide constant access to earthquake reporting with little or no support. Similar entities dealing with other types of disasters exist as well. Model and software users would benefit from online forum collaborations with these entities, as well as with the developers of such platforms (like the CAPRA forum, where users can ask questions and interact on the ecapra.org website).

Multirisk software packages such as RiskScape, CAPRA, HAZUS, SAFE, and ERGO exist and will continue to develop and improve. Many new risk models in various fields are being produced every year. The drawbacks and positives are mentioned in the risk reviews released in a 2014 report by the Global Facility for Disaster Reduction and Recovery (GFDRR).[1] Similarly, companies producing software specific to particular perils (for instance, earthquakes only), as well as dataset and methodology producers, need to present their systems in a transparent way for compatibility between datasets and models.

At the end of the day, the end users govern the process of any software production, but an open source and commercial platform providing datasets and models is plausible if incentives are provided and interoperability and data issues are covered, and the main goal is not to model every part of the world using an overarching system, given the dynamic nature of the globe and plethora of existing tools.

[1] GFDRR, Understanding Risk: Review of Open Source and Open Access Software Packages Available to Quantify Risk from Natural Hazards, 2014, International Bank for Reconstruction and Development/ International Development Association or The World Bank, 2014, https://www.gfdrr.org/sites/gfdrr/files/publication/UR-Software_Review-Web_Version-rev-1.1.pdf.

Visions for the Future: Model Interoperability

Andy Hughes, John Rees (British Geological Survey)

The following describes the standards that must be met to enable models to be interoperable—that is, to be able to pass data between them during a simulation—and their implementation.

Why connect models?

Model interoperability is important for a number of reasons. As is widely recognized, addressing environmental problems, including hazards, requires approaches that are increasingly interlinked and complex. The solution, therefore, has to be interdisciplinary. Model development can no longer be carried out by the enthusiastic amateur; domain experts are needed to develop models, which, in turn, need to be integrated with one another. If, for instance, we are to improve our understanding of the impact of environmental change, climate models have to be linked to hydrological models, and so on.

Different approaches

At its simplest, exchanging data between models requires data standards to be met to ensure the files used are compatible. An example of this would be XML (Extensible Markup Language), which is commonly used to exchange data via the Internet. Passing data between models using "flat files" after they have completed a simulation, however, means feedback between different parts of the system cannot be examined. To couple models in a way that allows interaction to be explored, a dynamic exchange of data at runtime is required. Various disciplines, which often have different needs, have developed approaches to solving this problem.

For dynamic linking to be successful, the models have to be recast as externally controllable components. This means the model has to take the form of the initialize, run, and finalize (IRF) structure. Once this has been achieved, the models can be made components and wrapped in the implementation of whatever model linking standard is chosen. Exposing the different variables to be coupled within each component then allows these variables (or exchange items) to be passed between the components, which enables two-way linkages to be developed and, therefore, feedback in the system to be simulated. This is challenging, but the net result is the availability of a set of linkable components that allows the creation of various configurations for testing different scientific and policy questions.

One thing to note is the difference between standards and their implementation. Put simply, a standard is a written description of what needs to be done, and implementation is how it happens. To take USB (Universal Serial Bus), the standard would be defining such aspects as the number of connections and how data are passed through them. The implementation of the standard refers to the physical plug and socket that can be used to connect devices.

Summary of each type

The following summarizes the most commonly used of each type of model coupling approach. Most of this text is taken from a 2014 study by Barkwith and others,[2]

[2] A. K. A. P. Barkwith, M. Pachocka, C. Watson, A. G. Hughes, "Couplers for Linking Environmental Models: Scoping Study and Potential Next Steps," British Geological Survey, Nottingham, UK, OR/14/022 (unpublished), 2014, http://nora.nerc.ac.uk/508423/.

which contains fuller descriptions and more information about each type of approach.

Climate. The Earth System Modeling Framework (ESMF) allows the building of complex applications for earth system modeling and is typically used to couple models of large physical domains.[3] ESMF originated with the Common Modeling Infrastructure Group (CMIWG), which was active between 1998 and 2000 and comprised major U.S. weather and climate modeling organizations. It was developed in response to the NASA Earth Science Technology Office (ESTO) Cooperative Agreement Notice, entitled "Increasing Interoperability and Performance of Grand Challenge Applications in the Earth, Space, Life and Microgravity Sciences," which called for its creation.[4] ESMF implements methods that allow separate components to operate as single executables, multiple executables, or web services.[5] It supports parallel computing on Unix, Linux, and Windows HPC (high performance computing) platforms.[6]

The Bespoke Framework Generator (BFG) was developed at the Centre for Novel Computing (CNC) in the School of Computer Science at the University of Manchester with the objective of creating a framework that would impose a minimum of requirements on a component's architecture and thus allow for straightforward and flexible model integration.[7] BFG only needs metadata, in the form of XML files, to generate the required wrapper code, which can then be used with a coupling system of the user's choice.[8] A component must comply with a small set of rules: it must be a subroutine or a function, and it must use "put" to provide data and "get" to receive them.[9] XML files must be entered manually by a user; in the future, they will be generated automatically from a GUI (graphical user interface.[10]

In 1991, the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS) began developing a software interface to couple existing ocean and atmosphere numerical general circulation models. OASIS3-MCT_2.0 is interfaced with the Modeling Coupling Toolkit (MCT), developed by the Argonne National Laboratory in the United States. MCT implements fully parallel regridding and parallel distributed exchanges of the coupling fields based on precomputed regridding weights and addresses. MCT has proven parallel performance and is also the underlying coupling software used in the Community Earth System Model (CESM).[11]

Low model component intrusiveness, portability, and flexibility were key concepts when designing OASIS3-MCT_2.0. The software itself may be envisaged as a coupling library that needs to be linked to the component models, the main function of which is to interpolate and exchange the coupling fields between them to form a coupled system. OASIS3-MCT_2.0 supports coupling of 2D logically rectangular fields, but 3D fields and 1D fields expressed on unstructured grids are also supported, using a one-dimension degeneration of the structures.

Hydrology. The Open Modeling Interface (OpenMI) Standard was established by a consortium of fourteen organizations from seven countries, in the course of the HarmonIT project cofunded through the European Commission's Fifth Framework program.[12] Originally developed to address a call from the Water Framework Directive for integrated water resources at the catchment level,[13] its application was later extended to other

[3] ESMF, Earth System Modeling Framework website, http://www.earthsystemmodeling.org, accessed November 14, 2013.
[4] Ibid.
[5] S. Valcke and T. Morel, "OASIS and PALM, the CERFACS Couplers," technical report, TR/CMGC/06/38, 2006, http://www.researchgate.net/publication/249728168_OASIS_and_PALM_the_CERFACS_couplers.
[6] B. Lu, "Development of a Hydrologic Community Modeling System Using a Workflow Engine" (PhD thesis, Drexel University, 2011); H. R. A. Jagers, "Linking Data, Models and Tools: An Overview" (paper presented at the Fifth Biennial Meeting of the International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Ottawa, Canada, 2010).
[7] I. Henderson, GENIE BFG, University of Bristol Geography Source website, 2006, last revised August 26, 2008, https://source.ggy.bris.ac.uk/wiki/GENIE_BFG, accessed November 14, 2013.
[8] Ibid.; R. Warren, S. De La Nava Santos, N. W. Arnell, M. Bane, T. Barker, C. Barton, R. Ford, H. M. Füssel, R. K. S. Hankin, R. Klein, C. Linstead, J. Kohler, T. D. Mitchell, T. J. Osborn, H. Pan, S. C. B. Raper, G. Riley, H. J. Schellnhüber, S. Winne, and D. Anderson, "Development and Illustrative Outputs of the Community Integrated Assessment System (CIAS), a Multi-institutional Modular Integrated Assessment Approach for Modelling Climate Change," Environmental Modelling and Software 23 (2008): 1215–16.
[9] Warren et al., "Development and Illustrative Outputs."
[10] Henderson, "GENIE BFG."
[11] S. Valcke, "The OASIS3 Coupler: A European Climate Modelling Community Software," Geoscientific Model Development 6 (2013): 373–88.
[12] R. Moore, P. Gijsbers, D. Fortune, J. Gregersen, M. Blind, J. Grooss, and S. Vanecek, "OpenMI Document Series: Scope for the OpenMI (Version 2.0)," ed. R. Moore, 2010, http://tinyurl.com/oxwpxnt).
[13] Roger V. Moore and C. Isabella Tindall, "An Overview of the Open Modelling Interface and Environment (the OpenMI)," Environmental

domains of environmental management.[14] OpenMI is maintained and promoted by the OpenMI Association[15] and is supported by the FluidEarth initiative of HR Wallingford,[16] which provides tools for robust model integration, such as the FluidEarth2 Toolkit. OpenMI is equipped with GUI (OpenMI Configuration Editor), which facilitates creating and running compositions.[17]

Components in OpenMI are called "linkable components,"[18] and their architectural design follows the IRF structure. They must be accompanied by metadata provided in the form of XML files[19] and encoded using either VB.Net or C#.[20] Models written in other languages (such as Fortran, C, C++, or Matlab, among others) can be integrated in OpenMI after implementing appropriate wrappers.[21] A number of tools (Software Development Kits, or SDKs) are available to assist users in developing their applications, including wrappers, and are provided in the form of code libraries.[22] A set of interfaces needs to be implemented to make a component OpenMI compliant,[23] with the central one being "ILinkableComponent."[24]

The Community Surface Dynamics Modeling System (CSDMS) is an international initiative, funded by the U.S. National Science Foundation (NSF), that promotes sharing, reusing, and integrating earth-surface models.[25] CSDMS implements the Common Component Architecture (CCA) standard for model coupling, which is adopted by many U.S. federal agencies. CCA development started in 1998 to address the demand for technology standards in high performance scientific computing.[26]

CCA is distinguished by its capacity to support language interoperability, parallel computing, and multiple operating systems.[27] Three fundamental tools underpin CSDMS: Babel, Ccaffeine, and Bocca.[28] CSDMS is equipped with GUI, called Ccafe-GUI, in which components are represented as boxes that can be moved from a palette into a workspace. Connections between components are made automatically by matching "uses ports" to "provides ports."[29] Results of simulations can be visualized and analyzed during and after the model run using a powerful visualization tool (VisIt),[30] which features, among other functions, the ability to make movies from time-varying databases.[31] A lightweight desktop application is provided, called CSDMS Modeling Tool (CMT), which runs on a PC but communicates with the CSDMS supercomputer to perform simulations.[32]

Insurance. The insurance industry relies on catastrophe models based on combining data and models for exposure, vulnerability, and hazard to determine insured loss. Most of these so-called "cat" models are proprietary and are "black boxes" (that is, the underlying assumptions, data, and code are not readily available to view or be interrogated by the user).

OASIS-LMF, described as a conceptual model for catastrophic loss modeling, is a framework for calculating insured loss. An open access framework, it integrates hazards, vulnerability, damage, and insured loss and is underpinned by a central calculation spine fed by datasets and parameters of the source models. It relies on the adoption of industry standards, such as those put forth by the Association for Cooperative Operations

Science & Policy 8 (2005): 279–86.

14 OpenMI Association Technical Committee (OATC), "OpenMI Document Series: The OpenMI 'in a Nutshell' for the OpenMI (Version 2.0)," ed. R. Moore, 2010, http://tinyurl.com/oymoljm.

15 OPENMI, OpenMI Association website, 2013, http://www.openmi.org, accessed November 14, 2013.

16 FluidEarth, FluidEarth HR Wallingford website, 2013, http://fluidearth.net/default.aspx, accessed November 14, 2013.

17 J. L. Goodall, B. F. Robinson, and A. M. Castronova, "Modeling Water Resource Systems Using a Service-Oriented Computing Paradigm," Environmental Modelling and Software 26 (2011): 573–82.

18 Lu, "Development of a Hydrologic Community Modeling System."

19 OATC, "The OpenMI 'in a Nutshell' for the OpenMI."

20 Lu, "Development of a Hydrologic Community Modeling System."

21 OATC, "The OpenMI 'in a Nutshell' for the OpenMI."

22 Ibid.

23 Ibid.

24 OpenMI Association Technical Committee (OATC), "OpenMI Document Series: OpenMI Standard 2 Specification for the OpenMI (Version 2.0)," ed. R. Moore, http://tinyurl.com/pxudwt4.

25 S. D. Peckham, E. W. Hutton, and B. Norris, "A Component-based Approach to Integrated Modeling in the Geosciences: The Design of CSDMS," Computers & Geosciences 53 (2013): 3–12.

26 Ibid.

27 Ibid.

28 Ibid.

29 S. D. Peckham and J. L. Goodall, "Driving Plug-and-Play Models with Data from Web Services: A Demonstration of Interoperability between CSDMS and CUAHSI-HIS," Computers & Geosciences 53 (2013): 154–61.

30 S. D. Peckham and E. Hutton, "Componentizing, Standardizing and Visualizing: How CSDMS is Building a New System for Integrated Modeling from Open-source Tools and Standards" (paper presented at the fall meeting of the American Geophysical Union Fall, San Francisco, USA, 2009).

31 Peckham et al., "Component-based Approach to Integrated Modelling."

32 Peckham and Goodall, "Driving Plug-and-Play Models"; CSDMS, Community Surface Dynamics Modeling System website, 2013, http://csdms.colorado.edu/wiki/Main_Page, accessed November 14, 2013.

Research and Development (ACORD), the insurance industry's standards body. In the future, other standards, to be defined by the industry, will be deployed to link to the spine.

Other. Applications operating as web services are based on independent, distributed, and loosely coupled components that exchange data over a computer network. In the hydrological domain, such web processing services are used in a number of ways—for example, to integrate hydrological data from heterogeneous sources; to link modeling frameworks with databases; to connect models, databases, and analysis tools into water resources decision support systems; or to join modeling systems from different domains, such as hydrology and climate.

One example of successful use of service-oriented technology for environmental data integration is the Hydrologic Information System (HIS), created by the Consortium of Universities for the Advancement of Hydrological Science Inc. (CUAHSI), an organization of more than a hundred U.S. universities that aims to develop infrastructure and services for the advancement of the hydrological sciences.[33] HIS is composed of hydrological databases and servers connected through web services.[34] It employs WaterOneFlow web service interface and Water Markup Language (WaterML) for data transmission to enable integration of hydrological data from heterogeneous data sources into one "virtual database."[35]

Conclusion

An assortment of types of model coupling approaches is available, and the choice is very much based on fitness for purpose. While the technology is in its infancy, a high degree of technical knowledge is still required to use these approaches. This has to be borne in mind when choosing any approach for disaster reduction and recovery.

33 Peckham and Goodall, "Driving Plug-and-Play Models."
34 Ibid.
35 Goodall et al., "Modeling Water Resource Systems."

Harnessing Innovation for Open Flood Risk Models and Data

Rob Lamb (JBA Trust[1], Lancaster University[2])

The harnessing of recent and future innovations in designing effective risk platforms, models, and data is essential to the reduction of flood risk. Doing so ensures those assets can gain long-term traction for disaster risk reduction, while realistically reflecting an uncertain world. Although the central concepts of flood risk analysis are well established, fragmentation around them is considerable in the data and models used in practice. The following discusses the reasons for this fragmentation and provides recommendations for addressing it.

Flood risk

Flooding accounts for a third of the economic losses caused by natural hazards globally and is among the most frequent of natural disasters. Damaging floods can occur unpredictably, even though some of the physical drivers, such as monsoons and cyclones, are understood. They can affect coastal and inland areas, displace people, ruin crops, and paralyze cities.

Not only are the weather and climatic causes of flooding unpredictable; so, too, is the damage caused by any particular event. Impacts on people and economies depend on both the footprint of the flood and how it affects—and is in turn affected by—flood protection infrastructure. The performance of infrastructure systems and the damage to communities in flood events can rarely be predicted with certainty.[36] Flooding poses a hazard over a wide range of scales, from recurrent localized flash floods to prolonged, widespread events of regional significance. Mitigation measures can also cover a range, from very local actions to large-scale infrastructure projects embodying significant capital investments.

For these reasons, flooding has come to be viewed in terms of risk, with recognition of a need to account both for events that have been experienced or are happening "now" and for those that might occur in the future. Flood risk concepts are intellectually well established across a number of sectors, including engineering, investment planning, civil disaster or emergency management, and insurance.[37] A strong conceptual core views flood risk in terms of the probabilistic analysis of extreme natural weather events, performance of infrastructure, assessment of harm, and evaluation of mitigation measures related to risk reduction.

Since risk is inherently immeasurable, and the systems involved in flood disasters are often very complex, testing and validating flood risk models and data are extremely difficult. While historical events or modeled events that resemble them may be adopted as prototypical scenarios to test resilience[38] or disaster plans,[39] there is, of course,

[36] K. J. Beven and J. Hall, *Applied Uncertainty Analysis for Flood Risk Management* (River Edge, NJ: Imperial College Press, 2014).

[37] D. van Dantzig, "Economic Decision Problems for Flood Prevention," *Econometrica* 24 (1956): 276–87; J. Hall, R. Dawson, P. Sayers, C. Rosu, J. Chatterton, and R. Deakin, "A Methodology for National-scale Flood Risk Assessment," Proceedings of the Institution of Civil Engineers—Water and Maritime Engine 156 (2003), 235–47; National Research Council, Committee on Risk-based Analysis for Flood Damage Reduction, Water Science and Technology Board, Risk Analysis and Uncertainty in Flood Damage Reduction Studies (Washington, DC: National Academy Press, 2000); J. Schaake, T. Hamill, R. Buizza, and M. Clark, "HEPEX: The Hydrological Ensemble Prediction Experiment," Bulletin of the American Meteorological Society 88 (2007): 1541–47; G. Woo, The Mathematics of Natural Catastrophes (River Edge, NJ: Imperial College Press, 1999).

[38] Lloyd's, "Realistic Disaster Scenarios: Scenario Specification," January 2015, https://www.lloyds.com/the-market/tools-and-resources/research/exposure-management/realistic-disaster-scenarios.

[39] UK Cabinet Office, National Risk Register of Civil Emergencies, Ref:

no guarantee that the next major event will look like any of the prototypes.

Fragmentation

The diversity of sectoral interests and scales gives rise to fragmentation in the tools, models, and datasets that are applied in practice to assess or manage flood risk. An array of standards and protocols are also applied to elements of the flood risk modeling "chain" (for example, FEMA—the U.S. Federal Emergency Management Agency—provides extensive guidance on flood modeling)[40] and to a wide range of risk models and platforms, some competing and some evolving cooperatively, within a growing market in risk analysis information.

Whether driven by competition, regulatory requirements, or the stresses of actual events (for example, North Sea flooding in 1953 or Hurricane Katrina in 2005), innovation in flood risk models and data in developed economies has stimulated development of a variety of risk modeling approaches and datasets. Most are specialized for particular applications, which brings advantages in terms of focusing on the contributions to risk perceived to be important in each case, whether they be variability in weather patterns, infrastructure systems, population vulnerability, or economic damage assessments. Specialization, and the variations in emphasis within alternative technical methodologies, can also lead to debate over the most appropriate approach to developing a view of risk, however, even between alternative datasets and models, each of which is credible from a technical perspective.

The challenge: To harness innovation effectively

This multimodel, multiplatform world reflects uncertainties and limitations in knowledge and data. Rather than seeking to eliminate uncertainty, which is unrealistic (despite technology offering increasingly detailed data),[41] the alternative is to accept it and work with it to help inform robust decisions. This approach is already established in climate change adaptation and mitigation, where an ensemble of models[42] effectively informs scientific advice to policymakers.[43]

In managing the flood risk, it may be that different models and data are relevant over time scales ranging from the immediate disaster management and recovery to longer-term preparedness, which will often boil down to decisions about investment or resource allocation. Some common core elements will be identifiable, however; for example, both the ensemble simulations used for real-time event forecasting and the Monte Carlo methods used for investment risk analysis require software that can rapidly and robustly compute multiple "scenarios"—ideally, software that can be scaled to work on appropriate computing systems as information technology advances.

New platforms, models, and data for flood risk reduction should harness the innovation within academia and industry, while building on the strong core concepts of flood risk, by concentrating on establishing reusable, open software architectures for such core tasks and setting standards for describing the datasets they consume and produce. Some initiatives already demonstrate how these concepts can be applied—for example, in real-time flood prediction[44] and flood risk management planning[45] and in tools used primarily in the reinsurance sector, including (among others)[46] RMS's RiskLink and RMS(one)[47] software, JBA's catastrophe modeling platform JCalf,[48] and the Oasis Loss Modeling platform.[49] These approaches are evolving to handle multiple hazards (perils), potentially adding value in the broader context of disaster risk reduction.

408697/0212, 2012, www.cabinetoffice.gov.uk.

40 FEMA, *Guidelines and Specifications for Flood Hazard Mapping Partners Flood Studies and Mapping*, 2009, Appendix C: Guidance for Riverine Flooding Analyses and Mapping.

41 K. Beven, H. Cloke, F. Pappenberger, R. Lamb, and N. Hunter, "Hyperresolution Information and Hyperresolution Ignorance in Modelling the Hydrology of the Land Surface," Science China Earth Sciences, 58 (2015): 25–35.

42 Coupled Model Intercomparison Project, http://cmip-pcmdi.llnl.gov/cmip5/index.html.

43 IPCC, Climate Change 2014 Synthesis Report, Fifth Assessment Report, 2015, http://ar5-syr.ipcc.ch.

44 http://www.delft-fews.nl.

45 http://www.hec.usace.army.mil/software/hec-fda.

46 http://www.aon.com/attachments/reinsurance/elements.pdf; http://www.air-worldwide.com/Software-Solutions/Touchstone.

47 http://www.rms.com/rms-one/rms-one.

48 http://www.jbarisk.com/research-and-opinion/jcalf.

49 http://www.oasislmf.org.

Recommendations

Investment in risk analysis platforms, models, and data should include long-term mechanisms to build professional communities of practice that can develop an understanding of the credibility of risk models and data in disaster management and to maintain partnerships between academics and industry to develop robust standards for data and software. Such collaborations would shift the focus away from finding a unique technical solution and more toward other issues:

- Managing software evolution
- Data sharing, maintenance, and standards
- Designing now for future advances in information technology
- Building communities of practice for coproduction of risk information and proposed mitigations

In addition, long-term commitment is required to invest in partnerships that enable the coproduction[50] of information about risk, evaluated critically from a position of knowledge and understanding through ongoing dialogue among scientists, decision makers, and communities. This can be achieved by ensuring teams from industry, nongovernmental organizations (NGOs), and community organizations are embedded into major research projects, which requires suitable funding mechanisms to exist. Furthermore, the use of open (not necessarily no-cost) system architectures, software adaptability, and long-term engagement with communities to build a social understanding of risk should all be considered in the procurement of risk platforms, models, and data.

[50] S. N. Lane, "Acting, Predicting and Intervening in a Socio-hydrological World," Hydrology and Earth System Sciences 18 (2014): 927–52, doi:10.5194/hess-18-927-2014.

Toward Reducing Global Risk and Improving Resilience

Greg Holland, Mari Tye (National Center for Atmospheric Research)

That improved tools are urgently needed in support of community planning and decisions regarding adaptation to the effects of climate change is obvious. Surveys by several organizations have shown the frequency of natural disasters has increased globally by three to five times, and they disproportionately affect developing countries and poorer people. Some highly sophisticated tools are in use, especially in the insurance and reinsurance industries, but their cost and complexity make them unavailable to the general community. A number of specialized risk and impact tools and approaches have been developed, but their wider application is made difficult by lack of standardization and related community support.

Here we first summarize the major challenges involved in developing relevant, community-based risk and impact tools and how they might be addressed by following the highly successful community-focused approach for climate and weather models. This involves developing community expertise and capacity by doing the following:

- Establishing and managing a global framework and set of protocols in support of specialized tools and applications
- Enabling and encouraging both free public domain and for-fee private applications
- Incorporating a comprehensive community database with an archive of data access applications
- Setting up a help desk to respond to community questions and issues
- Offering regular tutorials to train new participants
- Offering workshops to encourage community developers and to discuss problems and solutions

The challenges to carrying out these objectives are presented below, followed by solutions and recommendations based on the community-driven and supported approaches adopted by the National Center for Atmospheric Research (NCAR) and a concluding discussion.

Challenges

The chain of steps that lead to an objective impact assessment can be grouped according to four interdependent questions, as illustrated by figure 1:

FIGURE 1. **Hazard impact assessment stages**

- What is the risk of a specific hazard's occurring?
- Is there an exposure to this hazard?
- Given a risk and an exposure, what is the vulnerability?
- How do these three combine to produce an impact?

Carrying out each of these steps requires specialized expertise and data, but communication among specialists in these areas during the development and even the application stages can be haphazard. This leads to our first major challenge.

Challenge 1. *Ensuring community and cross-disciplinary involvement at all stages of development and application of impact assessment approaches*

Given the need for community and cross-disciplinary involvement, how can this development and application best be accomplished? This raises two basic questions:

- Should a single, all-encompassing model be used, or a large number of specialist models?
- Should the components be publicly driven open sources, or privately driven?

The advantages and disadvantages of each are well known:

- A single, global model can attract and make efficient use of substantial resources and expertise, and it enforces standards and consistent quality control. This approach lacks the stimulus for excellence and innovation that comes from competition and openness, however, and it may not be responsive to specialist needs, especially where resources are scarce.
- Developing a number of specialist models brings the advantages of competition and diversity, but this approach can suffer from the inefficiencies of multiple parallel developments, nonstandardization, and availability of expertise.
- Public usage of a system typically requires openness, whereas privately developed systems require some protection.

We suggest these are not necessarily either–all approaches, and the real challenge lies in the adoption of an approach that encompasses all.

Challenge 2. *Establishing an approach that has the advantages of being global but incorporates specialist public and private requirements, is inherently competitive in nature, and taps into the wide perspectives, expertise, and data from the community at large*

The entire approach, from risk assessment to impacts planning, involves substantial degrees of uncertainty that arises from, for example, relatively short records of high quality data, or is associated with climate variability and trends and changing demographics. Exposure and vulnerability assessments are increasingly sophisticated in terms of both the detail and the quality of the available data, but they necessarily contain implicit assumptions, such as the level of adherence to building codes.

We suggest uncertainty is best accommodated by a *combination* of traditional probabilistic approaches and changes to the entire planning approach to minimize the impacts of uncertainty through increased resilience, which leads to the third challenge.

Challenge 3. *Incorporating resilience procedures that minimize the importance of uncertainty in the planning and decision process*

The use of traditional catastrophe ("cat") modeling approaches requires a high degree of technical knowledge and sophistication. It also can require significant computing and personnel resources, which drives the cost up considerably. In many cases, a simplified system that provides the required core planning and decision information may be preferable. Where complexity is required, the effort must include some level of training. Development of the system must, therefore, be in conjunction with the users and accommodate their decision perspectives, capacity, and priorities. This requirement is encompassed by the final challenge.

Challenge 4. *Understanding community priorities and providing relevant tools and an appropriate level of training and community support*

Solutions and recommendations

In deciding on approaches to meeting the four challenges outlined above, it is useful to consider other successful models. NCAR provides a suite of climate and weather models for community use, and our group has been heavily involved in the development of the Weather Research and Forecasting (WRF) model. This is a huge international undertaking, with over thirty thousand registered users in more than 135 countries. It includes an operating framework and central archive, complete with web download of source code, a rigorous test and development protocol for new modules, and a full help desk for user problems. We conduct several tutorials each year to train new users or refresh existing users, together with specialist workshops where developers and users can interact on idea development, technical issues, and so on.

NCAR has combined the lessons learned from the WRF experience with the outcomes of a number of community meetings over the past four years to define our development of a public–private risk and planning approach that addresses the four challenges outlined above.

The Engineering for Climate Extremes Partnership (ECEP)[51] is an interdisciplinary collaboration that brings together engineering, scientific, cultural, business, and government groups to develop robust, well-communicated, cutting-edge science, aimed at reducing the impacts of weather and climate extremes on society. It arose following recommendations from the U.S. National Academies Summit on Managing Extremes in 2011 and U.S. president Barack Obama's Climate Action Plan, and it supports Obama's Climate Services for Resilient Development, announced in June 2015. The established approach has been developed through several community workshops in Zurich and at NCAR and the American Geophysical Union (AGU).

ECEP has three flagship activities, described below: incorporating "Graceful Failure" into risk and impact planning; the Global Risk, Resilience, and Impacts Toolbox (GRRIT); and community involvement and outreach.

Graceful Failure[52] is an operating concept that stresses a "safe to fail" approach by including response and recovery directly into strategic planning and by explicitly accounting for uncertainty. Integral to this approach is acknowledging that all systems will fail at some level and placing due emphasis on resilience to such failures. We stress that this is quite different from the more traditional approach of resistance to impacts from weather and climate extremes. Rather than decreasing impacts, resistance may engender greater catastrophes through cascading failure. Resilient systems, by comparison, are able to adjust to changing circumstances and to recover efficiently should a disaster occur.

Our view is that incorporating the response and recovery at the design and development stage is a win-win process that reduces the importance of uncertainty and improves community resilience.

The Global Risk, Resilience, and Impacts Toolbox (GRRIT) is a collection of tools based on a common operating framework and established protocols that can be used together or individually to provide information on hazard and impact probability in a manner suited to, for example, engineering design, societal adaptation planning, or improving community resiliency. GRRIT is built on the well-established principles and approaches in place to support the NCAR weather and climate modeling systems, which include the following:

- A framework for utilizing existing tools, together with protocols and test and acceptance procedures for including new community-developed tools
- Capacity for both free public domain and for-fee private applications
- A community database drawn from several sources—both observations and models—together with statistical applications for deriving specialized data from the broader base
- A help desk to respond to community questions and issues
- Regular tutorials to train new participants in the use of the GRRIT and to make them aware of common mistakes and lessons learned in its use
- Regular workshops to enable developers and the user community to discuss problems and solutions and to present new applications and tools.

Community involvement and outreach involves the facilitation by ECEP of direct interactions with the wider community that are aimed at communicating relevant information on risk, vulnerability, and potential impacts, including providing advice on issues specific

[51] M. R. Tye, G. J. Holland, and J. Done, "Rethinking Failure: Time for Closer Engineer-Scientist Collaborations on Design." *Proceedings of the Institution of Civil Engineers* 168 (2015): 49–57, http://dx.doi.org/10.1680/feng.14.00004.

[52] M. R. Jones, G. J. Holland, and J. M. Done, *"Integrating Science and Engineering to Reduce Vulnerability to Climate Extremes" (workshop presented at Rethinking Failure: Engineering for Climate Extremes, Boulder, Colorado, August 8–9, 2013*, as reported in Eos 94 (2013): 474, DOI: 10.1002/2013EO490006).

to individual communities. This activity encompasses groups with societal, cultural, local government, and/or business perspectives and needs who are vulnerable to the impacts of weather and climate extremes.

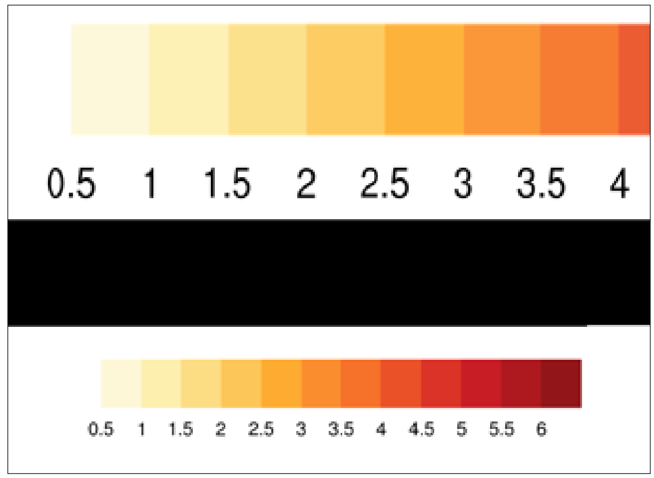
In particular, annual meetings of ECEP establish the strategic directions of both the partnership and GRRIT. These involve two days of workshop-style discussions to obtain views of a wide community, followed by a day on which just the ECEP partners and invited participants convene to formalize our overall plans, decide on joint work, and so on.

The GRRIT approach has been generated from extensive community consultation of this kind, as well as from incorporating lessons learned from our long experience with WRF. Progress to date includes the following:

- Establishment of a database of model and related information for community use. This includes a web component containing commonly requested information, plus a tape archive for specialist users
- Provision of a range of applications, including bias correction techniques to code for regional climate simulation, statistical downscaling of weather and climate extremes, and the use of an index approach for initial assessment of impact potential.
- Establishment of a series of international tutorials on use of the data, lessons learned in data use, and the gathering of more data
- Establishment of the basic GRRIT system, including a framework, database access software, and initial tools, including a tropical cyclone risk model; a tropical cyclone damage potential index; an application to support construction industry project planning; and an urban climate adaptation tool. This will be released in beta mode in 2016.

To give just one GRRIT example, the Cyclone Damage Potential (CDP) index[53] has been developed to provide a first-order assessment of potential risk, a means of objectively comparing the risk among widely separated regions, and, when combined with known impacts, an indication of the combined exposure and vulnerability of a region. It contains a physically correct combination of cyclone intensity, size, and translation speed.

FIGURE 2. Mean CDP for current climate using observed tropical cyclone data from 1980 to 2012. Higher damage potential is indicated by warmer colors.



Application of the CDP to the North Atlantic provides a quick assessment of those regions most at risk, as figure 2 shows. Clearly, cyclones with the highest net damage potential primarily affect the Yucatan and nearby Central American areas and the area around Louisiana.

We have held discussions with World Bank people on potential joint development work, for example by incorporating their cat model into GRRIT.

Conclusion

To summarize, we have outlined what we consider the four major challenges to be addressed in developing improved community planning and response to impacts from weather and climate extremes:

1. Ensuring community involvement
2. Establishing an approach that has the advantages of being global and incorporates specialist public and private requirements
3. Enhancing resilience in a manner that minimizes the impact of uncertainty in the planning and decision process
4. Providing appropriate community training and

[53] G. J. Holland, J. M. Done, R. Douglas, and M. Ge, “Global Tropical Cyclone Damage Potential,” 2015, under review by *Natural Hazards Review*.

support in the use of the tools

We also have outlined our philosophy and approach to addressing these challenges through the development of the Global Risk, Resilience, and Impacts Toolbox under the Engineering for Climate Extremes Partnership.

Referring to specific World Bank questions and needs, we recommend a focus on building capacity by making strategic investments in the establishment of a framework and related training and community support that does the following:

- More effectively uses existing data, knowledge, and techniques
- Increases expertise and understanding in impact modeling and planning, including improved resilience
- Encourages bottom-up community consultation and development
- Provides a framework for encouraging and utilizing such future community developments in risk, exposure, vulnerability, and impact tools and thus encourages both innovation and a healthy level of friendly competition

Based on extensive experience with community approaches of this type, we are confident that relatively modest investment now will lead to substantial returns in the future through both increased community understanding and the development of community-relevant specialized tools.

Priorities for the Short and Medium Terms: Which Are Better?

Susan Loughlin (British Geological Survey)

The Global Volcano Model (GVM) network is a public–private network comprising regional and international organizations and institutions concerned with identifying and reducing volcanic risk and building the resilience of society to volcanic eruptions. One of the original objectives of GVM was to develop an accessible and sustainable information platform on volcanic hazards and risk. GVM also recognizes the need, however, to use existing platforms, as well as be more strategic in our investments in risk data and modeling than we have been in the past.

One challenge for volcanology is the lack in many countries of basic data even to establish the eruption histories of volcanoes (their frequency, magnitude, intensity, and eruption characteristics). In addition, many active volcanoes are unmonitored, so the ability to anticipate future events (short-term risk analysis) through real-time monitoring is also compromised. This absence of data requires investment in geological mapping, geochronology (dating of past events), and volcano monitoring.

Data are also lacking in many locations for social and physical vulnerability and exposure to volcanic hazards. Raising awareness of this issue at high levels in government is a priority and requires investment in a key national institution or collaborative group of institutions, such as geological surveys, universities, and meteorological agencies, that can be responsible for filling the data gaps through research, monitoring, and supporting early warning and mitigation actions. The international community can support such national investment by adding value and providing additional resources, tools, training, and long-term collaboration.

Below we outline several key priorities for the short and medium terms, placing particular emphasis on data, risk assessment, monitoring, and filling knowledge gaps. The following information is adapted from background papers put together by the Global Volcano Model network and originally produced for the 2015 UNISDR Global Assessment Report (GAR15).

Priorities for the short term

Without knowledge of hazard, vulnerability, and exposure, risk analysis and assessment in volcanology are extremely challenging. For many of the world's active volcanoes in developing countries, we have only rudimentary eruption records, at best. In addition, many of the data that do exist are not in a standardized form, and they lack quality control. These knowledge gaps can only be closed by systematic geological, geochronological, and historical studies and support for national and international collaborative activities attempting to address issues around data collection, analysis methods, and databases. Among the short-term priorties are the following.

The hazard level of many volcanoes is highly uncertain, mostly reflecting the paucity of geological knowledge and, in many cases, a low frequency or absence of historical eruptions. Those volcanoes that combine high uncertainty levels with high population exposure should be prioritized for geological studies that document recent volcanic history for hazard assessment. Recommended studies include stratigraphy, geochronology, petrology, geochemistry, and physical volcanology. In some cases, findings are likely to increase the currently known risk. This work requires government funding to resource geological surveys and research institutions, as primary funds are not likely to come from the private sector. Where commercial activities are associated with active volcanoes, however, such as geothermal energy, tourism or insurance potential, it would be reasonable to ask for contributions to this baseline work.

Probabilistic assessment of hazard and risk that fully characterizes uncertainty is becoming mandatory to inform robust decision making. Deterministic approaches cannot fully characterize either hazard or risk, are limited, and can be highly misleading. Assessments and forecasts typically combine interpretations of geological and monitoring data and various kinds of modeling. Probabilistic event trees and hazard maps for individual volcanoes are best made by local or national scientists, and we recommend they be made for high-risk volcanoes. Some data from beyond the specific volcano in question are, however, also needed for these event trees and maps, especially if the volcano is poorly known.

Global databases can serve as references for local scientists, providing analog data and distributions of likely eruption parameters. The creation and maintenance of global databases on volcanoes, volcanic unrest, and volcanic hazards and quality assurance on data, hazard assessment methods, forecast models, and monitoring capacity are best done through international cooperation. Funding for the compilation of such databases does not fit easily into national and regional research funding and needs stronger international support.

Forensic assessments of volcanic hazards, vulnerability, impacts, and risk drivers are needed during and after eruptions. Such studies are essential to improve knowledge of hazards and vulnerability in particular and to improve and test methodologies, such as forecast modeling based on real observational data, in general. A great deal of valuable information about volcanic disasters is unpublished and often anecdotal, so formal publication of post-hoc assessments of emergency responses should be encouraged. Evaluations of "lessons learned" from past disasters are likewise important to improve future responses and avoid the repetition of mistakes.

Risks from volcanic ash fall associated with a particular volcano or region can be characterized by detailed probabilistic modeling, taking into account the range of physical processes (atmospheric and volcanic) and associated uncertainties. Also needed is a better understanding of the impacts of volcanic ash, as well as definition of the thresholds of atmospheric concentration and deposit thickness for various levels of damage to different sectors. We recommend further analysis be performed for all high-risk volcanoes to enable more conclusive statements about expected losses and disruption and to support resilience and future adaptation measures.

Many active volcanoes are either not monitored at all, or have only rudimentary monitoring. Some of these volcanoes are classified as high risk. A major advance for hazard mitigation would be if all active volcanoes had at least one volcano-dedicated seismic station with continuous telemetry to a nominated responsible institution (a volcano observatory), combined with a plan for use of satellite services. This matches a strategy from space agencies to monitor all Holocene volcanoes and make data available (see http://www.congrexprojects.com/2012-events/12m03/memorandum). The provision of funding to purchase equipment must be complemented by support for scientific monitoring and the training and development of staff, along with long-term equipment maintenance. We recommend regarding this action as a high priority in addressing volcanic risk.

Volcanoes identified as high risk should ideally be monitored by a combination of complementary multiparameter techniques. These should include volcano-seismic networks, as well as ground deformation, gas measurement, and near-real-time satellite remote sensing services and products (such as satellite-based geophysical change detection systems). We recommend all high-risk volcanoes have basic operational monitoring from all four domains. This should be maintained, interpreted, and responded to by a nominated institution (a volcano observatory). Donations of equipment and knowledge transfer schemes need to be sustainable over the long term with respect to maintenance and consumables. Supporting monitoring institutions and sustaining local expertise is essential.

Technological innovation should strive toward reducing the costs of instrumentation and making the application of state-of-the-art science as easy as possible so more *volcanoes can be monitored effectively.* Lower costs, easier access, technological training, and better and more timely sharing of data are needed to realize the potential of innovation. Many new models derived from research of volcanic processes and hazardous phenomena for forecasting can be made into accessible and easy-to-apply operational tools to support observatory work and decision making, and more such tools are needed to aid decision making in general. Model comparison and validation to standards that might ensure robust application are also lacking. More resources need to be put into converting research into effective tools.

Priorities for the medium term

Among medium-term priorities should be building international support for these efforts that is sustainable and well anchored in the host countries' own development plans. Another challenge to address is coordination, which can be difficult. Some volcanic emergencies cross borders, and hazards and attendant risks may occur on regional or global scales. The following are recommended:

Exchange visits, workshops, summer schools, and international research collaboration are good ways to share experience and expertise in volcano monitoring, appraisal of unrest, assessment of hazard and risk, and communication. Cross-disciplinary training is particularly useful. The value of interdisciplinary science is becoming more evident, and an understanding of methodologies across disciplines can greatly strengthen effective collaboration. Volcanoes often have cross-border impacts, and collaborative regional networks of countries can work together to build capacity, conduct research, carry out coordinated monitoring and planning, and make effective use of leveraged resources.

Free and easy access to the most advanced science and data will greatly enhance the ability to develop a volcanic risk platform. Access to knowledge is very uneven between the developed and developing nations. Regarding volcanic hazards specifically, easy access to high-resolution digital elevation data and remotely sensed data, together with appropriate training, would significantly improve the scientific capacity of many countries. We encourage the promotion of open access scientific knowledge for all and support the deployment of advanced technologies and information wherever it is needed.

Index-based methods to characterize hazard, exposure, risk, and monitoring capacity used in the GVM study (Loughlin et al. 2015) are straightforward, intended to provide a basic broad overview of volcanic hazard and risk across the world. The Volcanic Hazards Index and Population Exposure Index should not be used to assess or portray hazard and risk in detail at individual volcanoes, which is the responsibility of national institutions and volcano observatories. Nonetheless, combinations of the two at many volcanoes will enable improved and more robust global and regional assessments and identification of knowledge gaps.

Open Risk Data and Modeling Platform

Tracy Irvine (Oasis, Imperial College London, EIT Climate-KIC)

The European Union's EIT Climate-KIC is a pan-European partnership of businesses, public sector entities, and academic bodies that have been supporting the development of European climate adaptation services for a number of years. The following review will illustrate the types of initiatives we are advancing as approaches to improving the development and expansion of disaster and resilience modeling and associated decision making for catastrophe and climate risk assessment and adaptation and resilience planning.

Even within Europe, expanding the use of more sophisticated, multidimensional models that include exposure, hazard, vulnerability, damage, probability, and financial information is a new undertaking that has until now been led by developments in the global insurance sector. Lower-income countries may, potentially, integrate their efforts relatively rapidly with developed-world initiatives in this area by partnering with innovation hubs already in existence or by replicating them in regional hubs and through the development of specific skills and entrepreneurship.

The need in this area goes far beyond hazard models. Integrated modeling approaches provided by calculation kernels such as the Oasis Loss Modelling Framework (Oasis LMF) will encourage the development of standards which, in turn, will stimulate the development of models that provide the levels of accuracy and risk assessment urgently needed by the global community. They will also enable evidence-based planning and resilience initiatives that embolden policymakers and investment communities to support work in this area.

Sharing experiences in Europe: necessary foundations

Oasis+ is an innovation hub supported by the EU's EIT Climate-KIC, whose objective is "to become one of Europe's leading providers of software, tools, services, data and models that will enable catastrophe and climate risk assessment and adaptation planning by public, finance and other private sector organisations and create greater resilience against future catastrophes and climate impacts."[54] The Oasis+ consortium currently has twelve partners: ARIA Technologies and the Commissariat à l'énergie atomique (CEA) in France; Delft University of Technology and Deltares in the Netherlands; the German Research Centre for Geosciences (GFZ), Global Climate Forum, and Potsdam Institute for Climate Impact Research (PIK) in Germany; Imperial College London, Oasis Loss Modelling Framework (with forty-four global reinsurance and insurance members), Oasis PalmTree Ltd., and RYW Systems Ltd. (RYW) in the United Kingdom; and the Technical University of Denmark (DTU) in Denmark.

The consortium, which acts as a learning, collaboration, and innovation hub for the organizations involved, is developing sectorial demonstrators in city systems, developing and emerging economies, new insurance models, natural resources, and health (that is, converting the Oasis LMF kernel for uses related to understanding risks of health emergencies linked to climate events, such as heat waves). This type of hub provides multiple opportunities for participants to network, collaborate, innovate together, develop new services, tools, and

[54] See http://www.plateformesolutionsclimat.org/wp-content/uploads/2015/07/Oasis-business-plan-Executive-summary.pdf. Full text available from the author.

frameworks, and co-design and make links to end users. Extensions or replications of this approach would promote market understanding and expansion, skill development, and further innovation of comprehensive catastrophe and climate models and frameworks.

Communicating risk and increasing demand: Oasis+ eCommerce site

EIT Climate-KIC are supporting the development of an eMarket (a kind of Amazon) for catastrophe and climate data and models that is due for an initial prototype testing phase release in 2016. These are its key elements:

- The eMarket will provide *catastrophe, climate data, and model venue for model suppliers* seeking to sell licenses and services around data and models. (This is a commission-based service venue.) Users will be able to sample the data and understand model assumptions, and most of the models will be Oasis Loss Modelling Framework compliant. Models will be peer reviewed for quality compliance.
- The eMarket will have a *crowdfunding and matchmaking section* with two functions. It will provide (1) a space for researchers wishing to develop new models, tools, and framework innovations with end-user support and (2) a matchmaking function for end users who need specific models and services, connecting them with suppliers and, thus, linking demand with supply.

EIT Climate-KIC wish to support market-based approaches to catastrophe and climate adaptation model development, thus ensuring a more sustainable marketplace for those involved in this sector, both through small and medium-sized enterprise (SME) development and commercial activity from academic and research bodies. This is seen as more sustainable than current approaches that create one-off hazard or regional models that are unlikely to be updated once initial funding has ceased. Instead, our approach creates long-term growth by developing the necessary data and models through market demand and, as a consequence, encouraging increased accuracy through the constant updating of data and models for the market. The creation of flourishing markets through eMarketplaces as catalysts for data and modeling interactions is believed essential for market development. Equally important is the entrepreneurship training of young modelers, through initiatives such as the EIT Climate-KIC education, ideation, and accelerator programs.

Sectorial demonstrators

To expand markets and user group understanding, Oasis+ is developing sectorial demonstrators and sees this as a way to validate the use of the Oasis Loss Modelling Framework in areas beyond the insurance sector. The sector demonstrators currently under development are in city systems, developing and emerging economies, new insurance models, natural resources, and health. The demonstrators are intended to be co-designed with appropriate authorities in each sector and act as awareness-raising and innovation environments to stimulate new markets for disaster and resilience information, while also enabling the wider society to increase disaster preparedness more rapidly.

EIT Climate-KIC and relationship with Oasis Loss Modelling Framework (Oasis LMF)

EIT Climate-KIC are supporting the continued development of the Oasis LMF platform as a means to crunch exposure, hazard, vulnerability, and damage data with standard damage and financial data to enable the calculation of risk for specific events in different scenarios. Prerequisites are for wider society to understand how to use this information and the global modeling community to understand how to build models to a standard sufficient to instill confidence in the financial sector. New users can be educated on the use and value of these models by supporting Oasis LMF development of massive open online courses (MOOCs). This education initiative is critical to extending model access to broader communities.

Significance of paper

Oasis+ has conducted a market scan of products and of catastrophe modeling companies currently in the market. Four companies have accumulated the majority market share. Their models tend to be very large-scale and are sold with licenses costing in the neighborhood of US$1 million per model. These prohibitively high costs act as a barrier to use of these models by other sectors. These companies also offer a “black box” service with traditionally little transparency on model assumptions, which has resulted in a lack of comparability among insurance sector models.

The Oasis+ ecosystem intends to disrupt this closed market and open up the modeling sector to governments and industry by reducing the costs of obtaining high-quality models developed specifically for different sectorial needs. Clearly, the standards set by the insurance sector for catastrophe risk modeling are likely to meet most of the requirements of developing countries that wish to develop their adaptation and resilience strategies. Currently, however, sectors outside the Insurance sector have little understanding of why the use of these types of high-quality models would benefit industry and government more broadly. They instead opt for models from different consultancies on a case-by-case basis and are unlikely to include accepted standards for damage data, comparability, and quality. Thus, those models adapted for the insurance market account for physical climate risk and vulnerability but have an additional element—that of calculating financial losses and the probability of such occurrences. These additional measures would help countries and cities to cost–benefit proposed adaptation measures and would provide greater leverage within the political and investment process, enabling adaptation measures to be implemented.

In the developing world, data beyond regional hazard (typhoon, flood, earthquake, and so on) need to be collected at the local level. For instance, exposure (property information), vulnerability (property behavior linked to hazard), and damage and financial data are likely to be quite different than in Europe or the United States. A dual approach of local-level data development, specific to regional contexts, and larger frameworks for more traditional and often existing data (such as global meteorological data) needs to be developed and integrated to assess risk adequately in the developing world. In essence, new data needs to be collected locally and regionally in the developing world, and open markets for existing data and calculation frameworks should be implemented.

Challenges

Several challenges must to be met to improve the development of disaster and resilience modeling and its expansion to the developing world.

First, education and capacity development for both users and modelers is important.

Second, support is needed for the development of initiatives, such as the Oasis+ eMarket, that act as catalysts for market expansion.

Third, confidence must be increased in risk assessment models through the support of frameworks that reflect quality standards and the level of detail required to ensure the data and the output from models are as accurate as possible.

Finally, depending on the purpose of catastrophe and climate models, the deficiencies in provision vary and are exacerbated in developing countries because, historically, data on hazard and on damage from events have not been collected. This has produced gaps in useful data—in particular, damage data—that are specific to particular regions and cannot be transported from other locations. The report should, therefore, focus on addressing specific gaps in data and capacity, with hazard data the most likely to be currently available and damage data the least.

Recommendations

To address the challenges listed above, the following are recommended.

First, the development of de facto global standards should be supported through the use of a small number of data frameworks in this area, thus ensuring the risk models delivered will be as accurate as possible. This will raise confidence in catastrophe and climate modeling frameworks, such as Oasis LMF.

Second, to stimulate the growth of businesses producing much-needed data and models in the developing world, market-based, educational, and entrepreneurship environments should be supported.

Third, the creation of innovation hubs as learning, collaboration, and innovation environments should be initiated, and such environments should be enabled to reach the standards required by frameworks to bring about accurate risk assessments and adaption planning.

Finally, gaps in data and models beyond those linked to hazard need to be addressed. In particular, damage and disruption data, vulnerability models, and decision-making frameworks that more accurately assist regional decision making should be developed.

Visions for the Future: Multiple Platforms and the Need for Capacity Building

John Rees, Andy Hughes (British Geological Survey)

Many parties interested in risk analysis are bewildered by several existing conditions:

- The proliferation and diversity of algorithms, models, platforms, and frameworks, with different accessibility, resources, standards, and approaches, that are claimed to be useful in risk management
- The fact that most of these are standalone and can only be "hard wired" into other systems
- The complexity and, often, the lack of transparency in their ownership, licensing, and governance

These conditions are unhealthy when trying to make sense, and sensible decisions, in an increasingly complex, interconnected, interdependent world. Bringing together multiple models to simulate and explore risk options is highly desirable but, except in a few cases, is currently impossible.

Concerns about this position have been voiced and discussed at many events, not least the Connecting the Models workshop at the Understanding Risk meeting held in London in July 2014, which clearly demonstrated the multiplicity of modeling platforms.[55] Participants discussed the problems caused by such diversity but also recognized several trends which provide some confidence that interoperability should be easier in the future:

- A lot of resources and initiatives, not just dedicated to risk analysis, are available to ease access.
- Significant developments have taken place recently in interoperability, both in data and models.
- Cloud computing is becoming increasingly available.
- Web services to serve data and model results over the Internet are easy to access.
- Smart phones have a huge amount of uptake and development behind them (see, for example, http://agresearchmag.ars.usda.gov/2011/feb/agro).
- The science of user uptake for both model results and presentation of future risk is maturing.
- Pilot projects to enable users to run relatively simple models (see, for example, EVOp, http://www.evo-uk.org) are rapidly increasing in number.

Even so, the movement toward increased conformity, interoperability, and open access among platforms remains painfully slow.

For greater interoperability to be achieved, models need to work to standards that allow them to be used together easily. Most parties involved in modeling see some degree of standardization—where appropriate—as beneficial. The question is how far standardization should be coordinated and set, in a top-down fashion, as opposed to letting it develop in a bottom-up, evolutionary, way. Broadly speaking, there are three options:

- *Maintaining the status quo,* in which considerable resources exist but are fragmented—an approach

[55] Examples include RMS One (Risk Management Solutions platform, rms.com/rms-one/rms-one); Touchstone—AIR's modeling platform (www.air-worldwide.com/Software-Solutions/Touchstone/); Oasis—Loss Modelling Framework (www.oasislmf.org); RASOR— a project funded by the European Union (EU) to develop a multihazard risk platform (www.rasor-project.eu); FEWS—risk-based flood forecasting (https://www.deltares.nl/en/software/flood-forecasting-system-delft-fews-2/); GEM (Global Earthquake Model, www.globalquakemodel.org); DEWETRA—real-time hydro-meteorological and wild fire forecasting (www.cimafoundation.org/en/cima-foundation/dewetra/); NCAR (National Center for Atmospheric Research, ncar.ucar.edu); GAR (Global Assessment Report, www.unisdr.org/we/inform/gar); and CAPRA—probabilistic risk assessment capability-building project (www.ecapra.org).

whereby standardization is almost totally evolutionary and bottom-up

- *Developing a single model platform into which all models and platforms fit,* based around a common set of standards, which is a top-down approach
- *Developing a multiplatform structure* that would allow the connection of existing platforms and services

The high-level strengths, weaknesses, opportunities, and threats associated with these are outlined in table 1.

Of the three options, maintenance of the status quo offers the least opportunity to increase platform accessibility and interoperability rapidly. The parties with the most to gain are organizations that already dominate the risk modeling market. Adoption of this option means the introduction of new approaches would remain stifled. It is, thus, the least desirable.

The development of a single risk modeling platform has, at first glance, some attractions. The creation of a unique set of standards by which all modelers abide would rapidly increase interoperability (think of how the standardized music score revolutionized music, once adopted). The single platform would, however, stifle competition and the development of new approaches. Most significantly, it would be onerous to manage, particularly as it would hamper involvement of the private sector.

The best option would seem to be that in which multiple platforms exist but are interoperable across many of their basic functions, allowing models to run across different platforms. Instead of inhibiting innovation (as an approach based on a single platform would do), the multiplatform option would enhance it by allowing different models, including those from different disciplines and from public and private sources, to be used easily together.

The questions of how to design modeling adapters or connectors to significantly improve global risk modeling interoperability and how many of them there should be have been raised by many parties. The view that one, or

TABLE 1. SWOT Analysis of Potential Options for Risk Platform Development

	Strengths	Weaknesses	Opportunities	Threats
Status quo	No additional resource is required.	Evolution of interoperable systems is slow.	The best systems evolve through market forces.	The pace of change is set by a few market leaders.
Single platform that dominates all	Once established, a single platform would support rapid interoperability, as it would have a unique set of standards, formats, and modes of operation.	Having just one platform would discourage the evolution of new methodologies, architectures, and approaches. A single platform would require a worldwide (difficult to manage) governance mechanism. How feasible, useful, and sustainable would this be?	Fast adoption of the platform might encourage the development of new applications. With speedier uptake of the platform (there being only "one show in town"), users would be more ready to invest time in learning to use it.	Many existing platforms would become redundant, unless they rapidly adapted to conform to the new one. The platform could easily stifle innovation.
Multiplatform (Note: Would need adapters or interoperable major platforms—for example, GEM, WRF, or OASIS—with which most models are compatible.)	Some standardization would increase interoperability but would not constrain coevolution of methodologies, architectures, or approaches.	Because many platforms exist, most users would find using more than one (or a few) challenging. Multiple, easy-to-use adapters or routines would be needed to ensure compatibility.	A multiplatform would allow more options for existing model users to find major platforms or adapters to enable compatibility. Domination of the market by one provider would be more difficult.	Managing interoperability of multiple platforms would be challenging.

a few, interoperability protocols or standards (such as OpenMI) should be developed to facilitate interaction among multiple platforms has limited support, however. Instead, practitioners of integrated modeling recognize that if some of the major open platforms are encouraged to make themselves interoperable and all others are encouraged to ensure interoperability with at least one of them, all models should—in principle—be interoperable. This "hub and spoke" approach may be expected to evolve anyway (GEM, WRF, and Oasis-LMF, for instance, are exploring ways to make themselves interoperable); nevertheless, some coordination may still be desirable.

The acceleration of the rate of increase in platform interoperability and its application to building resilience may require the formation of a body (either separate from or within an existing organization) to do the following:

- Review the availability and application of risk modeling platforms
- Recommend where standards may be needed
- Provide inventories of models (possibly an "Amazon of models")
- Ensure ease of access, particularly to those who have little modeling experience or capacity training (perhaps through massive open online courses [MOOCs] or training materials—for example, an *Idiot's Guide to Modeling*)

Such a body would require some commitment from both model platform providers and potential users to ensure it remains useful and relevant. These parties, as well as funders of the body and of the functions it undertakes, would comprise a board. Some functions could be carried out at relatively little additional cost; others (for example, an advanced "Amazon of models") might require significant additional resources.

The case for building capacity as well as pursuing multiplatform interoperability

Ensuring ease of access, the last point in the list of proposed governance functions described above, is the most important. The benefits of encouraging those who use risk information to engage actively in its analysis, production, and application have been well demonstrated. These parties gain an understanding of the processes that drive risk and the uncertainties of its evaluation and make better decisions as a consequence. Too often, however, it is those communities facing the greatest natural hazard risks that have the least capacity to analyze and manage them. Increasingly, those with little modeling capacity are developing it or have clear ambitions to do so, but the slowness of progress is frustrating, particularly when we see rising natural hazard risks caused by increased exposure and vulnerability. A case can be made not only for increasing risk modeling capacity globally, but for making sure it directly benefits (and does not sideline) those who need it most. (The principle that economic inequalities may be diminished over time by helping the poor to support themselves also pertains to managing risks.) Many challenges are associated, however, with developing the necessary skills and ensuring the availability of affordable data, models, and hardware to enable ready computation of the multiple realizations required to explore uncertainty and produce probabilistic understanding of risk.

Most risk-based products are currently produced by organizations with ready capacity to provide analytical services to those who require risk information. The provision of such services is relatively easy for them, as they already have access to observational networks and well-developed modeling capacity and skills. Increasing computational capacity, expanding networks, use of open data, evolving diverse mobile technologies, and meeting the other multiple facets of the "big data" agenda will conspire to continue enabling such organizations or accelerate the growth in their capacity to deliver risk products to whomever requires them. Any move toward increasing interoperability will favor these parties. Thus, models of rapidly changing natural systems (for instance, weather systems) that require assimilation or are complex (for instance, incorporating multiple feedbacks) will likely be mainly produced by organizations that already have the capacity to readily provide these services for some time to come. The current leaders in risk modeling are highly likely to remain the leaders for the foreseeable future.

How fast can the risk modeling capacity of those at the other end of the spectrum, who most need it, be increased? This depends on many factors:

- Their starting positions (see unpan1.un.org/intradoc/groups/public/documents/un/unpan008092.pdf)
- Their access to physical resources (such as internet connections)
- The social and economic conditions facilitating or constraining change (for example, governance and culture)
- The needs (for example, the scale of risks or the required speed of access to risk information) of the modeling agent, community, or institution
- Their skills—the most important factor

While building risk modeling capacity also depends on the development by the global risk modeling community of interoperable platforms to facilitate improved access to risk analysis tools, the urgency remains to develop the capacity of those who have the greatest need of risk modeling.

We suggest that increased modeling platform interoperability will benefit those with the resources to exploit it. If the Global Facility for Disaster Reduction and Recover (GFDRR), the UK Department of International Development (DfID), and other organizations interested in reducing the risks of the communities and countries most affected—which commonly have least access to resources—wish to see benefits extended equally to them, enhanced capacity building, particularly training, will also be required.

The Anatomy of a Next Generation Risk Platform

Deepak Badoni, Sanjay Patel (Eigen Risk)

A plethora of different products and tools are being marketed as "risk platforms" today. This development is rooted in the siloes and intellectually competitive nature of a risk management ecosystem that often comingles the three essential pillars of what a risk platform needs to address: data, modeling, and analytics.

While the data management and analytics needs are currently being met by a multitude of point solutions, the modeling market has been dominated by a handful of players. This has led to inefficient business processes, higher costs, and lack of transparency into modeling assumptions and methodologies. We believe the next generation of risk platforms will leverage the latest technology and the power of crowd sourcing to create a paradigm shift in the way data are shared, risk is analyzed, and models are deployed.

The following reviews the current landscape of the risk analytics and modeling field and the challenges it presents to the risk community, and it provides a framework to help assess and develop the ideal risk platform for addressing those challenges.

The current landscape

A survey of the products and tools related to the quantification of risk reveals the following classes of solutions:

- *Data visualization solutions* that emphasize geospatial mapping combined with basic data interrogation
- *Data analysis and business intelligence solutions* that are typically customizations of market-leading business intelligence products
- *Modeling solutions*, the classical "models" that consume exposure data and produce modeled losses as results
- *Model deployment solutions*, the newest wave of solutions that allow multiple modelers to "plug and play" their models within a common framework

Many solutions are marketed as "risk platforms" today, but comparing them is difficult because they often are not only serving different constituents, but are solving fundamentally different problems. For example, some solutions are used to assess exposure that is "in force," to evaluate changes and/or measure performance using key financial metrics, and to take corrective action after the fact. Others are used more proactively as part of the underwriting process. At their core, however, all solutions contain three key architectural elements—data, modeling, and analytics, typically with emphasis on one of the three.

The differences among data, modeling, and analytics

It is important to recognize that data, modeling, and analytics are different aspects of a risk platform that must be correctly identified and handled.

The term *data* refers to any fundamental entity used as an input into a risk platform that is not subject to interpretation. Examples of data include the following:

- *Exposure data,* comprising location names, addresses, number of building stories, and so on
- *Contract data*, comprising contract number, effective and expiration dates, and terms and conditions
- *Historical event data*, comprising event name, date of occurrence, location, category, and so on

- *Historical loss data*, comprising amount of loss, date, currency, and so on

The availability and quality of data and sources and the tools to validate them vary by organization, region, and peril. The reliability of model output is only as good as the quality and completeness of the exposure data and values provided.

Model applies to those input entities that represent views open to interpretation by different parties. These entities can take different forms—from simple input variables to imported data files to running code. Multiple views must not only be supported by the model but carefully built into its design. The following are examples of models:

- *Geocodes.* Different "geocoders" may produce different latitude and longitude for a location.
- *Construction and occupancy codes.* Since different modelers may choose to describe the same building differently, these are not data; they actually constitute a model of a building.
- *Hazard layers, such as earthquake zones and hurricane tiers.* These may look like data but are actually the result of fairly sophisticated modeling and often differ by source.
- *Contract loss calculation.* The flow of losses through the terms and conditions of a contract is often subject to interpretation.
- *Historical event footprints.* Multiple representations of historical event footprints can be based on different sources, or even the same source, emerging from "reanalysis" projects.
- *Peril models.* Though a more obvious example typically associated with the term "model" today, peril models, as noted above, also encapsulate a number of modeling assumptions that are confused with "data."

The lack of models or the poor resolution or quality of underlying data in some underdeveloped regions continues to be an issue. Without proper tools or data to manage aggregations, risk managers have been disproportionally affected by infrequent events in seemingly "cold spots."

Analytics refers to the output of a risk platform that operates on both data and models (via intermediate data produced by such models) to produce insights. Examples of analytics include the following:

- *Visualization* of data and model results, which can sometimes produce remarkable insights without any additional effort
- *Slicing and dicing*, the typical "business intelligence–style" querying applied to both data and model output
- *Model interrogation*, the ability to trace intermediate model calculations for sense checking
- *Model comparison*, the ability to compare different points of view, but in a controlled environment to avoid comparing apples to oranges
- *What-if analysis*, the ability to alter data or modeling assumptions and regenerate results on the fly
- *Model blending*, a blending of two or more outputs from proprietary or commercial models to create a synthesized output and protect against significant changes in any one model
- *Model sensitivity*, the ability to change key exposure or model attributes in a controlled environment to determine components driving change or loss in modeled output

A risk platform must address the three fundamental elements of data, modeling, and analytics because most real-world problems require users to move among them seamlessly to arrive at the best insights. For example, when a model produces a PML (Probable Maximum Loss), users may wish to determine the contributors to it, all the way down to individual assets. This may bring to the surface data quality issues with these assets, and users would then correct these results, rerun the model, and reassess the contributors. Such a workflow was nearly impossible to conceive with yesterday's technology, but next generation platforms must be designed to support this type of iterative questioning.

The role of technology

We believe that, for too long in our industry, products, tools, and business processes have been designed as workarounds for technology constraints. For example, an underlying premise holds that model runs must be "slow" because the nature of the underlying problem is prohibitively expensive to solve with speed. This has led to several problems:

- *Inaccurate modeling*, due to the use of simplifying assumptions, such as by employing analytical approximations—for instance, the Beta distribution of secondary uncertainty
- *Black box modeling*, the result of long run times that leave little time for reruns and often limit model investigation to a set of pregenerated reference exposure datasets
- *Disconnected analysis*, due to the building of independent downstream analytical tools that can only consume summary model results (versus granular results) and are inherently limited

We believe the latest wave of "big data" and high performance computing technology has now finally caught up with the computational demands arising from the unique problems faced by this community. But to convert this promise into reality will require a fresh approach to designing business solutions, not just retrofitting existing tools and processes with new technology. Innovations like cloud computing make using high performance servers affordable; they are optimized for regular use and can be scaled during peaks to maintain workflow efficiencies.

The risk platforms of the future will be able to leverage the latest technology to replace the current prepare–model–analyze paradigm with a more intuitive question–answer–follow-up approach, where the models can run on an as-needed basis, depending on the specific question being asked. This means decision makers can now ask more follow-up questions and, in doing so, make more informed decisions in less time. Analysts can spend more time actually analyzing data and models as opposed to pushing data. Of course, doing this requires orders of magnitude reduction in cycle times and a solution architecture that is designed from the ground up to take advantage of the new paradigm.

The power of crowd sourcing

Although the term "open modeling platform" is now widely used, the definition of "open" ranges widely. Most offerings available can, however, be classified into the following categories:

- *Open source models* that provide their source codes for others to copy and create their own models
- *Model integration platforms* that can send data to and fetch data from other models running in their own separate environments via automation
- *Multimodel platforms* that integrate models from multiple sources into the framework of an existing model but are still selective in who can participate
- *Model agnostic tools* that are "open" in the sense that they essentially support some standard format to which most model outputs can be converted

What is missing is true "crowd sourcing," in which any modeler—not just a modeling company, but even an individual—can easily contribute and share its model with the broader community. To do this right, there are several considerations:

- *Incentive.* The platform must provide a strong incentive for modelers to contribute, ideally a monetary one.
- *Intellectual property protection.* The platform must be designed to protect the modelers' intellectual property, via both technical design and strong legal protection.
- *User experience.* Modelers must be treated as users, and their user experience must be tailored to their specific needs, not just be an afterthought.
- *Decoupling.* The platform must decouple the engineering and science from the execution of the models, allowing modelers to focus on what they do best.

A platform that gets these factors right will not only be able to attract existing modelers and modeling companies, but will also attract new entrants of different sizes and specializations across perils, regions, and industry verticals.

What impact will future risk platforms have on the risk community?

The best risk platforms will do more than bring incremental improvements to the risk community; they will offer openness and insight into model components, as well as potentially create a new marketplace for risk models. They will bring about a fundamental transformation across several dimensions:

- *Accessibility.* Anyone, anywhere will be able to access the same platform to use or contribute data, modeling, or analytics.
- *Cost.* More choices and decoupling of models from software will lead to lower costs for all.
- *Ease of use.* Platforms will be fast and easy to use, with interfaces designed specifically for different user profiles.
- *Transparency.* Transparency will be built into the design so users can always ask "why?" instead of stopping at "what?"

The result of all this will be a cultural shift away from today's silos to a technology-enabled, thriving ecosystem of analysts, modelers, and commercial and noncommercial consumers.

Development of an Open Platform for Risk Modeling: Perspective of the GEM Foundation

John Schneider, Luna Guaschino, Nicole Keller, Vitor Silva, Carlos Villacis, Anselm Smolka (GEM Foundation)

The GEM Foundation was formed in 2009 as a public–private partnership to improve our understanding of earthquake risk globally. It has developed the OpenQuake computational modeling platform to address this need, as well as an extensive global collaboration network for the development and application of tools, models, and data. The platform was launched in January 2015 and now has over one thousand registered users in fifty-five countries.

Based on this experience, the UK Department for International Development (DFID) and the Global Facility for Disaster Reduction and Recovery (GFDRR) asked the GEM Foundation for its views regarding the need for open risk data and a modeling platform for improved understanding of disaster risk in developing countries. GEM recommends investments be made in the integration of existing tools and platforms. If a single, multihazard platform is desired, existing platforms, including GEM's, should be considered as candidates for this purpose.

Beyond the analysis platform, further investment is warranted in developing tools that can be used to help translate complex information from risk analyses into sensible choices for DRR applications. More investment is needed in the development of open source databases, as well as in standards and guidelines for risk assessment. The common ground should be the following:

- The principles of openness, accessibility, and technical credibility
- Common input and output formats
- The sharing of data and results, and, thus, reproducibility

Finally, these activities must be complemented by similar investments to facilitate and build capacity and collaboration.

These views are discussed in detail below.

Utility of the GEM OpenQuake platform

The GEM Foundation has created the OpenQuake platform, an integrated computational platform for earthquake risk assessment comprising a number of components:

- The OpenQuake computational engine
- More than a dozen global databases and models
- Hazard and risk results at national to regional scale generated by GEM and its partners
- A suite of users' tools called the modeler's toolkit

Officially launched in January 2015, the platform is openly accessible and free to all users. It allows any user free access to a number of datasets, models, and tools for developing a hazard or risk model, analyzing risk, and interpreting and understanding the risk analysis results. The OpenQuake computational code (or engine) allows the user to conduct a wide range of hazard and risk calculations, including for single-event scenarios and comprehensive probabilistic analyses of all possible events. OpenQuake can be used for analyses ranging from single-asset/site calculations to complex portfolios at national, regional, and global scales.

OpenQuake provides users free access to a number of datasets, models, and tools for (1) developing a hazard or risk model, (2) analyzing risk, and (3) interpreting/understanding the risk analysis results. Users in the first category generally have a great deal of scientific and technical knowledge about hazard and risk modeling. They are often interested in developing new hazard and risk models or improving existing models for application to new areas. In the second category are practitioners, such as risk analysts or engineers, interested in using the tools to analyze hazard or risk for a particular application, such as for a national hazard map or an urban-scale earthquake scenario. The third category is for those interested in using post-processing tools for application of the results, such as cost–benefit analysis for risk management decision making or visualization of results for raising public awareness or for training and education.

As mentioned above, the OpenQuake Platform currently has over one thousand registered users, with an overall access distribution covering most of the countries of the world (see the map in figure 1). A total of fifty-five countries count at least one registered user of the platform, with peaks registered in the United States and Italy.

More importantly, the use and application of the GEM resources available through the OpenQuake Platform are increasing worldwide. GEM-developed tools and methodologies have been utilized to prepare regional models for Europe (SHARE Project), the Middle East (EMME Project), Central Asia (EMCA Project), South America (SARA Project) and Sub-Saharan Africa (SSAHARA Project). Increasingly, too, countries around the world are adopting GEM's OpenQuake engine to prepare their national hazard and risk models. Australia, Canada, Colombia, Ecuador, Italy, Indonesia, New Zealand, Papua New Guinea, Rwanda, Switzerland, Taiwan, Tunisia, and Turkey are among those that have adopted or are adopting OpenQuake to address their modeling needs.

Applications for developing countries

The GEM Foundation has a strong focus on partnerships with and training for developing countries. It has developed strong partnerships with a number of

FIGURE 1. Countries around the world where OpenQuake registered users are located, with color intensity reflecting numbers of users.

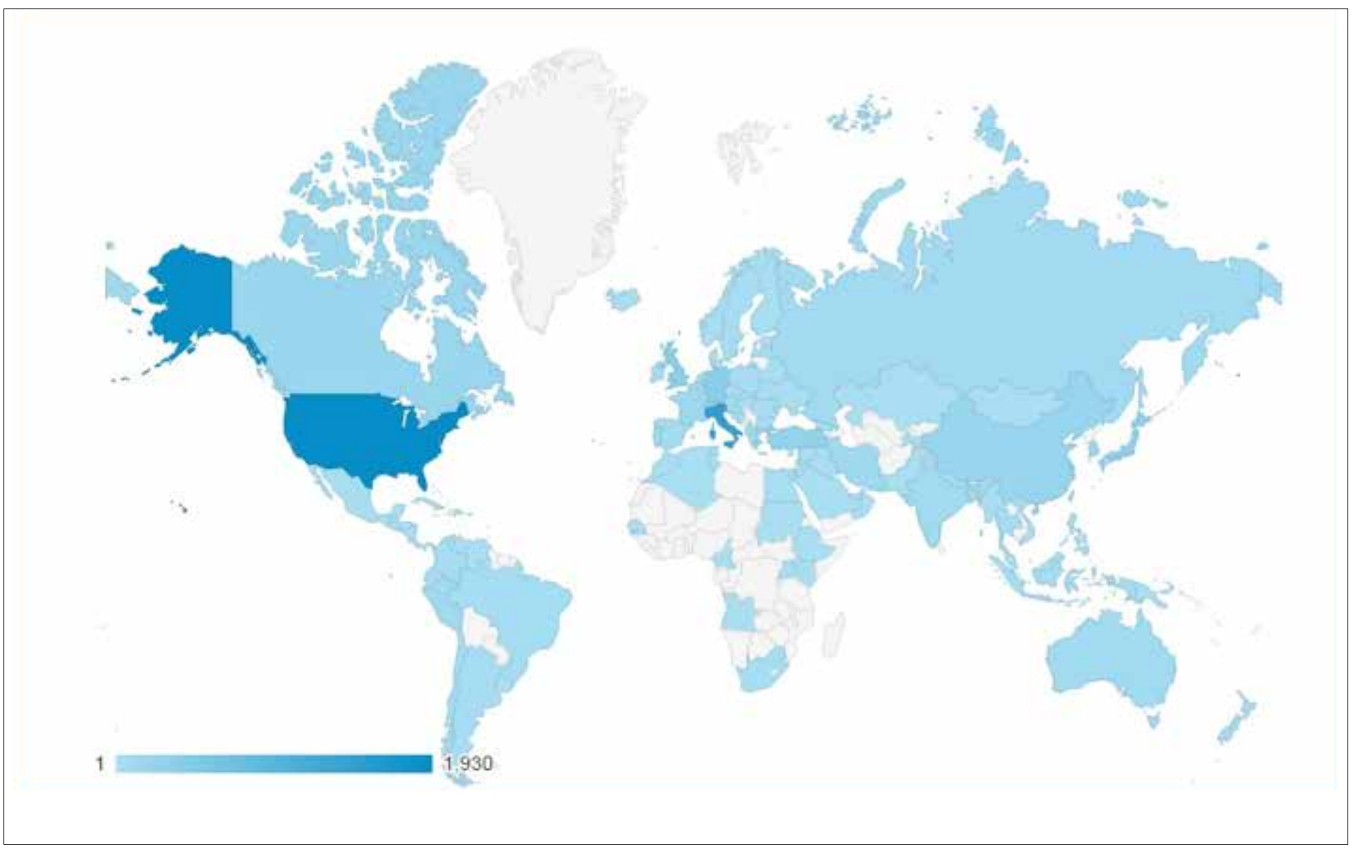
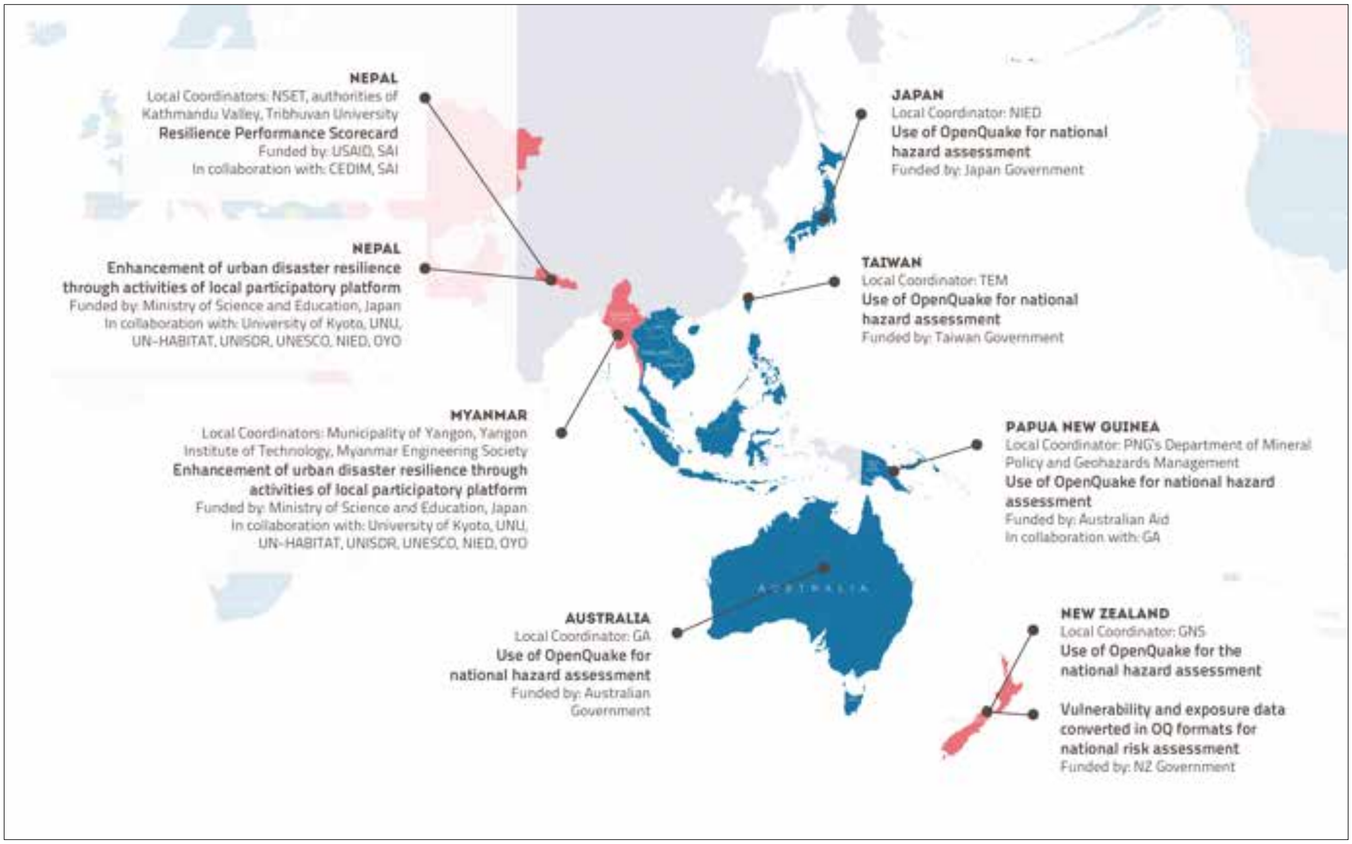


FIGURE 2. Locations and brief descriptions of projects in the Australasian region where OpenQuake has been implemented with local and regional partners.



countries for the development of national earthquake hazard maps and, in some instances, national and local risk assessments. Among other examples of these activities are the following:

- The Colombia Geological Survey has asked GEM to facilitate training and technical capacity building for a national and urban risk assessment program.
- In partnership with Geoscience Australia, GEM has been working with national organizations in Indonesia, Papua New Guinea, and the Philippines to provide training in OpenQuake.
- After receiving training on the use and application of GEM tools, the National Center for Disaster Risk Evaluation, Prevention, and Reduction (CENEPRED) of Peru and the Metropolitan Municipality of Quito, Ecuador, are now leading the preparation of exposure models for residential buildings. The results will be used to assess the earthquake risk of Lima and Quito, respectively.

GEM has been involved with or led several regional and national initiatives on all the continents, as well, covering a total of more than eighty countries, of which about half are classified as developing. Training exercises have been conducted in most of these, as well as other countries that have not been involved directly with hazard or risk assessment initiatives. Figure 2, for example, shows the projects on which GEM has collaborated with governmental and nongovernmental bodies in the Australasian region.

In general terms, our experience has shown the following:

- Many public entities responsible for earthquake hazard and/or risk assessment in their countries do not have sufficient capacity or understanding to carry out quantitative hazard and/or earthquake risk modeling. Growing and fostering technical capacity requires long-term investment in education and training to develop hazard and risk experts. As noted previously, however, such long-term investment is beginning to pay off in more and more countries.

- A big disconnection often exists between decision makers and experts in risk modeling and assessment. Besides communication issues, this disconnection is due to a lack of high quality data and models. Risk information often is not available in a form that can be understood and used, or it is of insufficient quality to formulate specific advice. Moreover, much of the data and many of the models used for such studies are not openly available to others, so the ability to assess the validity of the results is limited.

Public good/Community perspective

At the community level, the needs and caveats are much the same as they are for developing countries—that is, expertise may be lacking, and results are rarely tailored to risk reduction needs. GEM is trying to address some of these shortcomings by focusing on products that are more useful with regard to the public good and local communities. Applications now include cost–benefit analysis, which can be used to assess the merit of reconstructing or retrofitting buildings. Another application focuses on assessing community resilience using statistical analyses of a wide range of socioeconomic data, as well as locally driven community surveys. In all cases, it is essential to include end users in the risk assessment process to increase the chances of the results being used. Developing and using local information about hazards, vulnerability, and exposure to achieve credible results is also essential.

Part of GEM's philosophy is to encourage openness and sharing of data across all sectors and on all geographical scales, as well as to provide the platform upon which such information can be accessed and used. Ultimately, one of the biggest limitations to risk assessment is not the availability of tools, but the development and accessibility of the data and information required to give meaningful and accurate analysis results.

Next steps/Vision for the future

To maximize access to compatible tools and data and to minimize overall cost, a single platform or a network of interconnected platforms that could serve the entire DRR community would be best. The platform would need to be flexible enough to accommodate the diversity of applications and the continuing evolution of methods, models, and tools required to improve risk analyses over time. Existing platforms address elements of what is required. Other platforms (for example, OASIS) are being developed to accommodate inputs and outputs of a wide range of software applications in a multihazard environment. In this way, different datasets and models may be linked to solve complex problems on a platform that is relatively versatile and flexible. The downside of this approach is that such linking of different datasets developed by different entities using different codes can lead to unintended or erroneous results. The approach could be improved by establishing standard methodologies and formats, as well as standard testing procedures for different combinations of applications.

Taking a different approach, GEM has developed the OpenQuake platform to address a single peril—earthquake—with a single engine for hazard and risk analysis and a wide range of supporting tools for preparing input data and analyzing the output. Linking of programs and databases in this system is inherently compatible because elements are designed, implemented, and tested within a single platform. Because the numerical algorithms for probabilistic hazard and risk analysis are completely transferrable to other hazards, the OpenQuake platform could be modified into a multihazard platform by accommodating other hazard models and by expanding the exposure and vulnerability modules to include a broader range of attributes relevant to other hazards. The current GEM taxonomy already incorporates features for flood and hurricane wind and storm surge modeling (for example, presence of a basement, grade height, type of roof, connections, and so on), and the risk component of OQ has already been used to perform storm surge and flood modeling calculations.

While greater compatibility of models and access to results is clearly needed, a growing need for even greater diversity of tools to address complex problems for different applications is clear as well. Not everyone needs a detailed probabilistic approach that can be used to assess risk to a nuclear power plant or conduct a global assessment of risk. Tools that are flexible and adaptable to a wide range of applications tend to be inherently complex and difficult to apply without extensive training. More investment is needed in developing tools that can be used to help translate complex information from risk analyses into sensible choices for DRR applications. The common ground should be the principles of openness, accessibility, and technical credibility; common input and output formats; and sharing of data and results, and thus, reproducibility.

What is missing and/or needed?

A founding principle of GEM was that by sharing and opening up "black boxes," we could learn and advance earthquake risk assessment together and build on each other's work rather than reinventing the wheel. To that end, GEM is committed to all aspects of openness: open data, open models, open sources, and open computational infrastructure. Openness needs to start at the beginning of the process, whether in the development of a computational tool or the implementation of a risk assessment. Developers should be welcome to participate in and critique the coding process, and testing and validation of the code should be open and independent of the developers. Giving everyone access to a code does not by itself make the code open. Similarly, providing access to results of an analysis does not make the analysis open. The input data and the analysis methodology and tools also need to be available for replication by anyone who wishes to do so.

An ingredient essential to implementing the open philosophy is proper licensing of software and data products. GEM licenses products using the Creative Commons Attribution-ShareAlike (CC BY-SA v3.0) for databases and GNU AGPL v3 or any later version for software.56 Unfortunately, a misconception is still widely held, particularly within the science and engineering community, that by invoking a license, one is merely limiting the use of a product. The purpose of the license is actually to ensure and facilitate open access to products and their derivatives. Much more investment in education and legal processes is needed to convince providers to make information available and to support licensing mechanisms.

[56] See also http://www.globalquakemodel.org/licensing, which outlines GEM's licensing policy for the release of data and software.

A significant investment should also be made in the development of common and multihazard exposure and vulnerability databases, which can be scaled from local to national, regional, and global dimensions. GEM's exposure database was designed with this in mind, but it is only fully realized for common building types at the global to national scales. A much more complete global exposure database could be developed by integrating several parallel efforts. A merging of GFDRR, the UN's International Strategy for Disaster Risk Reduction-Global Assessment Report (ISDR-GAR), and GEM global-regional exposure databases would be a good place to start.

For vulnerability, GEM's approach has addressed three elements: the damage/cost ratio of common buildings; injury/mortality from building damage; and social vulnerability/resilience on the community scale. While the building-related information is generally valid at global to national levels, it tends to be quite coarse at subnational to local scales. The information at these levels is gradually being improved through collaboration with local partners. Notwithstanding the general lack and incompatibility of the data, the methodology and software of OpenQuake are suitable for extension to other hazards.

Challenges and recommendations

Since its inception in 2009, GEM has gained experience in the development and operation of a global public–private partnership. This section summarizes the strengths and weaknesses of GEM's partnership approach and provides recommendations for future partnership efforts.

Public–private partnership. A lesson the GEM Foundation has learned over the years is that the public and private sectors have broadly similar goals and motivations for investing in risk information. GEM's most notable success in operating as a public–private partnership has been to unify the diverse perspectives, skills, and experience of the members under a common interest: credible, accessible risk information that is widely used and understood. As a result, public and private sector representatives are able to find the common ground and integrated solutions necessary to forging the way forward for GEM.

Some clear differences have arisen between public and private partners in their needs for specific analysis capabilities and results. For instance, public partners are often interested in identifying risk in a given region or urban center to provide advice on risk reduction investments or the possible outcomes from the occurrence of a number of earthquake scenarios. They are also often interested in a wider range of loss information than private partners, including economic losses, human losses, and numbers of homeless, displaced, and injured people. Private partners, on the other hand, have been focused mainly on probabilistic economic losses.

Also interesting to note is that expertise in these types of analyses has typically been more advanced in the private sector, and thus its main interest is in having access to models with specific and unique features. The public sector has tended to have a broader interest in training and capacity building, as well as in having tools that can translate complex risk metrics to something easily used and understood by DRR experts and other decision makers. These differences have helped ensure the suitability of OpenQuake for a broad range of risk assessment needs and applications.

To make a public–private partnership and collaborative effort work, flexibility and compromise are needed. In general, because GEM is a multistakeholder effort that works with many types of organizations from all parts of the world, it needs to be flexible and adjust to changing circumstances while ensuring progress is made. For example, “open data” and “open software” have been viewed in different ways, with divisions between, but also within, public and private sponsors over the distribution of products under free or commercial licenses. Lacking clear precedence or guidance elsewhere, GEM formed a special task force of its governing board to develop a path forward that would be acceptable to most public and private participants.

Part of GEM’s success to date has been in its ability to identify a community of stakeholders with sufficiently common as well as complementary interests. The resulting thirty-five sponsors and partners have been able (after six years of development) to complete a comprehensive computational platform that is now attracting a very wide range of users globally. While no technical barrier stands in the way of expanding this platform to include other perils, whether the various hazard and risk communities would come together to build, manage, and use the result is in question. In any approach (single platform or multiplatform), a major effort is required to develop the collaboration network. Thus, GEM’s ongoing investment in software is complemented by a similar investment in maintaining and growing the collaboration network, maintaining and improving databases, and facilitating the adoption of tools and data by users and practitioners.

Funding/management. The effort required to fund GEM is a continuous exercise in convincing governments, public and private organizations, and individuals to contribute both financially and intellectually to supporting a new initiative with a common vision to improve the understanding of earthquake risk globally. It took more than two years to realize the formation of the GEM Foundation and the governance structure to support it. Six years on from its incorporation in 2009, GEM has produced significant products, but, equally importantly, it has fostered a large and expanding collaboration network. Thus, significant overhead is required to renew funding continually and to manage staff internally, as well as relationships with sponsors, partners, and other interested parties externally.

To attract public and private sponsors, GEM developed a strategy that takes into account the differences in their ability to pay. In the first five-year working program (2009–14), private sponsors were required to invest 1 million euros for membership, while public sponsors were assessed a fee based on an Organisation for Economic Co-operation and Development (OECD) formula called the GERD (gross expenditure on research and development), with annual sponsorship on a sliding scale from 15 thousand euros for the poorest countries to 275 thousand euros for the richest. Each member institution has an equal say in the governance of GEM (that is, one vote per member). Associate members (such as the World Bank, UNISDR, the OECD, and the International Association of Earthquake Engineering) are appointed as nonvoting advisors.

Altogether, there are about twenty-five paying sponsors and another ten associates. While GEM currently obtains about 30 percent of its funding from projects, its overarching policy is not to enter into competitive proposals for funding to avoid conflicts with its sponsors and maintain its non-profit, non-commercial status. GEM will participate in proposals with its sponsors where it can provide a unique contribution, such as for OpenQuake training.

This funding model has some limitations. First, only relatively wealthy private companies can afford membership. For this and other reasons, private sponsorship comes primarily from the global insurance/reinsurance sector. GEM has addressed this by opening up an affiliate sponsorship at a much lower (and flexible) rate to attract engineering companies and other sectors. So far, two global engineering companies have joined. GEM is keen to continue expanding its funding model to a wider range of users and industry sectors.

Second, despite activities and involvement by technical experts in about a hundred countries, only about fifteen countries are directly sponsoring GEM. One way of addressing this has been to obtain project funding from development donors to, for instance, develop risk models and conduct training exercises in developing countries.

Finally, many potential sponsors do not join GEM because, insofar as its products are open, accessible, and free to sponsors and nonsponsors alike, the additional benefits of being a sponsor (for example, the opportunity offered by participation in the governing board to help set strategy) are not sufficiently valued.

It is worth noting that other governance models for GEM and/or global risk modeling more broadly have been considered. In 2011, at the request of the government of Italy, the OECD Global Science Forum considered a proposal to create a global risk modeling organization as an intergovernmental organization (IGO).[57] Its purpose would have been to facilitate the development of a global multihazard risk modeling capability. The GSF concluded international support was apparently insufficient for creating such an IGO.

Similarly, the Sendai Framework for Disaster Risk Reduction specifically calls for coordinating science and technology by creating an international network of existing organizations. As a result, the UNISDR will launch the Science and Technology Partnership in January 2016. An opportunity now exists to create a governance framework for global risk modeling as an element of this broader S&T Partnership.

Communication. With the ratification of the Sendai Framework 2015, risk communication takes on a new role and provides unique opportunities to bridge the gaps between science and people and between knowledge and action. Risk communication is a key factor in this framework.

In the past few years, GEM has invested much in nurturing and growing its community by constantly maintaining the scientific debate and keeping its democratic nature sustainable. The main efforts have gone into smoothing internal processes and liaising with heterogeneous partners, as well as promoting the open and transparent scientific approach as a democratic way toward development.

Now the challenge for GEM is to enter the global debate and demonstrate how its knowledge and resources can be of help in reducing earthquake risk. The approach should be twofold, encompassing risk information and risk communication:

- *Risk information.* GEM should ensure the collection, analysis, production, and dissemination of any relevant information about earthquake risk, in accordance with its open source philosophy.

Among the activities:

- Find applications of GEM products in support of DRR by providing comprehensive information about their potential for use.
- Integrate best practices and evidence-based examples into the narrative.
- Improve the usability of GEM tools by strengthening the dialogue with local communities and identifying needs and gaps.
- Give innovation a space in the debate.
- *Risk communication.* GEM should contribute to the

[57] Delegation of Italy to the Global Science Forum, “Rationale and Feasibility of a Global Risk Modelling Initiative” (discussion paper submitted to the 24th Meeting of the Global Science Forum, Lisbon, Portugal, March 2011).

global understanding of earthquake risk and liaise with any relevant player to promote a culture of disaster prevention.

Among the activities:

- Underpin the progressive integration of the "communication factor" into risk reduction projects.
- Promote collaboration with the international media to guarantee a well-informed and reliable flow of news.
- Simplify core concepts of earthquake risk reduction by using multimedia and advanced communication tools while opening up a route for better decision making and stakeholder involvement.
- Develop emergency protocols and similar documentation aimed at standardizing communication outputs and external relations.

Along with these activities, GEM is committed to continuing its effort to facilitate the dialogue between private and public sectors, as well as to building upon the existing collaborations among scientists, donors, and end users to bolster a real democratic debate about earthquake risk.

Status of Risk Data/Modeling Platforms and the Gaps: Experiences from VHub and the Global Volcano Model

Greg Valentine (University of Buffalo)

VHub is an online resource for collaboration in volcanology research and risk mitigation.[58] It provides easy mechanisms for sharing tools to model volcanic processes and analyze volcano data, for sharing resources such as teaching materials and workshops, and for communicating with other members of the volcanology community and members of the education and stakeholder communities. Volcanologists can use VHub to collaborate with people around the world and have full control over the privacy of their collaboration. Provided to users at no cost, VHub's mission is to build a virtual organization that enables collaboration across geographical and economic boundaries and promotes integration between basic volcanology research and real-world risk mitigation.

The VHub website is powered by the HUBzero software developed at Purdue University. HUBzero was specifically designed to help members of a scientific community share resources and work together. Users can upload their own content—including tutorials, courses, publications, and animations—and share them with the rest of the community. But each hub is more than just a repository of information. It is a place where researchers and educators can share data and simulation tools online. Users can launch simulations and post-process results with an ordinary web browser, without having to download, compile, or install any code. The tools they access are not just web forms, but powerful graphical tools that support visualization and comparison of results.

[58] Greg Valentine (director, Center for Geohazard Studies, Buffalo University, and principal investigator for VHub) sits on the board of GVM.

At its core, a hub is a website built with many familiar open source packages: the Linux operating system, an Apache web server, a MySQL database, PHP web scripting, and the Joomla content management system. The HUBzero software builds upon that infrastructure to create an environment in which researchers, educators, and students can access simulation tools and share information.

Specifically, we define a "hub" as a web-based collaboration environment with the following features:

- Interactive simulation tools, hosted on the hub cluster and delivered to the user's browser
- A simulation tool development area, including source code control and bug tracking
- Animated presentations delivered in a lightweight, Flash-based format
- A mechanism for uploading and sharing resources
- Access to five-star ratings and user feedback for resources
- A user support area, with a question and answer forum
- Statistics about users and usage patterns

Challenges

The challenges experienced in initiating and maintaining VHub are likely similar to those encountered by any risk platform. They include the following.

Ongoing infrastructure costs. VHub.org is currently supported by the U.S. National Science Foundation, but broader support is needed, particularly if objectives expand. This and any other platform established will have similar ongoing infrastructure costs. In VHub's case, "infrastructure" refers to the servers and data storage and the HUBzero software that underpins the platform itself.

The need to develop a certification process for modeling tools (benchmarking, validation, verification). VHub users have initiated development of a certification process, have held a couple of sessions and workshops in conjunction with meetings of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), and are working on a paper. The process needs to be formalized, however.

A need for resources for more tool deployment (developer time required to implement tools on the hub). Model developers need support for the time and effort required to deploy a model for online execution through VHub or any similar platform.

The need for training. Training is an essential component for applications that requires ongoing resources and significant personnel time.

Toward an Open Platform for Improving the Understanding of Risk in Developing Countries

Micha Werner, Hessel Winsemius, Laurens Bouwer, Joost Beckers, Ferdinand Diermanse (Deltares & UNESCO-IHE)

Disaster risk reduction (DRR) is the concept and practice of reducing disaster risks through systematic efforts to analyze and remove the causal factors of disasters. Understanding risk is the foundation of DRR. To develop this understanding is, however, a complex process, involving a wide range of issues and stakeholders, and with many different methods applied, depending on location, area, or country of interest. Although a general consensus exists as to what constitutes risk—that is, the combination of hazard and impact—agreement is less on how to characterize and quantify hazard, and perhaps even less than that on how to characterize the impacts of a hazard's occurring.

The implementation of a proper risk assessment requires capacity in terms of scientific and engineering knowledge and expertise, information and data, supporting infrastructure, and appropriate tools. Availability of this capacity, which may be an issue in developed countries, is often even more so in developing ones. The Global Facility for Disaster Reduction and Recovery (GFDRR), in collaboration with the UK Department for International Development (DFID), is developing a scoping report exploring the need for an open platform that can support the understanding of risk, specifically with reference to challenges posed in developing countries. With this short opinion paper, we aim to contribute to this report.

We first consider the user perspective in understanding risk, as we feel this is fundamental to the development of a successful platform. Next, based on our experience in developing an open platform for flood forecasting, we describe what we think is prerequisite to developing the intended platform, in terms of capacity, mobilization of knowledge, and technical tools; for it to be adopted; and for it to have real impact.

Developing the demand: Connecting to user needs

As with any technical tool, an open platform for understanding risk will have to suit the needs of intended users in developing that understanding and acting upon the resulting information. The methods applied should depend on the users and the understanding of risk they require. We define four main groups of users:

- *Local and regional agencies*. Agencies are responsible for developing an understanding of risk in their local or regional focal areas, often to comply with national or international policy. They use that understanding for developing DRR strategies. This means a platform supporting the process of these agencies should focus on developing the understanding of the risk at a local or regional level and support the process of identifying measures that are both effective and feasible to implement under local or regional conditions. An example of such a platform is MULINO,[59] which was developed to support the implementation of the European Union Water Framework Directive. The local MULINO case studies were on the 25 to 100 km^2 catchment scale.
- *National planning and international agencies*. On a larger scale, the objective for understanding risk may be quite different. At the national level, a more strategic view may be required, allowing prioritization among different natural hazards and geographical areas, depending on their susceptibility to risk. This objective is broadly shared by

[59] C. Giupponi, "Decision Support Systems for Implementing the European Water Framework Directive: The MULINO Approach," *Environmental Modelling and Software* 22 (2007): 248–58.

international agencies (such as the World Bank and the Inter-American Development Bank) that have an interest in identifying risk hot spots at the national or regional level. Descriptive rather than absolute approaches to assessing vulnerability at national and community levels are often used for this purpose.[60]

- *Insurance and reinsurance.* Insurance can provide compensation to those adversely affected by flood events, while reinsurers transfer a part of these risks to the global market. Insurance companies have an interest in understanding the risks of their portfolios within their areas of operation and a primary interest in expected losses and probable maximum losses over their portfolios in economic terms. Reinsurers have a similar interest, though more global. While local or regional risk assessments may ignore the correlation of natural hazards and impacts in space and time, the insurance, and particularly the reinsurance, industry cannot neglect this, as their portfolios may be distributed over larger geographical areas.
- *Academia.* The final group of users we identify is the academic community, whose members may use a platform to conduct research and develop new methods for assessing risk or apply existing methods to a new domain.

The remainder of this discussion focuses on the first and last of these groups, as the objective of the effort initiated by GFDRR is to develop a platform primarily for practical applications, especially in developing countries. The objectives of these two groups are very different, but to establish a sustainable approach to risk assessment they should be intricately linked.[61] Developing a platform that suits the needs of both is complex, particularly in developing countries, where in many cases data, capacity, or both are lacking.

To be useful, the understanding of risk, as generated by the platform, should comply with local policies and strategies and contribute to plans to reduce that risk. The link to the research community should enable an active interface between science and policy. [62] In some countries, a policy for DRR may not (yet) exist. This does not negate the need for an understanding of risk, but it lowers the incentive to take action and is likely to hinder the adoption of a platform to fill that need.

Establishing a framework for understanding risk

The developing of an understanding of risk should follow a framework that guides the user through the process without becoming restrictive. While exploring the details of such a framework is beyond the scope of this short discussion, it should clearly follow the constituent components of risk, including identification of the hazard (type, probability, and intensity), assessment of its impacts, and assessment of the performance of risk mitigation strategies. Many avenues are available for establishing these components.[63] The framework should, however, guide the process by posing key questions to be addressed.

The first of these questions asks what the objective is of developing the understanding of risk. The answer will determine how the risk assessment should be carried out and the type of data and knowledge required. For example, a risk awareness campaign should aim to develop risk zones and communicate clear messages, whereas an insurance objective requires a more quantitative approach.

A second key question seeks to identify the policies that govern the process of risk analysis and risk reduction, since these may prescribe the required outcomes. A good example of a risk reduction policy is the European Union Floods Directive,[64] which requires member states to develop an understanding of flood risks at the river basin level and for coastal stretches. While the directive describes what that understanding should entail, it

[60] J. Birkmann, "Risk and Vulnerability Indicators at Different Scales: Applicability, Usefulness and Policy Implications," *Environmental Hazards* 7 (2007): 20–31.

[61] P. Quevauviller et al. "Integration of Research Advances in Modelling and Monitoring in Support of WFD River Basin Management Planning in the Context of Climate Change," *Science of the Total Environment* 440 (2012): 167–77.

[62] Ibid.

[63] GFDRR, *Understanding Risk in an Evolving World: Emerging Best Practices in Natural Disaster Risk Assessment*, World Bank, 2014, http://www.preventionweb.net/english/professional/publications/v.php?id=38130.

[64] European Union, *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks*, 2007, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007L0060&from=EN.

does not prescribe how the understanding should be gained. This allows users to choose how to implement the risk assessment; to utilize existing knowledge and experience; and to develop their own modeling and data systems. Not prescribing how to implement the necessary steps may be a weak point of the Floods Directive; it is also its strength. It stimulates local authorities to develop an understanding of risk for their specific situations while using available knowledge and data. In a developing country, this may seem less logical, as fewer data and less knowledge may be available; but starting from existing knowledge and capacities is as important there for the acceptance and sustainable adoption of an approach as it is where more data are available.

Finally, a third key question asks what methods are appropriate and what data are required to develop an understanding of risk, given the objectives and policy requirements. Once they are identified, the framework should provide guidance on the necessary steps to develop the understanding, on the scope of its application, and on how knowledge and capacity can be mobilized.

Mobilizing knowledge and capacity

Clearly, the models and methods mobilized for developing an understanding of risk should adhere to minimum standards, and they should be able to deliver the required information, as detailed in the framework. In our experience with integrating existing knowledge and models in operational flood forecasting systems,[65] we have found mobilizing local knowledge and capacity key to ensuring the adoption of any system by those who ultimately need to use it.

While this experience was gained to some extent in developed countries where models were already available, we found the same to be true in developing countries. One example was Sudan, where a forecasting system was originally set up in the early 1990s using satellite rainfall estimation and hydrological and hydraulic models that were then state of the art. This system, however, proved unsustainable due to lack of capacity, despite concerted efforts to build it. Local staff was trained, but most soon moved on to better prospects. In an effort to revive the system some twenty years later, another approach was followed, which ensured models developed by research groups at local universities were used, as well as openly available satellite rainfall products.[66] This proved more successful.

We find in this example and several others that the integration of local knowledge and capacity is a prerequisite for the sustainability of any effort to develop an understanding of risk and indispensable if that understanding is to be used in practice. Capacity may be bolstered through focused capacity-building efforts, but the results are often short-lived if no connections exist to locally available knowledge, research groups, and communities of practice. We believe getting the required buy-in to a sustainable approach to understanding risk in any setting, developed or developing, depends on joint developing and on working with key local experts to champion the approach. We propose, therefore, to focus the development of the platform on both local and regional authorities, as well as (national) academia and research groups.

Open platforms, open data, and interoperability

Mobilizing local knowledge and, where available, existing models and methods is challenging. Particularly in developing countries, the sharing of data and models is difficult, often because of the institutional setup. To circumvent this and other issues, efforts to create an understanding of risk have often developed platforms from scratch, including models and methods, and have complemented the unattainable local data with global datasets. This approach may well result in establishing an understanding of risk, but, as pointed out, it is often not embedded in the local community of practice, and it may not be championed to the extent that it can be used in effective DRR.

Additionally, implementation constraints may dictate simplifications that impede adequate representation of the specific local situation. For instance, the

[65] M. Werner and D. Whitfield, "On Model Integration in Operational Flood Forecasting," *Hydrological Processes* 21 (2007): 1521.

[66] M. Werner, J. Vekade, and Y. A. Mohamed, "Flood Forecasting in Developing Countries: Challenges and Sustainability," *European Geophysical Union* 13, EGU2011-13163 (2011).

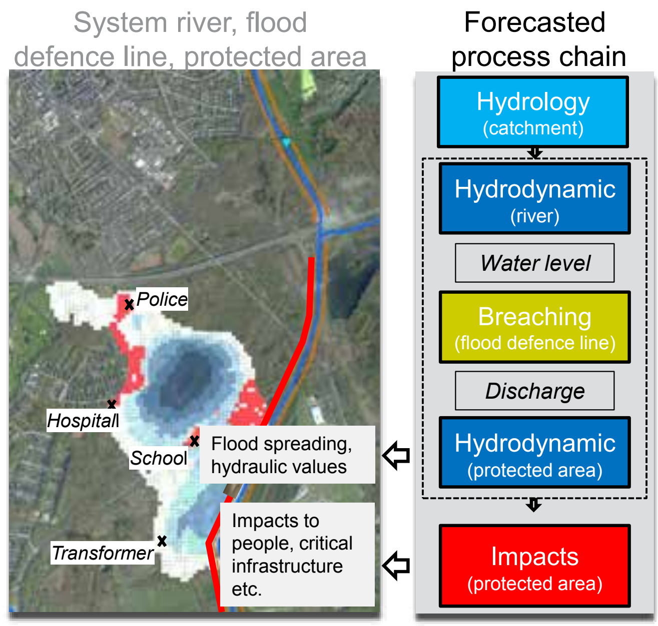
Central America Probabilistic Risk Assessment (CAPRA) framework[67] was developed to help improve the understanding of risk in support of government agencies,[68] but the underlying software tools were built upon fixed hazard modeling suites and schematization concepts, hindering their application beyond the domains for which CAPRA was originally developed.

With the development of Delft FEWS,[69] an open platform originally focused on flood forecasting but since applied widely in the understanding of water-related risks (see Figure 1), we found taking a more flexible and open approach to integration of models and data successful. No more than a platform that provides the technical infrastructure to guide the implementation of a framework for understanding risk, Delft FEWS has the flexibility to integrate local data and models. Global datasets, which are constantly improving in resolution and reliability, can be integrated as they become available and readily compared with local data to ensure they are fit for the purpose. We found adhering to international standards in data exchange important to ensure interoperability and inclusion in the wider international community of practice. The open approach supports easy adoption of new methods and models from local, as well as international, research and practice as local experience and capacity develop.

Conclusions and recommendations

Above we briefly discussed the development of a platform to support the understanding of risk. This platform would be aimed at local and regional agencies, in cooperation with research groups and academia, to support the implementation of policies and measures related to DRR. We argued that for any such platform to be adopted and have a real impact, it must fit into a framework that guides that understanding.

FIGURE 1. Example workflow in the FEWS-risk system built using the Delft-FEWS platform



Such a framework should, however, not be prescriptive but rather descriptive in the steps to be taken. A platform that enables implementation of the steps in risk assessment can be helpful, but it should be inclusive and mobilize local knowledge and available models, data, and experience. To have true impact in both developed and developing countries, a sustainable understanding of risk must be achieved by establishing local capacity and communities of practice, as well as links to international research and communities of practice groups. A successful platform should enable that.

[67] O. Cardona, M. Ordaz, and E. Reinoso, "CAPRA–Comprehensive Approach to Probabilistic Risk Assessment: International Initiative for Risk Management Effectiveness," in *Proceedings of the 15th World Conference on Earthquake Engineering*, 2012, http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_0726.pdf.

[68] GFDRR, "Understanding Risk: The Evolution of Disaster Risk Assessment," 2014, http://www.preventionweb.net/english/professional/publications/v.php?id=38130.

[69] M. Werner, J. Schellekens, P. Gijsbers, M. van Dijk, O. van den Akker, and K. Heynert, "The Delft-FEWS Flow Forecasting System," *Environmental Modelling and Software* 40 (2013): 65–77.

Oasis: The World's Open Source Platform for Modeling Catastrophic Risk

Dickie Whitaker, Peter Taylor (Oasis Loss Modelling Framework Ltd)

The Oasis Loss Modelling Framework (Oasis LMF), funded by the world insurance industry under the banner of "'cat' (catastrophe) modeling for the masses" over the past three years, will, in 2016, be fully open source and the only extant platform that can "plug and play" catastrophe loss models without changing the results of originating models. Oasis also has the backing of over ninety other organizations comprising technology providers, software houses, consultants, and academic and nongovernmental institutions.

Oasis already provides a de facto standard for the catastrophe loss modeling paradigm of event footprints and vulnerability that is model agnostic yet applicable to a wide range of deterministic and probabilistic models. With the global benefits already seen from such standards as those of the Open Geospatial Consortium (OGC) for geographical data, this could be extended to a de jure standard.

Oasis is extensible (that is, able to take on any catastrophe loss model into any user organization), scalable (able to handle complex models and massive property numbers using the same technical architecture), and deployable (able to be run on a very wide range of commodity computers and mobile devices).

At the beginning of 2016, Oasis will offer MOOCS (massively open online courses) funded by the European Union's Climate-KIC to explain catastrophe loss modeling and how models can be built, delivered, and used. To simplify installation for users, Oasis will also provide an automated model installer, akin to an "app installer." This will facilitate development of an e-marketplace allowing for the licensing of models from one central hub.

Finally, Oasis is working with Climate-KIC on an e-commerce platform for finding and disseminating environmental data and models.

The discussion below covers six ways in which Oasis will benefit developing countries and others who need to assess catastrophe risk models throughout the world:

- By establishing a worldwide standard for catastrophe loss modeling comparable to the Open Geospatial Consortium (OGC) standard for geographical data that will, as OGC has done for geospatial models, increase the ease of use and development of catastrophe models
- By being open source, offering the ability to take advantage of the world's entire resources for model, software, and technology development and simplifying adaptation and development
- By making the quantitative expertise in catastrophe risk of the insurance market freely available to the world, with particular benefits for the developing world
- By using the increasingly available detailed data on location and construction and use of properties that allow catastrophe loss models to produce meaningful results
- By deploying the latest developments in commodity multicore, fast memory, and big data technologies needed for large and complex risk estimates, while still allowing the use of standard computers for many standard types of analysis
- By providing access to data and models with appropriate information and providing the right levels of utility.

Challenges

Catastrophe loss models made their first appearance thirty years ago, with Karen Clark's Applied Insurance Research. These early models were market share–based systems used by treaty reinsurers. Since then, their use and application have proliferated to the point that most property insurers and reinsurers use models, and regulators expect them to be used. Their use outside the insurance sector, however, has been very limited because of significant barriers to their introduction.

Catastrophe loss models simulate the impacts of catastrophic scenarios, termed "events," to estimate the frequency and severity of both economic and insured losses. The models are simplified representations of events and their effects in what might be termed a "static event paradigm," in that they take footprints of the damage caused by an event, driven from a worst-case measure of a damage-causing peril, such as the maximum depth of water in a flood. At first glance, little suggests such a static worst-case model would be a good representation of a complex, interacting, dynamic reality. The way these uncertainties are handled is through probability distributions, although they are not guaranteed to be informative.

While classification of the many sources of uncertainty within catastrophe loss models is somewhat arbitrary, we can identify three broad categories:

Model uncertainty covers the uncertainties that exist within the scope of the model. Among these is model inadequacy, which represents the unsuitability of the underlying physical hazard and vulnerability models, as well as the effects of ignoring secondary perils, such as demand surge (sometimes termed "loss amplification") and fire following earthquake, or secondary coverages, such as business interruption. Model risk is the risk that the particular model is wrong or provides an incomplete and misleading picture. Parameter risk is the risk that the model's parameters (often expressing assumptions or calibration factors) are wrong, and calculation error is the risk that the model has been insufficiently discretized or sampled.

Data uncertainty in this case applies to information describing the insured exposures, which are typically properties and structure. This can cover location, which is generally the most important attribute of an interest (such as a building), and situations in which, for various reasons, the insured values do not reflect the indemnity that would be incurred. Data uncertainty can also include the risk profile of a building—that is, the attributes that make it subject to damage, among them "primary modifiers," such as construction and occupancy, and "secondary modifiers," which are other attributes that affect the potential for damage, such as roof geometry. And, of course, any data may be out of date.

Unmodeled uncertainty is set apart from the data and the model, as it relates to the part of the representation of the problem that is outside the domain of the model. It covers a range of factors, which include secondary perils such as business interruption, demand surge, and fire following earthquake (although these are sometimes included in the model, and any weaknesses then fall under model inadequacy). A particular cause of unmodeled loss in recent years has been contingent business interruption losses caused by supplier failure. The interpretation of policy wordings by the relevant jurisdiction can also materially affect losses, and a component of insurance cost generally ignored by modelers is the expenses and fees from adjusters and lawyers and other third parties involved in a claim, termed loss adjustment expenses. In some cases, these can be a material overhead on top of the pure indemnity cost.

This preamble leads into the five key challenges facing any catastrophe loss model:

- How to define catastrophe loss models as a worldwide standard through which model developers can deliver their models
- How to handle the wide variety of catastrophes and be able to run them at high fidelity with discrete probability distributions
- How to use the platform in a wide variety of organizations, each with its own data for exposures and financial protections
- How to deliver the technology cheaply and globally
- How to educate everyone as to what these models are and how to build and take them to market

Solutions and recommendations

In designing the methods and options for the calculation, four features were incorporated into the Oasis Loss Modelling Framework to address the challenges summarized above (further details are available in Oasis Financial Module 2015, by Peter Taylor):

- Representation of uncertainty using *discrete probability distributions* with discontinuities (including for intensity as a "miss factor" and for damage as "no loss" and "total loss" and failure modes of constructions)
- Description of loss distributions with *complete statistics*, not assuming convenient but unrealistic simplifications such as beta distributions
- Calculation of financial losses using *Monte Carlo sampling*, not convolutions and assumptions about truncated distributions
- Representation of *correlations* between the loss distributions and the range of outcomes that follows from uncertainty about correlation

To communicate these ideas, Oasis will, as mentioned above, offer MOOCS, funded by the EU's Climate-KIC, that will explain catastrophe loss modeling, show developers how to create loss models and take them to market and how Oasis facilitates this process, and show them how to explain to users and customers the utility of information coming from a catastrophe loss model. Hitherto, these techniques have been unknown except to a small group of specialists, mostly in commercial organizations. The Oasis MOOCS will inform researchers and users worldwide of the power and capability of catastrophe loss models and how they can be built, delivered, and used.

Oasis technical architecture

The technical architecture of the Oasis LMF addresses three key criteria:

- *Extensibility*, the ability to cope with a very wide variety of models and business users within the paradigm of event-based loss modeling. Oasis achieves this through the agnostic kernel (which flexibly handles data types), variable definition tables (called profiles), and connectors, which are pieces of code that transform data into the Oasis agnostic format.
- *Scalability*, the ability to run with a wide range of data sizes, from small, coarse-grained models for a few properties right up to high-resolution models with hundreds of thousands of events for millions of properties.
- *Deployability*, which Oasis achieves by using an open source set of components (the LAMP stack—Linux, Apache, MySQL Python, and Django), a standard data definition and manipulation language (SQL), and back ends for persistence of data that are SQL compatible (which include Hadoop engines, for example, as well as the more obvious relational database providers) or POSIX compliant. Oasis has also adopted "Virtual Machine" solutions (Oracle's Virtual Box, EMC's VMWare, Microsoft's Hyper-V), deployable on a wide variety of platforms.

Conclusion

Technology is a critical if overlooked element of all catastrophe model operating solutions. By designing it around open operating systems, notably Linux, as well as Windows, Oasis is geared to taking advantage of future developments,

To summarize, then, here is how Oasis solves the challenges facing a catastrophe loss modeling platform:

- *How to define catastrophe loss models as a worldwide standard through which model developers can deliver their models.* Oasis already defines the standards and how "connectors" can map from simpler models to the fully discretized probabilistic data formats used in Oasis.
- *How to handle the wide variety of catastrophes and be able to run them at high fidelity with discrete probability distributions.* Oasis has an "extensible" and "agnostic" design that transforms any model meeting the paradigm of event footprints and vulnerabilities into a generic format that can be computed rapidly.
- *How to use the platform in a wide variety of organizations, each with its own data for exposures*

and financial protections. The Oasis Front-end "Flamingo" provides component web services and stored procedures that allow any front end to integrate into it. Moreover, by using a design based on files, not predefined standards or databases, Oasis allows for an unlimited variety of data structures and formats for exposures and financial conditions.

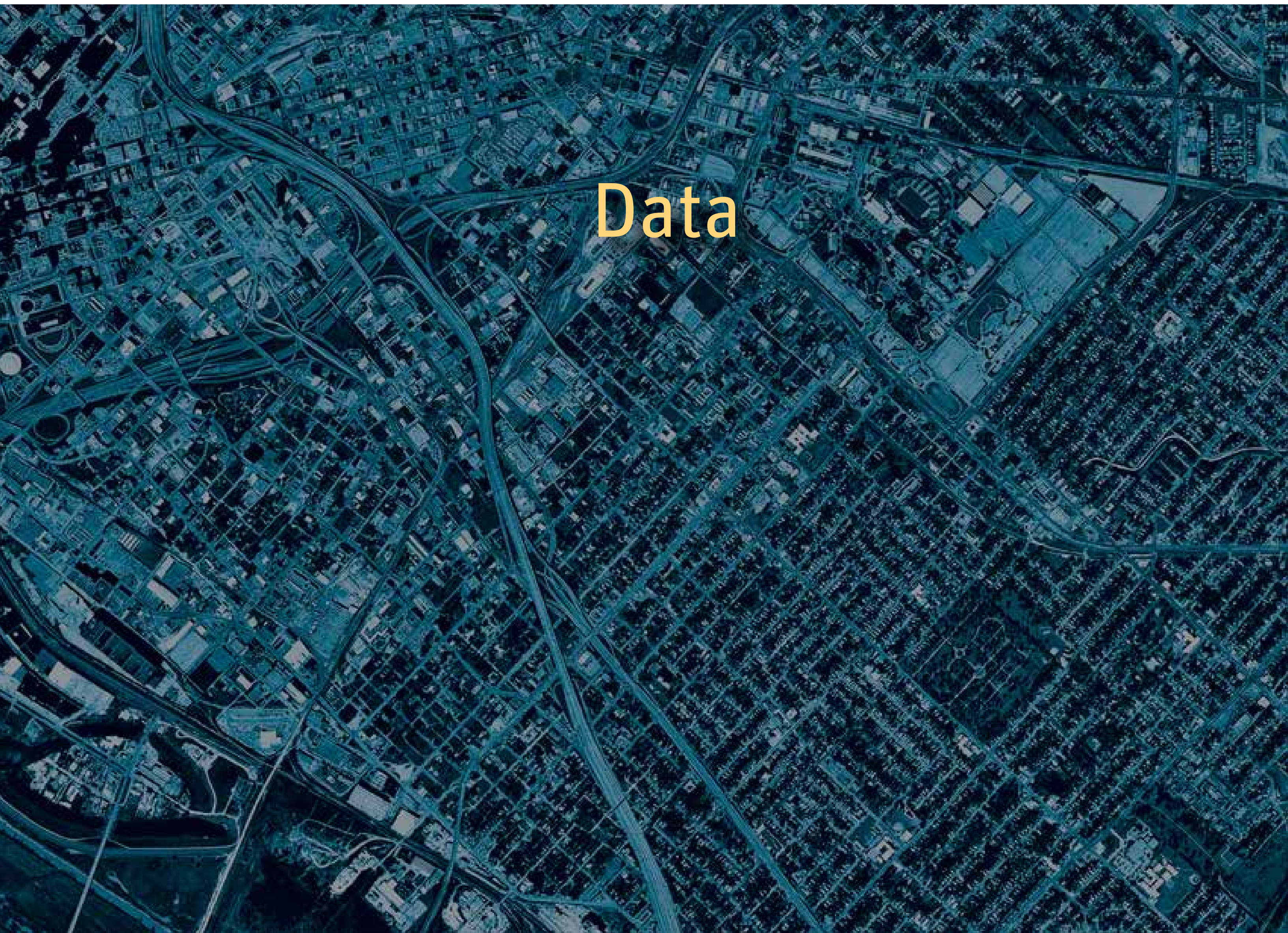
- *How to deliver the technology cheaply and globally.* This has two elements—the software and the runtime. Oasis backend calculators use entirely open source free software. The frontend uses SQLServer and R-Shiny. Cheap versions of these are available, and R-Shiny is open source and free if used without security. Runtime execution of the programs requires a "hosting" provider, and Oasis has used existing suppliers (such as Equinix). For global operation, AWS (Amazon) and Azure (Microsoft) or others may well provide free compute power as a social responsibility public good.
- *How to educate everyone as to what these models are and how to build them and take them to market.* The MOOCs Oasis makes available free worldwide will help model developers and user organizations understand what is on offer and what needs to be done to take advantage of these new tools for risk assessment. In addition, in partnership with Climate-KIC (http://www.climate-kic.org/for-public-bodies/), Oasis is working on a prototype of an e-commerce portal—in essence, an "Amazon for data." This initial prototype project seeks partners to globalize a solution to the challenge of finding and acquiring data and models for use in catastrophe risk assessment.

SOLVING THE PUZZLE

Innovating to Reduce Risk

WRITTEN CONTRIBUTIONS

Data



Open or Closed? How Can We Square Off the Commercial Imperative in a World of Open and Shared Data?

Justin Butler (Ambiental)

The Open Data Institute (ODI) defines open data as "data that anyone can access, use and share."[1] A wider definition by Open Knowledge provides additional insight: "'Open knowledge' is any content, information, or data that people are free to use, reuse and redistribute—without any legal, technological, or social restriction." The definition continues:

- Open data are the building blocks of open knowledge. **Open knowledge is what open data become when it's useful, usable, and used.**

The key features of openness are:

- **Availability and access.** The data must be available as a whole and at no more than a reasonable reproduction cost, preferably by downloading over the Internet. The data must also be available in a convenient and modifiable form.
- **Reuse and redistribution.** The data must be provided under terms that permit reuse and redistribution including the intermixing with other datasets. The data must be machine-readable.
- **Universal participation.** Everyone must be able to use, reuse, and redistribute—there should be no discrimination against fields of endeavour or against persons or groups. For example, "non-commercial" restrictions that would prevent "commercial" use, or restrictions of use for certain purposes (e.g., only in education) are not allowed.[2]

Open data has the power to help us improve education, better manage natural hazards, build better cities, improve public health, and bring about a host of other positive outcomes. For "data-poor" countries, especially, located primarily in the developing world, free-to-access data sets such as Google Earth, OpenStreetMap, and similar resources have provided a much-needed boost to meeting citizens' needs for improved navigation, city planning, and risk management. For example, in 2013, Edo State in Nigeria became the first subnational government body in Africa to launch an open data portal, joining more than two hundred international governments with open data initiatives. According to the data portal, the driving force behind the Nigerian initiative is "for improving transparency, catalyzing innovation, and enabling social and economic development."

How to go about bridging the gap between governments and the public via digitization is not obvious, however. It requires exploring and specifying the needs of end users and the ways in which the information can be used in their everyday lives. Simplicity is key. Only when users can derive value from the data on first use—unaided—will they be prepared to come back for a second try. Without this ease of use, the success of open data projects may become limited, with the result that low-value, poor-quality data are inefficiently made available to a small group of people who find interacting with them extremely difficult.

The case for closed or, at least, shared data

Whereas open data can be accessed, used, and shared by anybody, closed data are typically held internally—for example, for national security purposes—and sometimes for good reason; personalized mobile phone records are

[1] ODI, "What Is Open Data?" http://theodi.org/what-is-open-data.

[2] Open Knowledge, "What Is Open?" https://okfn.org/opendata.

an obvious case in which a data source is kept closed to protect privacy. Restrictions on data sources related to disaster risk, however, such as earthquake and flood models that are often kept closed by model vendors and data suppliers, are driven by a need to protect income derived from licensing out the data to well-funded end users, as well as the high cost of maintaining national-scale, high-resolution datasets. Similarly, detailed natural hazard datasets are frequently created from valuable input data such as digital topographic models (DTMs), which can be highly costly to acquire or, in some countries, subject to national security considerations. These, too, are deemed closed.

Between the opposites of open and closed lies the world of "shared data," where information is shared with groups of end users for specific purposes. Whether they comprise electoral registers or information on shopping habits, shared data are often transmitted at a cost, and permission is given, or restricted, in terms of how they can be used or published.

Within this framework a key caveat applies: good quality data are costly to create and maintain, and if investments are not made by international governments or behemoths such as Google or Microsoft to generate them, reputable commercial data suppliers will always be valuable sources of sharing (at a cost) high quality data with specialist end users for the most critical applications.

Taking the plunge: Opening up detailed flood data to those in need

Flood risk is a growing international problem. From an insurance industry perspective, flooding is now ranked as having the highest catastrophic loss potential, exceeding earthquakes and other natural hazards.

For example, according to the World Bank, the estimated damage and losses from the Thai floods of 2011 was US$46.5 billion.[3] For insurance and reinsurance companies, total claims—many of them from business interruption and contingent business interruption—came to an estimated $12 billion, according to figures from Swiss Re.[4] The torrential flooding claimed hundreds of lives, displaced hundreds of thousands of residents, and directly and indirectly affected thousands of businesses. Global supply chains were severely affected, with companies such as Western Digital registering multimillion-dollar losses from flood damage and lost production.

In Australia, the 2010/11 Queensland floods caused an estimated reduction in Australia's gross domestic product (GDP) of around $A30 billion,[5] making them the costliest natural disaster in the country's history, and the frequency of extreme flood events in many regions appears to be on the increase.

Following a major flood event, and to prepare better for future flooding, key decision makers have a vital need for access to expert data, advice, and tools relating to flood risk assessment and management techniques. Accordingly, it is important to remember that the risk of flooding at a particular location is controlled by a number of factors, including topography and elevation, hydrology, soil types, existing flood defenses, and the nature of development in catchments. Modeling flood risk is complex and highly data dependent; the truism of "good data in = good data out" certainly applies here.

Alexander Pope's axiom that a little knowledge is a dangerous thing has particular relevance to important applications such as flood risk mapping—especially when poor quality modeling can directly affect people's lives and property. Inappropriately specified or inaccurate flood data can give a false sense of security by underestimating the extent or depth of potential flooding. By the same token, false reads can attract "cry wolf" accusations if they show an area to be at risk when years of experience would suggest otherwise. Highly specialized data and modeling are required to show that just because an area hasn't flooded in the past does not mean it is unlikely to flood in the future, especially under conditions of a nonstationary climate and rapid urbanization.

3 World Bank, *Thai Flood 2011—Overview: Rapid Assessment for Resilient Recovery and Reconstruction Planning*, report no. 69822, vol. 1 (Washington, D.C.: World Bank, 2012), 4.

4 Swiss RE, *Flood—An Underestimated Risk. Inspect, Inform, Insure* (Zurich: Swiss RE, 2012), 7.

5 Zurich Australian Insurance Limited, "A Land… of Droughts and Flooding Rains," Australian Storms and Floods White Paper (Sydney: Zurich Australian Insurance Limited, 2013), 10.

Ultra-high-resolution digital flood maps, such as those shown in figure 1, are based on costly DTMs built using airborne Light Detection and Ranging (LiDAR) technology, which can cost hundreds of dollars per square kilometer. Zero-cost or fully open delivery of the detailed depth grids essential for planning and insurance risk-rating purposes is often not commercially viable once aggregating up to countrywide scale has been taken into account and the costs of the labor, computer processing, and manual quality assurance and validation needed to produce them are factored in.

In the UK, the government has recently moved to ensure that the Environment Agency—the government body whose roles and responsibilities are similar to those of the Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA) in the United States—steps up its program of open data. This development guarantees key datasets are freely available—those the government has a statutory obligation to collect and maintain and those for which user demand is highest, such as the types and locations of flood defense assets.

The UK's national mapping agency, Ordnance Survey, has also made a number of its proprietary datasets open, such as postal code boundary vectors and street-level mapping. Its flagship product, MasterMap, remains firmly in the commercial domain, however, being shared only with skilled practitioners with the expertise and geographic information system (GIS) software to access and manipulate the data. As with detailed flood maps, a high cost is associated with maintaining and updating highly detailed and accurate digital databases such as Mastermap, which contains 450 million geographical features found in the real world, from individual addresses to roads and buildings.

What is the optimum level of openness?

In a 2008 working paper, Tom Eisenmann of the Harvard Business School discussed how, within platform-mediated networks that include end users, developers, platform providers, and IP (Internet provider) owners, individual roles can be open or closed, depending on a series of complex decisions (see table 1).[6]

[6] T. R. Eisenmann, "Opening Platforms: How, When and Why" (working paper, Harvard Business School, 2008).

FIGURE 1. **UKFloodMap. 1-in-100-year flood depth grid—fluvial (river) flood risk, created using LiDAR topography and showing flood depth estimates every 5 meters for the entire UK (Copyright © Ambiental 2015).**

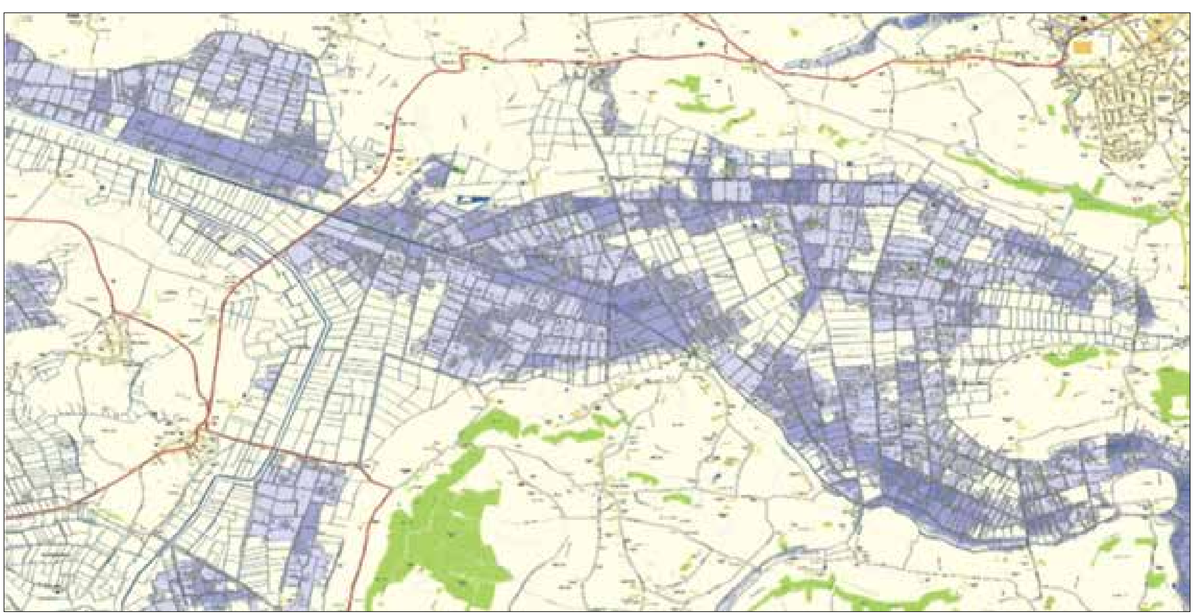


TABLE 1. Comparison of Openness by Role in Platform-Mediated Networks

	Linux	Windows	Macintosh	iPhone
Demand-Side User (End User)	Open	Open	Open	Open
Supply-Side User (Application Developer)	Open	Open	Open	**Closed**
Platform Provider (Hardware/OS Bundle)	Open	Open	**Closed**	**Closed**
Platform Sponsor (Design and IP Rights Owner)	Open	**Closed**	**Closed**	**Closed**

Source: T. R. Eisenmann, "*Opening Platforms: How, When and Why*" (working paper, Harvard Business School, 2008).

At the platform provider/IP owner ("sponsor") level, a drive toward interoperability with rival platforms so as to capture market share by licensing additional platform providers is often seen as a driver for opening up access. One example of this is the insurance catastrophe ("cat") modeling industry, where leading model vendors are looking to secure customer loyalty and generate new income streams by granting access to underlying loss modeling engines by third-party hazard model and data providers.

In contrast to the previous "black box" business models typical in the industry, the interoperability trend is now seen as making good business sense, as end users (insurers, reinsurers, and brokers) are also given a wider choice of models (for example, digital flood hazard maps, probabilistic event sets, and so on) for previously "nonmodeled" territories. This, in turn, can help global reinsurers penetrate new markets and make better pricing decisions in terms of premiums. They can also improve capital management so sufficient resources are available to pay out future claims. By the same token, regulatory initiatives, such as Solvency II in the insurance industry, mean insurers and reinsurers need to be increasingly open, transparent, and knowledgeable about both the risk models and the data they use to ensure liquidity when the next major catastrophe strikes.

With respect to end users and app developers ("demand-" and "supply-side" users), platform owners may decide to open or close their operations out of a desire to ensure backward compatibility with previous versions or because they want to absorb high quality, open source libraries and code that have been created by the wider developer community. This represents a win-win for both platform providers and end users, as has been demonstrated by the success of the iPhone developer community and Apple itself.

As Eisenmann states in his paper,

> Over time, forces tend to push both proprietary and shared platforms toward hybrid governance models characterized by centralized control over platform technology (i.e., closed sponsorship) and shared responsibility for serving users (i.e., an open provider role).[7]

Selecting optimal levels of openness is crucial for organizations that create and maintain platforms, especially when a decision made by an end user can have a significant impact, as in the case of flood risk management and insurance. The decision to open a platform and component datasets inevitably entails a tradeoff between adoption and appropriability. In this situation, appropriability—the capacity of the firm to retain the added value it creates for its own benefit—will continue to be a necessary requirement if high quality, validated data and associated delivery platforms are opened up in the future. Yet it is equally important to remember that which party benefits from this added value depends on the decisions of the organization, the structure of the market in which it operates, and the sources of the added value itself.[8]

7 Ibid., 1.

8 J. Kay, *Foundations of Corporate Success: How Business Strategies Add Value* (Oxford: Oxford University Press, 1995).

Opening a platform and associated data also can spur adoption by harnessing network effects, reducing users' concerns about lock-in, and stimulating production of differentiated products that meet the needs of user segments. At the same time, it typically reduces users' switching costs and increases competition among platform providers, making it more difficult for them to secure repeat revenues from the platform.

In conclusion, real advancement in the open data market will continue to require government backing, with buy-in from expert data modelers, who will always be needed to safeguard the quality, currency, and usability of the end product. Only in this way can the explosion of open data be harnessed to making better decisions. The age-old adage, "You get what you pay for," will always apply.

Understanding Disaster Risk Through Loss Data

Melanie Gall, Susan L. Cutter (University of South Carolina)

We have only a crude understanding of historic losses from natural disasters. We broadly know that (a) economic losses are on the rise; (b) developing countries experience more fatalities and greater economic losses relative to their gross domestic products (GDPs) and populations than developed countries; and (c) we are unaware of a link between disaster losses and climate change.[9] Our knowledge of how these trends play out at local levels, though, is very limited and fraught with uncertainties.

The lack of knowledge on disaster losses is particularly problematic when we consider that losses are one of the few tangible measures of climate change adaptation and disaster risk reduction. Without understanding where and subsequently why disaster losses occur, it will be difficult to devise strategies that successfully curb the effects of extreme weather and other climate-sensitive hazards. The absence of a baseline knowledge—when, where, what—impedes any sound modeling of future or anticipated impacts because the existing loss data are inadequate for model validation and parameterization.[10] The Sendai Framework for Disaster Risk Reduction recognized this and underscored the need for better data.[11] Several challenges associated with loss data need to be addressed if they are to become effective metrics for disaster risk reduction and climate adaptation, as outlined in the following.

Challenge 1: Who assesses the damage from natural hazards and how?

Technological and scientific infrastructure exist for data collection on physical aspects of extreme events. Physical data (for example, measures of humidity, precipitation, and temperature) are collected remotely by satellites, as well as locally by automatic or human-operated instruments, such as weather stations or seismographs. This comprehensive spatial and temporal coverage of physical observations facilitates sound empirical and cross-boundary climatological research. Additionally, the remote collection of physical data fills information gaps whenever national meteorological and climatological agencies, especially in developing countries, lack the resources to deploy and maintain extensive national data collection systems.

Such infrastructure is absent for the societal impacts of disasters. Instead, loss data collection is mired in issues of low data quality and inconsistent reporting of losses, both spatially and temporally. The result is a patchwork of information sources of varying quality. In developing countries, humanitarian agencies, media outlets, and government accounts provide the bulk of loss information, while in developed ones local emergency managers, weather agencies, media reports, and even the public share loss information.

These sources provide mostly descriptive assessments of losses (for instance, number of houses damaged) and follow internal protocols (if they follow protocols at all) for assessing impacts. Some have implicit incentives

9 IPCC, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, ed. Christopher B. Field, Vicente Barros, Thomas F. Stocker, and Qin Dahe (Cambridge: Cambridge University Press, 2012). doi:10.1017/CBO9781139177245.

10 Melanie Gall, Kevin A. Borden, and Susan L. Cutter, "When Do Losses Count? Six Fallacies of Natural Hazards Loss Data," Bulletin of the American Meteorological Society 90 (2009): 799–809. doi:10.1175/2008BAMS2721.1.

11 UNISDR, "Sendai Framework for Disaster Risk Reduction 2015–2030," Geneva, Switzerland, 2015, http://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.

for exaggerating impacts to secure humanitarian aid,[12] as was seen in the 2010 Haiti earthquake.[13] How losses are assessed and what is considered a loss vary among sources, creating data inconsistencies and quality issues. Remoteness further hampers the spatial completeness and coverage of loss reporting, since humanitarian agencies or reporters may not operate in those areas. The result of this data-poor environment is a severe underreporting of losses from natural hazards, based on loss data sets of low quality.

Solution 1: Implement loss estimation standards and develop a network of loss reporters

To overcome this problem, a network of trained loss reporters who consistently follow established methods of loss assessment must be put into place. Such a network can involve universities and schools, public works and police departments, humanitarian aid agencies, health care providers, insurance agents, and more. Loss reporters must be trained in using loss assessment protocols and equipped to relay the information to loss data providers.

Loss estimation protocols should guide loss reporters through assessment steps that capture various loss categories (such as injured, killed), distinguish among the different types of losses (direct, indirect, insured, uninsured), and record impacts on different sectors (communication, transportation). The definition of loss categories and types should follow best practices, such as those developed by Integrated Research on Disaster Risk (IRDR), a research initiative cosponsored by the International Council for Science, the International Social Science Council, and the United Nations International Strategy for Disaster Risk Reduction.[14]

Loss assessment protocols should, furthermore, include default or base estimates for damage types (such as bridge collapse, road closure, killed livestock) that are reflective of local prices and cost of living. A conversion of descriptive loss categories (such as counts) into monetary units to improve a standardization of losses, along with guidance on how to capture and update losses of slow-onset events such as droughts, should be addressed, as well.

Challenge 2: Who compiles loss data and how?

Loss estimates are compiled in global or national loss databases operated and maintained by different stakeholders, such as government agencies, universities, insurance companies, and others. Just as loss data are not created equally, neither are loss databases. Incompatibility issues between databases arise from their use of incongruent data sources, data management structures, terminologies, and so on. Despite efforts to improve compatibility of loss information through the use of global disaster identifier numbers (GLIDEs), most databases are incompatible, with the exception of those built on the same system.

While many of the shortcomings of loss databases stem from the quality—or lack thereof—of the loss data themselves (see Challenge 1), database design choices muddy the picture further. Such choices include the use of event inclusion criteria, along with inconsistent hazard classifications, record lengths, and types of losses reported. The use of inclusion criteria, particularly loss thresholds, artificially limits the number of records in a database, often leading to an exclusion of high-frequency, low-impact events (for example, thunderstorms and small stream flooding). Focusing on catastrophic events only results in an underestimation of the cumulative effects of "small" events.

Loss databases also differ in the number and types of hazards included and how they are defined. Some may focus only on geophysical events, while others include biological, human-made, or other events. Even identically named hazards may mean different things due to differences in how a hazard is defined.

The most significant and visible differences among loss

[12] Hideki Toya and Mark Skidmore, "Economic Development and the Impacts of Natural Disasters," Economics Letters 94 (2007): 20–25. doi:10.1016/j.econlet.2006.06.020.

[13] J. E. Daniell, B. Khazai, and F. Wenzel, "Uncovering the 2010 Haiti Earthquake Death Toll," Natural Hazards and Earth System Sciences 1 (2013): 1913–42. doi:10.5194/nhessd-1-1913-2013.

[14] IRDR, "Peril Classification and Hazard Terminology," Beijing, China, 2014, http://www.irdrinternational.org/2014/03/28/irdr-peril-classification-and-hazard-glossary; IRDR, "Guidelines on Measuring Losses from Disasters: Human and Economic Impact Indicators," Beijing, China, 2015, http://www.irdrinternational.org/2015/03/10/data-report-2/.

databases occur in the compilation of event-specific loss information. In the broadest sense, databases vary based on the type of losses they report—that is, insured, direct, or a combination of losses. At the event level, some include a basic list of losses, such as number of people killed and monetary damage, whereas others dissect losses into economic sectors. Again, many of these variations originate with the data sources used by the loss database.

Efforts by the United Nations Development Program (UNDP) have significantly increased the number of countries with national loss databases in recent years, but most of these efforts are unsustainable without continued external support,[15] and little attention was given to database compatibility issues. Furthermore, many of these efforts essentially "recycle" information from other loss databases (most notably EM-DAT) due to limited resources.

Solution 2: Implement a scalable system of standardized loss databases

Databases that are compatible will not only enable comparative research but will, more importantly, allow for scalability from the bottom up. Local databases can feed into regional, national, or global databases, replacing the current and flawed top-down approach. Creating a system of local systems will provide a flexible environment capable of incorporating new databases as they become available.

While scalability is already possible with databases using the DesInventar system,[16] non-DesInventar databases should not be excluded. It is recommended to harmonize existing loss databases by applying and following best practices to reduce discrepancies in hazard and loss terminologies, such as those proposed by IRDR.[17] Furthermore, it is recommended to focus on a minimum set of losses categories (such as killed, injured) that can be consistently collected across events and databases. This will reduce the amount of missing data and enable compatibility between databases using different underlying systems.

All loss databases have inherent biases, meaning they over- or underreport certain hazard types and losses, favor certain locations or time periods, or use data sources of differing quality. Sound practices of internal quality control should be developed and implemented to eliminate such biases. This could be achieved through, for instance, the use of additional sources, extension of temporal records, use of uncertainty identifiers, and more.

Challenge 3: Who uses loss data?

The need for weather forecasts and early warning systems fueled advances in the physical data infrastructure. There has been no such demand for loss information in strategic planning decisions except those made by insurance and reinsurance companies. The Sendai Targets are a first (global) step in the right direction toward creating a demand for loss data, but it cannot be limited to global assessment purposes.[18] Instead, loss information must become an integral development measure, similar to GDP, child mortality, or literacy rates. Losses are a manifestation of broken land use planning and risk reduction processes (for example, the placing of people in hazardous zones or adherence to inadequate building codes), as well as inadequate emergency preparedness and response procedures.

The lack of a demand is fueled by the often rudimentary information provided by loss databases. For example, some economic losses, particularly sectoral losses (in transportation, agriculture, and so on), are frequently reported as counts—as number of houses destroyed, length of damaged road network, or number of livestock killed, for instance. Such metrics are impractical because they prohibit comparisons among places and times. Even absolute monetary values say very little about the severity of impacts. Without contextual measures, loss information remains useless for managing disaster risk, setting policies, or evaluating adaptation actions.

15 UNDP/BCPR, "A Comparative Review of Country-Level and Regional Disaster Loss and Damage Databases," New York, NY, 2013, http://www.undp.org/content/undp/en/home/librarypage/crisis-prevention-and-recovery/loss-and-damage-database/.

16 UNDP, Guidelines and Lessons for Establishing and Institutionalizing Disaster Loss Databases (Bangkok, Thailand: United Nations Development Programme, 2009).

17 IRDR, "Peril Classification and Hazard Terminology" and "Guidelines on Measuring Losses from Disasters."

18 S. L. Cutter and Melanie Gall, "Sendai Targets at Risk," Nature Climate Change 5 (2015): 707–9.

Solution 3: Translate loss data into meaningful information

For loss data to be used, it must be easily accessible and understandable.[19] Therefore, all loss databases, including databases of insured loss data, need to be publicly accessible and offer loss information that readily communicates the relative impact of extreme events. Impacts vary by community, largely driven by local vulnerabilities, such as poor socioeconomic conditions, population density, and more. A more effective communication of the severity of impacts can be achieved by putting losses into context, such as in relationship to a country's GDP or population. Loss database providers should incorporate such contextual information to allow for one-stop data access that eliminates the need for data processing and analysis on the part of the user. Database outputs could be supplemented with attributes such as losses as percentage of GDP, per capita losses, annual cumulative losses, and so forth.

Better data and information do not automatically lead to better decision making. Since stakeholders are unfamiliar with loss data, training should be offered on how to incorporate loss and hazard data into strategic decision making. For example, most community planners are not trained in disaster risk reduction planning. They are largely unaware of the unintended consequences of planning choices like zoning and siting on natural hazards and, subsequently, on how those choices exacerbate impacts on residents.[20] Thus, guidance must be developed to promote evidence-based decision making using loss information.

Conclusion

Providing sound loss data on par with observational climate and census data will require coordinated efforts. Not all communities and countries may be amenable to such efforts, however, since losses are indicative of unsustainable development and a testament to ineffective disaster risk reduction, climate mitigation, and adaptation strategies.

[19] J. C. Gaillard and Jessica Mercer, "From Knowledge to Action: Bridging Gaps in Disaster Risk Reduction," Progress in Human Geography 37 (2013): 93–114. doi:10.1177/0309132512446717.

[20] S. V. R. K. Prabhakar, Ancha Srinivasan, and Rajib Shaw, "Climate Change and Local Level Disaster Risk Reduction Planning: Need, Opportunities and Challenges," Mitigation and Adaptation Strategies for Global Change 14 (2008): 7–33. doi:10.1007/s11027-008-9147-4.

High-Resolution Elevation Data: A Necessary Foundation for Understanding Risk

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Digital Elevation Models (DEMs) provide basic information about the shape of the earth's surface and the features on it. This information is fundamental for understanding the processes that shape the landscape: sharp changes in topography can identify the locations of faults that generate earthquakes, while characteristically shaped scars and deposits can expose the locations of landslides. An accurate understanding of the surface of the earth is also needed to simulate hazards that flow over it, such as floods, tsunamis, and severe winds. Our ability to understand natural hazards depends, therefore, on digital elevation models (DEMs), and these vary widely in resolution, accuracy, availability, and cost.

At present, freely available global DEMs exist for topography data (that is, onshore elevation), and bathymetry data (elevation of the sea floor). Onshore, these include the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topographic Mission (SRTM) datasets, both derived from satellite remote sensing. Offshore, the General Bathymetric Chart of the Oceans (GEBCO), derived from a mixture of soundings and satellite gravity observations, is widely used to understand and model oceanic processes. These have become standard scientific datasets underpinning advances in our capability to understand and model the earth processes that cause disasters. Nevertheless, they are limited in horizontal resolution (thirty meters onshore, thirty arc seconds offshore) and vertical accuracy (greater than five meters). This, in turn, limits their applications, particularly for studies on a local scale.

The German Aerospace Agency's twin TanDEM-X and TerraSAR-X satellites are at present collecting data being used by Airbus to create a next generation global DEM, WorldDEM,™ which will have twelve-meter horizontal resolution and four-meter vertical accuracy.[21] DEMs collected using airborne technologies, including LiDAR (Light Detection and Ranging), HRSC (High Resolution Stereo Camera), and IFSAR (Interferometric Synthetic Aperture Radar), can have horizontal resolutions of a few meters or less and vertical accuracies approaching tens of centimeters. This allows for extremely high-resolution analysis and detailed modeling of earth processes, such as floods and tsunamis. These DEMs are generally available from commercial providers, with costs varying depending on the technology used.

Challenges

High-resolution DEMs, such as LiDAR, HRSC, and airborne IFSAR, are not available everywhere. In many parts of the world, their acquisition may be project based, which has resulted in an incomplete patchwork of high-resolution DEMs owned by different institutions with different licensing attached. Similarly, the next generation WorldDEM™ is, at present, globally incomplete and only commercially available. For many studies, therefore, only the globally freely available DEMs (ASTER and SRTM) are used, based on the argument that they are the "best available." Simply using the "best available" datasets without considering their vertical accuracy, however, can lead to dangerously misleading results, particularly when they are used for local-scale studies.

If disaster managers want to develop tsunami evacuation plans, for example, they need information on which areas

[21] http://www.geo-airbusds.com/worlddem.

of the coast may be inundated. As tsunamis tend to be infrequent (geological evidence suggests a return period of one thousand years for events like the 2011 Tohoku tsunami in Japan),[22] historical observations may not exist to define the potential inundation zone. Computer modeling of tsunami generation, propagation, and inundation for realistic hypothetical events can be used to fill this knowledge gap, but it needs high-resolution, high-accuracy DEMs to be effective.

Griffin and others assessed how the accuracy and resolution of DEMs translate into uncertainties in estimates of tsunami inundation zones.[23] The top part of figure 1 shows tsunami inundation models for the 1992 tsunami in Flores, Indonesia. For each model, all parameters are the same except for the elevation data, shown at the bottom of the figure. Model results are overlain with field observations of the actual tsunami inundation.[24] While LiDAR and airborne InSAR give inundation area extents comparable with historical data, results obtained using the globally freely available SRTM dataset, with lower vertical accuracy,[25] show negligible inundation.

From this study we see two things:

1. The most accurate and expensive data are not always needed, depending on the purpose. Airborne InSAR, which is an order of magnitude cheaper to acquire than LiDAR, may be suitable for tsunami evacuation planning.
2. SRTM and ASTER datasets, although freely available with near global coverage, should not be used for modeling onshore tsunami hazard, since the results can be dangerously misleading.

Similarly, other studies have demonstrated limitations in the application of SRTM to modeling floods[26] and mapping active faults.[27]

Solutions/Recommendations

High-resolution DEMs are fundamental to understanding natural hazards and risk. To move toward a next generation of globally freely available DEMs, strong partnerships among governments, scientific institutions, multilateral agencies, and the private sector are needed.

Two alternative strategies could be employed to achieve this goal:

1. *Stitching together a global patchwork of locally and regionally collected high-resolution datasets.* This would require agreements whereby institutions investing in elevation data agree to open access licensing. An online platform (a "Digital Elevation Data Marketplace") would be needed to make the data available through web services and for download.
2. *Investing in a uniform global DEM as a replacement for SRTM.* For example, next generation DEMs such WorldDEM,™ or others created using new technologies, could be made openly available through coinvestment from the global community.

Option 1 has the advantage of leveraging data collection efforts of a range of actors that will be prioritized to regions where project funding exists, meaning that collection of the data is more likely to be linked to disaster management activities. In addition, the highest resolution datasets can be collected through local-scale airborne surveys. The resolution and accuracy of the data will vary, however, making exact definition of their appropriate use difficult. Furthermore, if funding is limited, agencies may be unwilling to pay additional costs that may be required to purchase data with open access licensing, or, worse still, they may just continue to use the existing global DEMs.

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[22] K. Minoura, F. Imamura, D. Sugawara, Y. Kono, and T. Iwashita, "The 869 Jogan Tsunami Deposit and Recurrence Interval of Large-scale Tsunami on the Pacific Coast of Northeast Japan," *Journal of Natural Disaster Science* 23 (2001): 83–88.

[23] J. Griffin, H. Latief, W. Kongko, S. Harig, N. Horspool, R. Hanung, A. Rojali, N. Maher, A. Fuchs, J. Hossen, S. Upi, S. E. Dewanto, N. Rakowsky, and P. Cummins, "An Evaluation of Onshore Digital Elevation Models for Modeling Tsunami Inundation Zones," *Frontiers in Earth Science* 3 (2015).

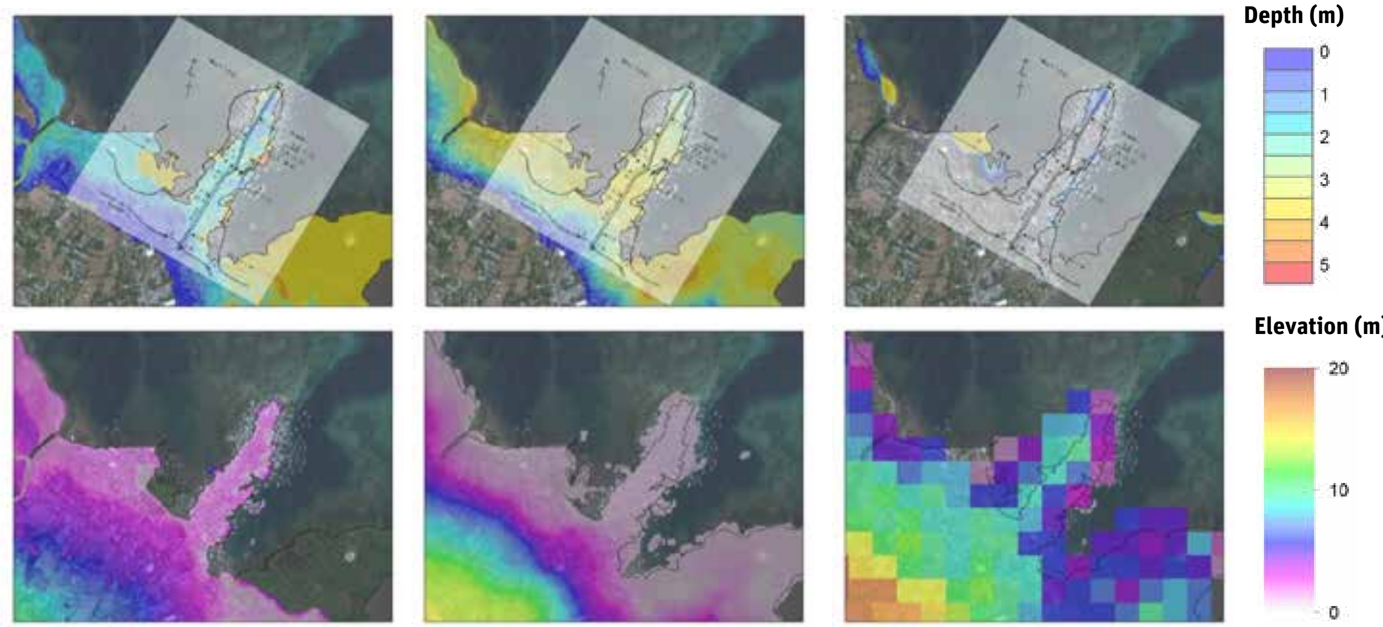
[24] The observation data are from Y. Tsuji, H. Matsutomi, F. Imamura, M. Takeo, Y. Kawata, M. Matsuyama, T. Takahashi, and P. Harjadi, "Damage to Coastal Villages due to the 1992 Flores Island Earthquake Tsunami," *Pure and Applied Geophysics* 144 (1995): 481–524.

[25] ASTER elevation data also significantly underestimate the wet area. See Griffin et al., "An Evaluation of Onshore Digital Elevation Models," for the full analysis.

[26] H. A. Gallegos, J. E. Schubert, and B. F. Sanders, "Two-dimensional, High-resolution Modeling of Urban Dam-break Flooding: A Case Study of Baldwin Hills, California," *Advances in Water Resources* 32 (2009): 1323–35.

[27] N. Horspool, D. H. Natawidjaja, E. Yulianto, S. Lawrie, and P. Cummins, An Assessment on the *Use of High Resolution Digital Elevation Models for Mapping Active Faults in Indonesia*, Record 2011/019, Geoscience Australia, Canberra, 2011.

FIGURE 1. Modeled inundation and underlying elevation data used in the model (Source: Griffin et al., *An Evaluation of Onshore Digital Elevation Models*)



Note: Top images show inundation estimates from the 1992 tsunami in Flores, Indonesia, with the arrow pointing to the black line showing the observed inundation limit. Bottom images show elevation data for LiDAR (left), airborne InSAR (middle), and SRTM (right).

Option 2 has the advantage of generating a uniform global dataset with known resolution and accuracy. Global coverage would provide data for regions that haven't been prioritized by governments and donors and allow direct scalability of models from global to regional to local scale. The cost of such a dataset may be less overall than that of Option 1, but it may be carried by fewer actors. Furthermore, whether next generation satellite technologies are producing DEMs sufficiently accurate to overcome the limitations of SRTM and ASTER remains to be seen.

Investing in high-resolution, high-accuracy global DEMs and making them freely available to the global community would have many benefits for society, including a better understanding of the earth processes that cause natural hazards and a better ability to model them. This would, in turn, lead to better-informed disaster management decision making.

Data Challenges and Solutions for Natural Hazard Risk Tools

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Natural hazard risk modeling tools produce information on the consequences of natural hazards by combining information on the spatial extent and intensity of the hazard, the infrastructure or population exposure to it, and the vulnerabilities of the exposed elements. The data needed to drive a risk tool vary according to the user's needs. Risk data are, therefore, multidisciplinary, bridging earth science, engineering, and social science, as well as incorporating the knowledge and experience of local experts.

For risk modeling to be useful, it needs to be done at a local scale, as the necessary data are often unique to the location both in terms of attributes and ownership. Risk modeling at the local level is inherently challenging, however. The diverse data required are conventionally owned by an equally diverse range of stakeholders, while those who are responsible for natural hazards management often have limited resources to acquire and use them. This dichotomy presents one of the biggest challenges in risk modeling and is in part why risk tools cannot be applied in many places around the globe.

The outputs from risk modeling tools are also very sensitive to the quality of the input data. Research has shown that, for earthquake risk models, uncertainty in the hazard input is the dominant source of uncertainty in the risk outputs.[28] Other sources are vulnerability models and exposure data.[29] So while use of the highest quality data is generally emphasized, effort should be focused on the datasets with the greatest influence on the quality of the risk tool outputs.

The building blocks of a risk model are the natural hazard models, information about what is exposed, the information on assets (such as buildings, roads, and people), and the vulnerability functions. The vulnerability functions provide the means of calculating the impact of a particular hazard on an asset. Data and information relating to these building blocks are essential to using a risk tool. Each is discussed in turn below.

Asset Data

The target scale of a risk tool is vital for planning the data requirements. For a model on the city scale, asset data requirements may be relatively manageable. For a national or international model, however, collecting and maintaining an asset database is a demanding task. In the scoping stage of RiskScape[30] (in 2005) in New Zealand, the project envisioned users supplying exposure data for the tool. By 2008, though, the project had found the target users (local and national government) were unable to use the tool because the country lacked a fundamental inventory of building assets.

The RiskScape program therefore undertook a multiyear initiative to develop a national building inventory with key attribute information per building for the entire country. This information was obtained from licensed national property valuation datasets, regional field surveys to build small statistical samples of building

[28] H. Crowley and J. J. Bommer, "Modeling Seismic Hazard in Earthquake Loss Assessment with Spatially Distributed Exposure," *Bulletin of Earthquake Engineering* 19 (2006): 249–73.

[29] D. J. De Bock and A. B. Liel, "Comparative Evaluation of Probabilistic Regional Seismic Loss Assessment Methods Using Scenario Case Studies," *Journal of Earthquake Engineering* 19 (2015): 905–37.

[30] J. Schmidt, I. Matcham, S. Reese, A. King, R. Bell, G. Smart, J. Cousins, W. Smith, and D. Heron, "Quantitative Multi-risk Analysis for Natural Hazards: A Framework for Multi-risk Modelling," *Natural Hazards* 58 (2011): 1169–92.

characteristics, and expert knowledge on construction methods and was then combined into a national building asset database. Other key asset data, such as lifelines, were collected from state-owned and private companies, subject to various levels of detail and data openness, while population asset data were taken from the New Zealand census.

This approach is a clear example of top-down data collection, supplemented with small field surveys. Recently, however, some local government authorities in New Zealand began collecting information on buildings and lifelines, and they are using these locally generated data for loss modeling.

Nonetheless, for any country, the ideal is to have both top-down and bottom-up approaches to exposure data collection to meet the needs of both national and subnational risk assessments.

Consequence and Loss Data

Consequence and loss data from disasters play an important role in developing vulnerability models, and they are used to calibrate and validate risk tools. However, the ways in which these data are collected, managed, and made available for further use are often uncoordinated. Global consequence and loss databases (for example, EM-DAT)[31] are available, but they lack the resolution needed for application at a national level. Many countries, New Zealand included, have no centralized loss database. Information exists on losses from natural disasters, but it resides in various institutions.

One great challenge is unlocking the vast amount of loss data held by private insurers. Detemining the economic consequences of natural disasters is a fundamental requirement of risk tools, yet the vulnerability models used to estimate direct economic loss are often based on very little data or on expert estimates of repair and replacement costs. A hopeful sign was the provision by government insurance schemes, such as New Zealand's Earthquake Commission (which insures residential dwellings up to NZ$100,000) of their loss and damage data from the recent Canterbury Earthquake Sequence to researchers to develop vulnerability models. Loss data for nonresidential buildings, however, have been locked up by private insurers, thus prohibiting the improvement of vulnerability models for those buildings using these data. More needs to be done to provide incentives to or impose regulations on private insurers to allow access to their loss data for developing vulnerability models or providing calibration data for risk tools.

Vulnerability Data

Lessons from past natural hazard events have highlighted the differing vulnerabilities of physical assets and people. Modeling the susceptibility of physical and social assets to losses is hampered by three major challenges.

First, the lack of consistent data constrains the ability to develop robust fragility functions. For instance, data on physical asset types (such as building materials and height) are not consistently categorized and collected on a scale most appropriate for modeling localized losses. Similarly, socioeconomic assets and attributes are limited to the data fields collected by the national census.

Second, the effects of temporal and spatial variability of different hazards on physical and social assets are currently not fully understood due to the lack of data from past events. Fragility functions based on empirical evidence from a limited number of hazard events create large uncertainties. This is particularly true for social vulnerability functions, as socioeconomic attributes affect human losses in different ways, given a distinct set of exposure and geographical parameters.[32]

Last, the limitation of existing risk models lies in the difficulties of accounting for other variables that affect losses but for which data are not systematically collected and analyzed. These variables include social behavioral attributes, including how people behave during a hazard event; factors relating to how they interact with their physical environment; other socioeconomic vulnerabilities, such as physical health and livelihoods; and factors that contribute to their adaptability.[33] These

[31] EM-DAT, International Disaster Database, http://www.emdat.be/ (accessed July 30, 2015).

[32] M. Ramirez and C. Peek-Asa, "Epidemiology of Traumatic Injuries from Earthquakes, Epidemiologic Reviews 27 (2005): 47–55.

[33] D. Alexander, "What Can We Do about Earthquakes? Towards a Systematic Approach to Seismic Risk Mitigation" (paper presented at

challenges provide significant opportunities for further research that will enhance the capability of risk models in predicting hazard losses.

Hazard Data

The collection and analysis of hazard data for risk tools incorporates hydrodynamic, meteorological, geological, and geophysical sciences. The separate evolution of these hazard sciences has led to variations in mapping and modeling, such as differences in data types, vulnerability function development, and even terminology, that add complexity to risk modeling tools, creating a major barrier for nontechnical end users.

One challenge in obtaining hazard data is that hazard models are often created by scientists who may or may not understand their use or applicability for risk tools. This often leads to hazard models and data that are not suitable for some risk tool applications due to inconsistencies in spatial resolution, the event(s) modeled, their annual probability of occurrence, or the hazard intensity metric used. End users, who often do not understand these complexities, may use inappropriate data for their modeling. Risk tools that integrate hazard models and data tailored for risk applications are, therefore, preferred.

An example of another challenge with regard to obtaining hazard data for risk tools concerns flood hazard data. In New Zealand and Australia, flood modeling is often commissioned by local governments and undertaken by consultants. Intellectual property (IP) conditions then make these data difficult to discover and be made accessible for applications beyond flood hazard mapping. Centralized databases exist that collate such information; one is the National Flood Inventory Database, created by Geoscience Australia. These need to be created for all hazard data, however, as similar challenges occur across perils.

Similar issues surround the fundamental spatial datasets required for many natural hazard models. Digital Elevation Models (DEMs), which are critical for flood, tsunami, storm surge, landslide, earthquake, and wind hazard modeling, exist in different resolutions and versions (for example “bare earth”; raw LiDAR; “built environment”). These are often difficult to track down and verify for scientific purposes, even though they exist in many regions. Issues around selling on such data or the cost of acquiring DEMs for risk applications hinder the widespread use of high-resolution DEMs in hazard and risk tools.

Data Standards

Data used by risk tools are provided in a multitude of proprietary or open source formats. Standards should be developed to facilitate a common format for data that feed into risk tools.[34] The Natural Hazard Markup Language used by the Global Earthquake Model (GEM) is one such example currently available. Such standards would allow the use of common datasets by many risk tools, as well as providing the opportunity to modularize risk tools on a common platform.

Recommendations

This brief review provides an insight into the diversity of data challenges for developing useful and used risk tools for natural hazards management. Many of these challenges can be overcome or avoided by considering the following:

- Risk tool users and their requirements should be defined, using a participatory process.
- Data requirements should then be mapped and gaps identified.
- Stakeholders should agree on lead agencies responsible for collecting and managing data, including maintaining the data in the long term, with financial resources provided for data collection and management.
- Users should be adequately trained to understand the data, their requirements, and uncertainties and included in the method design and practice for collecting them.

the New Zealand Society for Earthquake Engineering [NZSEE] Annual Technical Conference, Christchurch, New Zealand, April 13–15, 2012), http://www.nzsee.org.nz/db/2012/Paper001.pdf

[34] Integrated Research on Disaster Risk, *Guidelines on Measuring Losses from Disasters: Human and Economic Impact Indicators*, IRDR DATA Publication No. 2, 2015, http://www.irdrinternational.org/wp-content/uploads/2015/03/DATA-Project-Report-No.-2-WEB-7MB.pdf.

- Further research and analyzes should be conducted on the integration of socioeconomic vulnerabilities in predicting human and economic losses.
- A matrix of physical and socioeconomic vulnerability drivers should be created for each hazard type, as some drivers apply to certain hazards but not others.
- Centralized databases should be developed that provide information on the availability of hazard data and the fundamental spatial datasets required for hazard modeling.
- Standards should be developed to facilitate a common format for data that feed into risk tools.

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The Importance of Consistent and Global Open Data

Charles Huyck (ImageCat Inc.)

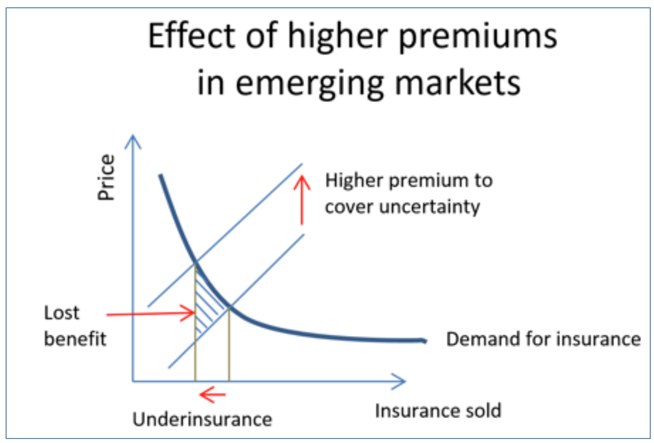
Nongovernmental organizations and governments are recognizing the importance of insurance penetration in developing countries to mitigating the tremendous setbacks that follow natural disasters. At the same time, the insurance industry is actively seeking ways to expand into these very emerging insurance markets, expecting them to be the primary source of growth in the coming decades. An assessment by the World Bank notes that reinsurance is available for developing countries "as long as their risk portfolio is properly structured and adequately priced."[35] In this essay, we examine the role of global exposure data in insuring emerging markets in developing countries.

The insurance industry is aggressively seeking methods to price these risks adequately, but developing countries lack the insurance infrastructure to provide the detailed location, occupancy, and structural attributes used by catastrophe ("cat") models to assess risk.

Without the proper exposure data, insurers, reinsurers, and brokers generally have two options:

1. **Underwrite business without an adequate understanding of the loss potential.** A poor understanding of exposure leads to inefficient distribution of risk among stakeholders, with many financial ramifications. If the risk is underestimated, too few insurers may cover a given catastrophic loss. To avoid this scenario, a hefty fee is added to premiums to cover the uncertainty. Higher prices, however, lead to insufficient insurance coverage in emerging markets. Figure 1 illustrates the economic impact of inefficient premiums.

FIGURE 1. **Uncertainty in risk estimates leads to higher pricing.**



2. **Decline to offer insurance products.** Many insurers and reinsurers will not offer products in challenging markets without dependable pricing instruments. Although the insurance industry forgoes profit on an estimated 1.5 billion to 3 billion policies,[36] the global impact is much greater. The World Bank estimates that, whereas up to 40 percent of direct catastrophe losses are covered by insurance in developed countries, less than 5 percent are covered in low-income ones.[37] The effects of underinsurance on the

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35 J. D. Cummins and O. Mahul, *Catastrophe Risk Financing in Developing Countries: Principles for Public Intervention*, World Bank, 2009, http://siteresources.worldbank.org/FINANCIALSECTOR/Resources/CATRISKbook.pdf.

36 Lloyd's and the Micro Insurance Centre, *Insurance in Developing Countries: Exploring Opportunities in Microinsurance*, Lloyd's 360º Risk Insight, 2010, http://www.lloyds.com/~/media/Lloyds/Reports/360/360%20Other/InsuranceInDevelopingCountries.pdf.

37 Cummins and Mahul, *Catastrophe Risk Financing in Developing Countries*.

ability of economies to rebound from disaster are devastating. Where governments and international relief organizations face conflicting demands and must prioritize providing for immediate life safety, shelter, substance, and infrastructure with limited resources, insurers have a stake in distributing funds rapidly to insured parties who are affected to avoid business interruption and hasten recovery.

Challenge

At a fundamental level, the impact from natural disasters depends on the spatial distribution and vulnerability of the exposed buildings and infrastructure relative to the hazard. Although spatial data describing the built environment have proliferated considerably over the past twenty years, very few are directly appropriate for analyzing risk reduction, unless expressly developed for these purposes. Cat models require data tabulating the number, square footage, and replacement costs of buildings, as well as their structural types, according to a specific vulnerability taxonomy, their occupancy or use, and a host of other attributes, depending on the hazard modeled.

Developing a building exposure database is typically a geographic information system (GIS) data fusion process, in which building-specific information from sources such as OpenStreetMap or local data is merged with regional data, and unknown values are replaced with bulk-coded default values based on what is known about a given country or region. This patchwork approach can lead to a skewed assessment of risk. Data are more detailed where concerted efforts have been made to collect them, and risk studies will generally indicate the presence of more damage where more data have been collected.

Consider a hypothetical scenario where two neighboring countries have an earthquake on their border. The loss estimate for country 1, which lacks a detailed exposure database, is US$1 billion, while for country 2, which has just completed an extensive building survey, it is $2 billion. Is one to conclude country 2 has twice as much damage as country 1, or that the building inventory for it was twice as detailed? Typically, no independent data source exists for end users to evaluate the completeness of the data or the basis of the building inventory assumptions that have gone into the loss estimation, because if other datasets were readily available, they would be included in the data fusion process. The data available lack spatial and attribute consistency, which skews loss estimates and results in inaccurate assessments of risk. Thus, exposure datasets are a source of great uncertainty in loss estimates, particularly in developing economies.

Solutions and recommendations

A consistent and objective building-exposure database derived from GIS, local observations, and remotely sensed data can increase the accuracy of loss estimates and the efficacy of decisions they support if the methods and accuracy are clear to end users. Rather than developing exposure by directly merging the most detailed datasets, a tiered approach to characterizing the built environment systematically offers the benefit of creating consistent data. ImageCat and the Center for International Earth Science Information Network at Columbia University (CIESIN) have developed a methodology using demographic and moderate-resolution satellite data to yield more accurate global exposure databases than are typically available without ground surveys. The method utilizes global CIESIN population, demographic, and remote sensing data to establish regions with similar development patterns. These regions are then combined with a nationwide assessment of construction practices to yield a "Level 1" estimate of building exposure (table 1).[38]

In addition, the ImageCat/CIESEN method merges "top-down" (remote sensing) and "bottom-up" (site survey) approaches, developed using the GEM Foundation's IDCTs (Inventory Data Capture Tools; see figure 2), by allowing users to integrate survey data where warranted ("Level 2").[39] Central to the creation of exposure data from remotely sensed imagery and/or survey data is

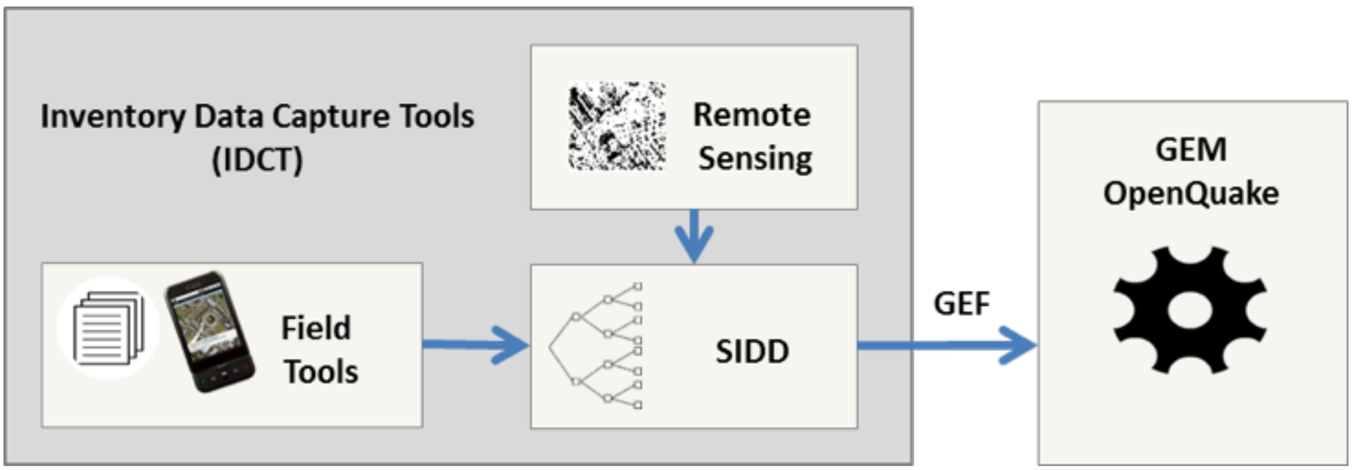
38 C. K. Huyck, G. Esquivias, P. Gamba, M. Hussain, O. Odhiambo, K. Jaiswal, R. Chen, G. Yetman, *D2.2 Preliminary Survey of Available Input Databases for GED: Report Produced in the Context of the Global Exposure Databases for the Global Earthquake Model (GED4GEM)*, 2011, http://www.nexus.globalquakemodel.org/ged4gem/posts/ged4gem-deliverable-d2.2-survey-of-available-input-databases-for-ged.

39 J. Bevington, R. Eguchi, C. Huyck, H. Crowley, F. Dell'Acqua, G. Iannelli, C. Jordan, J. Morley, M. Wieland, S. Parolai, M. Pittore, K. Porter, K. Saito, P. Sarabandi, A. Wright, and M. Wyss, "Exposure Data Development for the Global Earthquake Model: Inventory Data Capture Tools," in *Proceedings of the 15th World Conference on Earthquake Engineering* (Lisbon, September 24–28, 2012).

TABLE 1. **Examples of a Tiered System for the General Building Stock**

	Level I	Level II	Level III
General building stock	› Mapping schemes based on literature review and satellite/ground imagery › Default land classes › 30 arc second resolution	› Custom land classes by country › Extensive adjustment, given local experts › Extensive adjustment of land class detection, given local anomalies › 15 arc second resolution	› Onsite review › Adjustment of mapping schemes, given local sampling (IDCT) › Region-specific mapping schemes › Statistical characterization of detailed structure types › Integration of high-resolution data or digitizing for land classification

FIGURE 2. **The inventory data capture tools (IDCT) allow users to merge remote sensing and sampled survey data to develop a GEM OpenQuake–compliant dataset. The tools were developed for GEM by ImageCat, the British Geological Survey (BGS), and Nottingham University.**



the application of the Spatial Inventory Data Developer (SIDD).[40] SIDD is an exposure data creation workbench, where engineers and planners can link development patterns to building practices in an easy-to-use interface. The data are run through a Monte Carlo analysis to create a GEM-compliant exposure database.

The "top-down, bottom-up" approach to exposure development provides a flexible mechanism for incorporating additional data without skewing hazard results to areas where more detail is available. If a considerable amount of building footprint data is available for a given locality, for example, these data are used to characterize average building size, number of buildings per person, or square footage per person throughout the country or region, rather than being incorporated directly. Likewise, if key buildings or facilities are directly inventoried, the remaining features must be spread statistically so the risk is not skewed to represent only known facilities. Additional data must be incorporated through methods that are transparent and well documented. Table 1 (above) provides a basis for a formal development process for building exposure that can accommodate multiple levels of data consistently.

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[40] Z. Hu, C. K. Huyck, M. Eguchi, and J. Bevington, *SIDD User Manual*, Version 1.0, June 2013, GEM Inventory Data Capture Tools Risk Global Component, http://www.nexus.globalquakemodel.org/IDCT/posts/

SOLVING THE PUZZLE

Innovating to Reduce Risk

WRITTEN CONTRIBUTIONS

Capacity Building

Australia-Indonesia Government-to-Government Risk Assessment Capacity Building

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The Australian government has invested in a variety of disaster risk management (DRM) activities, including efforts to strengthen the capacity of partner government technical agencies to map risks from natural hazards. The aid program draws on the technical expertise of Australian government departments to help developing country partners build their capacity to reduce disaster risk.

The national agency Geoscience Australia provides geoscientific advice and information to support government priorities. For fifteen years, GA has engaged in disaster mitigation and preparedness, accumulating important research, tools, and experience in efforts to mitigate and prepare for the risks to Australian communities from earthquakes, tsunamis, severe wind, floods, and volcanoes. This work has included the development of open source software that can be used in the quantitative modeling of these hazards and risks. For the past six years, as part of the Australian aid program, GA has been actively applying its tools and experience to capacity-building activities with partner technical agencies in the Asia-Pacific region.

The Australia-Indonesia Facility for Disaster Reduction (AIFDR) represents a key bilateral commitment to reducing the impact of disasters and is a key part of Australia's development program in Indonesia. The risk and vulnerability (R&V) work stream of the AIFDR facilitates partnerships between Australian and Indonesian scientists to develop and demonstrate risk assessment methods, tools, and information for a range of natural hazards, helping to build Indonesia's risk modeling capacity by providing leadership for the R&V program.

A primary activity undertaken by the R&V stream since 2009 is the Indonesian Earthquake Hazard Project (IEHP), whose particular focus is building the risk modeling capacity of Indonesian technical agencies. The IEHP aims to build the capacity of the Indonesian government to understand the country's earthquake hazard, including the likely location, size, and frequency of earthquakes. By the end of the project, the Indonesian government will have a revised national earthquake hazard map for the country, designed for use within its building codes as well as for more general risk assessment. Government technical agencies will also have the capacity to maintain and update this map in the future, as well as the ability to produce real-time maps of earthquake shaking and impact forecasts to inform emergency earthquake response.

Another key output developed through AIFDR has been InaSAFE, an open source disaster impact modeling tool. Launched in 2012, InaSAFE is designed to help overcome obstacles to understanding and using impact information in disaster management decision making. Developed by the Australian and Indonesian governments in collaboration with the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR), InaSAFE enables communities, local governments, and disaster managers to generate realistic natural hazard impact scenarios for floods, earthquakes, volcanoes, tsunamis, and other hazards to underpin emergency planning, disaster preparedness, and response activities.

The following describes some of the challenges that have emerged in the course of capacity-building activities undertaken by Geoscience Australia through the R&V program in the AIFDR and details some of the strategies it has used to ensure successful outcomes.

Challenges

A key challenge in capacity-building activities is ensuring personal or institutional agendas are not forced upon the recipients. It is poor practice for donors to arrive with a predisposed "solution" to a perceived problem without sufficient consultation with stakeholders. This can easily be compounded by cultural differences that inevitably make rapid engagement and changes in established processes damaging for both partners.

In addition, by its very nature, strengthening the capacity of government technical agencies requires the intensive training and mentoring of small numbers of scientists by counterparts with specialist expertise. Gaining an understanding of the theory and methods for hazard and risk modeling is complex and time consuming, and they cannot be taught to large groups in a classroom environment. Consequently, this type of capacity building leads to multiple single points of failure within a system that has relatively few highly trained scientists.

Equally, in an institutional setting where the mandated functions of separate agencies overlap to some degree, skills may be duplicated among scientists from the different agencies. This leads to attempts by these agencies to develop similar but different hazard and risk products, which can result in confusion among stakeholders as to which is the most appropriate to use in decision making.

Solution/recommendations

Two broad factors have led to successful capacity building in Geoscience Australia's partnership with the Indonesian government: the presence of trust and the use of a catalytic approach.

Trust is an important foundation for working relationships among technical experts, and it develops for a variety of reasons:

- *Experts' knowledge and skill make them credible.* Technical experts' ability to communicate with and speak the same technical language as recipient partners is a crucial first step in building credibility, which in turn is the basis for developing relationships of trust.
- *Government scientists have shared experience.* The common understanding by scientists of government operations and the science-to-policy cycle can solidify foundations of trust built on scientific expertise.
- *Government-to-government relationships are institutional and national.* Because of their nature, G2G relationships can be an effective basis for long-term cooperation. Moreover, scientific exchanges between government officials include a dimension of diplomacy that ensures professional, respectful, and ethical interactions.
- *Personal agendas are absent.* Officials working solely to a government mandate (like those in GA) are less likely to push a personal agenda. In this environment, experts feel less pressure to seek high profiles or to publish project findings under their own names, and they are more willing to maintain a supportive role in the background.

The catalytic approach exemplified in the G2G projects described above focuses not on replacing or displacing capacity, but on building or strengthening it. A critical first step is for the agencies within which capacity is being developed to identify their own capacity gaps. Once these gaps are known, it becomes possible to showcase the potential impact of science in addressing them, without taking on a structural role or starting work that, in the long run, should be done by the recipient agency. The initial steps should always involve gaining an understanding of how the existing system works or should work, so capacity-building efforts can focus on realizing or strengthening this system.

To overcome the challenges of single points of failure and agency overlap, capacity building should take place within a framework of proper institutional governance. This ensures capacity is built within the system rather than in a series of individual officers and agencies. This is exemplified by the IEHP, for which the major deliverables were produced collaboratively with five key Indonesian agencies: the National Disaster Management Agency (BNPB); Badan Geologi (BG; the Geological Agency of Indonesia); Badan Meteorologi, Klimatologi, dan Geofisika (Indonesian Agency for Meteorology, Climatology, and Geophysics); Lembaga Ilmu Pengetahuan Indonesia (Indonesian

Institute of Sciences); and Institut Teknologi Bandung (Bandung Institute of Technology). To establish effective institutional governance, a memorandum of understanding was developed among these agencies, which marked the first formal agreement on roles and responsibilities for earthquake hazard work in Indonesia.

Another key element that can contribute to sustainable systemic capacity building is the development of simple tools that can be used to analyze risk information from "upstream" technical agencies in a way that is useful and usable for "downstream" decision makers. For example, InaSAFE provides a pathway for the products produced by the IEHP to be used by disaster managers. Earthquake hazard maps produced through the G2G partnership can be integrated with exposure data collected through participatory methods, such as OpenStreetMap, to help disaster managers prepare for earthquakes. InaSAFE can deal with different types of hazards and different types of data. For example, flood hazard inputs can be the result of a hydrodynamic model or obtained from participatory mapping of past flood zones. This unique ability to integrate the best of both scientific and locally collected data to inform decision making has made InaSAFE a valuable link between the capacity-building work in science undertaken by GA and other DRM investments in Indonesia.

Required Capacities to Improve the Production of, Access to, and Use of Risk Information in Disaster Risk Management

Sahar Safaie (UNISDR)

Disaster risk management (DRM) encompasses a wide variety of strategies and activities.[1] These include avoiding the creation of new risk, reducing existing risks, exploring mechanisms to share or transfer risk, and managing residual risk through effective preparation to respond to and recover from disasters. To be relevant and effective, all such strategies and activities require information and an understanding of the disaster risk in the region of concern. The availability of targeted and authoritative hazard and risk information enhances the ability of decision makers at all levels and from all sectors to develop and implement policies and make decisions that reduce disaster risks.

The Sendai Framework for Disaster Risk Reduction (2015–30), adopted at the Third UN World Conference in Sendai, Japan, on March 18, 2015, strongly emphasizes the increased availability and use of information in risk reduction policy and planning. This is clearly outlined under "understanding disaster risk," the first priority for action set out in the framework. Despite advances made in science and technology and in modeling risk under the Hyogo Framework for Action (HFA, forerunner of the Sendai Framework), significant challenges remain in developing and communicating risk information that enables decision makers actually to make better decisions. These challenges arise from a complex interplay of issues, including a shortage of capacities required at various stages of the risk information life cycle: from production by experts to application by end users. Other identified challenges are associated with a number of factors:[2]

- Political will and leadership
- Authority and credibility of the risk information
- Adoption of the risk knowledge by decision makers
- Competition for limited resources to implement solutions
- Communication of risk results in the right formats for different decision makers

The following overview summarizes the capacities required for the production, preparation, and use of risk information and access to it to improve its application in DRM decision making, with recommendations for building these capacities, especially in developing countries.

Three categories of capacities required in risk information life cycle

The capacities required at the various stages of the risk information life cycle fall into three categories: technical development, technical analysis, and understanding risk results.

Technical development capacity comprises the expertise and skills necessary for developing hazard and risk assessment, including the collection and preparation of data, the modeling of each component, and the production of results in an understandable and useful format. Conducting a complete hazard and risk assessment normally calls for a team of highly

[1] The information and views set out in this paper are those of the author and do not necessarily reflect the official opinion of UNISDR. Reproduction is authorized provided the source is acknowledged.

[2] World Conference for Disaster Risk Reduction (WCDRR) Proceedings, Risk Assessment and Identification Issue Brief, March 2015.

qualified individuals who have the expertise to develop such components as the modeling of various hazards, exposure modeling, vulnerability of various types of assets, and risk modeling. Individuals in a team must have the technical development capacity to conduct hazard or risk assessment on any scale or at any level. They may also have one or both of the other two types of capacities outlined below.

Extensive training is required to gain these skills. They can be acquired through graduate university programs focused on specific hazards or components of risk modeling, followed by training on the job. Alternatively, individuals with the relevant scientific or engineering backgrounds can gain the necessary technical development capacity from a few years of training-by-doing under the supervision of modeling experts.

The past decade has brought a considerable increase in the number of university programs that include modeling of various hazards and, to some extent, vulnerability and risk modeling in their curricula. But most of these programs are at universities in Europe or the United States.[3] Those that cover probabilistic modeling mostly have close links to one or another of the risk modeling initiatives in the public arena and are limited in number and the hazards they cover. Furthermore, no graduate program is solely dedicated to hazard or risk modeling at present.

Technical analysis capacity includes the skills to access the available datasets and models for hazard and risk results, run the relevant software to reproduce results using updated input data, and interpret and prepare the results in a clear and relevant format for DRM decision making. It calls for an in-depth understanding of approaches to hazard and risk modeling, its limitations, and uncertainties in the results—knowledge that is required for running sensitivity analyses, in which the researcher needs to change certain parameters with a full understanding of the impact of and rationale behind each set of parameters. Preparation of results in an understandable and usable format is a key skill in this category.

Individuals or teams who are supporting decision makers in the public or private sector must have the capacity for technical analysis. They prepare risk result reports that may include diagnosis of underlying factors from exposure, hazard, or vulnerability; briefings on limitations in the methodology and use of results; and sensitivity analysis. Depending on the field of work, and in close communication with disaster risk management experts, technical analysis experts may also do further research on cost-effective DRM activities.

Private risk modeling companies offer courses relevant to technical analysis capacity to their clients, mostly in the insurance industry. While a few public institutions have offered elements of technical analysis in capacity-building workshops as parts of various projects, at present no organized curriculum or certified program exists for building technical analysis capacity in the public arena.

Understanding risk results capacity includes understanding many aspects of the hazard and risk assessment process and results:

- The limitations and uncertainties of the process
- Fundamental concepts, such as probability, return period, risk layers in loss exceedance curve, and the use of hazard and risk maps
- The influence on results of underlying factors, such as hazard levels, assets concentration and values, vulnerability levels of various construction types, and so on
- The relevance of all such information to the questions and problems of concern for reducing the risk

Understanding risk results is especially important for decision makers in various fields of disaster risk management in both the public and private sectors. Although they receive support from individuals or teams of technical experts who provide and explain results to them, understanding the disaster risk results themselves is critical for absorbing the information, maintaining effective communication with the technical teams, and making the best possible decisions based on the available information.

As with technical analysis capacity, organized programs

3 Such programs are available at UME School, Italy; University College London, UK; Bogazici University, Turkey; ETH, Switzerland; University of Maryland, USA; Stanford University, USA; MIT, USA; and Universiteit Utrecht and VU University Amsterdam, Netherlands, to name a few.

and curricula for understanding risk results are rare and ad hoc. The subject is covered in a few relevant university programs, and elements are included in some capacity-building workshops in various risk assessment projects run by public institutions. In most cases, however, these workshops do not necessarily identify the most relevant decision makers to include among the participants, nor do they cover all the concepts relevant to the matters at hand.

Table 1 outlines the three categories of capacities required in the life cycle of risk information, from its production to its application in decision making. Depending on the role of the individuals and the objective, more than one set of capacities may be required.

Improving capacity-building programs

Thanks to the efforts of various technical and development institutions, as well as the guidance provided by the Sendai Framework, awareness of the importance of using risk information in policy and planning for disaster risk reduction at all levels is on the rise. The result has been increased demand for risk information and, in turn, for the capacity needed to develop and communicate it. The recommendations below for creating new capacity-building programs or expanding existing ones in each category of capacities take into account the current status of these programs and future needs. Many institutions at various levels are active in the risk information field, and leadership from international ones, such as the Global Facility for Disaster Reduction and Recovery (GFDRR), the United Nations Educational Scientific and Cultural Organization (UNESCO), and the United Nations International Strategy for Disaster Reduction (UNISDR), with their strong networks in the education sector as well as in the science and technology community, can contribute significantly to a more organized and harmonious approach to the effort.

Technical development. University programs focused on various hazards and types of risk modeling are needed to provide the extensive education and training required for building technical development capacity in this field. Fulfilling this need is best approached by encouraging institutions to set up programs relevant to hazards in each region of the globe, with appropriate financial and admission modalities to absorb students from the countries across the region.

In addition, the bilateral training-by-doing programs, in which technical institutions in developed countries are paired with ones in developing countries, need to be expanded. In risk assessment projects whose objectives include building technical development capacity, the outcomes of training-by-doing programs can be invaluable. The sustainability of these programs will depend on the careful selection of the recipient institution, which must be a technical public entity with an established, long-term mandate to conduct hazard and

TABLE 1: Categories of Capacities Required for Improving and Expanding the Practice of Risk Information Use in DRM Decision Making

Capacity	Description	Level of Effort (time)	Relevant Entities
Technical development	To conduct hazard and risk assessment	Extensive (a few years)	Technical public or private institutions conducting hazard and risk assessment
Technical analysis	To access available datasets and models, use modeling tools for further analysis, and prepare risk reports for decision makers	High (a few weeks to months)	Technical individuals or teams supporting decision makers or conducting relevant research
Understanding risk results	To understand the results and their limitations and uncertainties and use the results in planning and decision making	Moderate (a few days to weeks)	Decision makers in disaster risk management

risk assessment at the national level. A mechanism, such as a web-based portal, for the sharing of experiences on process and outcomes, as well as documents including project plans and terms of references, could facilitate expansion of such programs in various regions.

Technical analysis. The capacity for technical analysis can be strengthened, first, by developing a set of guidelines for creating the content of workshops run by technical and international institutions in developing countries as part of risk assessment projects or independently. The guidelines should include standards for the preparation of assessment results and be openly available on the platform. Second, certified programs should be set up that can be conducted online, in person, or with some combination of the two, to be run by qualified and certified experts. This would allow recognition of individuals with greater expertise on whom decision makers can rely for risk information and explanations.

Unfortunately, the cost and effort required to develop such programs have so far put them beyond the budgets and mandates of the public risk modeling entities. A potential alternative resource is the experience of private risk modeling companies engaged in training and capacity building in the insurance industry, although input from DRM experts would be needed to develop training materials and programs focused specifically on disaster risk management.

Understanding risk results. Capacity in understanding risk results can be obtained with moderate effort from educational modules presented in person or online. Although preparation of the content for such short courses is not very costly, no such organized comprehensive and accessible set of materials is presently available. An important element that should be included in the training materials is the interpretation of results for purposes of disaster risk management decision making.

Also recommended is the creation of a certified program to train risk assessment “product managers” in disaster risk reduction—that is, experts with combined capacity in technical analysis and in understanding risk results for use in disaster risk management. These individuals can act as risk assessment project leaders and/or advisors to decision makers for initiating, designing, and utilizing hazard and risk assessments for DRM decision making in different countries.

Concluding notes

Credible and understandable risk information is needed to design any policy or activity for reducing disaster risk. Significant progress has been made in the past decade in the production of hazard and risk information at various levels, but the adoption and use of such information in disaster risk management decision making is still a rare practice, even in developed countries.

Each of the three categories of capacities—technical development, technical analysis, and understanding risk results—requires different levels of effort and training that are customized to the objectives of the trainees. Leadership from international entities active in the risk assessment field and creation of a central, open, web-based platform could provide critical support for creating or scaling up existing capacity-building programs, including university graduate programs, training-by-doing programs, and in-person or online workshops and webinars. Such a platform would also be valuable for facilitating the use of risk information in DRM decision making by giving access or guiding trained individuals to credible hazard and risk datasets and models.

Understanding Assumptions, Limitations, and Results of Fully Probabilistic Risk Assessment Frameworks

Mario A. Salgado-Gálvez (CIMNE-International Centre for Numerical Methods in Engineering)

Fully probabilistic risk assessments are not trivial affairs, since they require a multidisciplinary environment and an understanding of different stages and of input and output data, in addition to prior knowledge about the data requirements and underlying methodologies for them, which can be generally classified under hazard, exposure, vulnerability, and loss categories. "Fully probabilistic" refers to any risk assessment framework that accounts, in a rigorous manner, for the uncertainties that exist at different stages of analyses, such as those that exist in the side of hazard (both spatially and temporally)[4] and vulnerability (in any of its dimensions). Also, fully probabilistic assessments produce results in terms of metrics such as loss exceedance curves (see figure 1), from which other metrics such as the average annual loss (AAL), the probable maximum loss (PML), and the loss exceedance probabilities for different exposure time frames can be obtained.

The discussion below, which is based on a recent review of available open source tools, attempts to explain, with typical examples, the importance of investing in capacity building in probabilistic risk assessment methodologies and frameworks to do the following:

- Widely incorporate results obtained from those assessments into feasible and comprehensive disaster risk management (DRM) schemes
- Increase the number of potential users at the technical and executive levels
- Ensure a correct understanding of the results by stakeholders and decision makers
- Support new capacity building processes which incorporate the lessons from successful ones

According to a recent study developed by the Global Facility for Disaster Reduction and Recovery (GFDRR),[5] over eighty open access software packages are available for quantifying risks posed by natural hazards, along with a wide range of methodologies and state-of-the-art options from which users can choose. All comply with most of the general and particular needs of the DRM field and allow users to address a wide variety of risk dimensions.

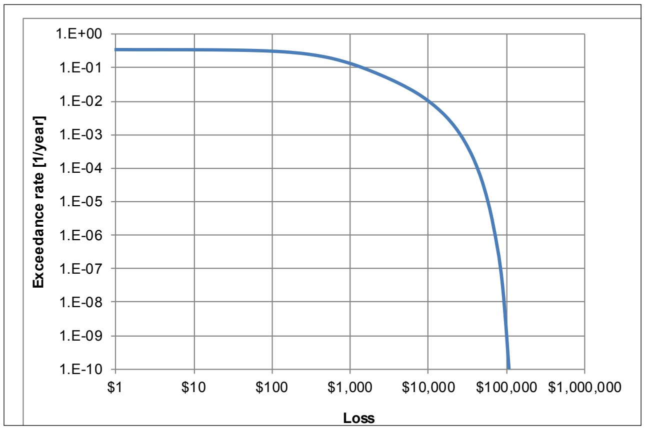
The present scoping report discusses, as one of three possible options, investment in a new open platform for risk modeling, along with capacity building. Consideration by itself of such a platform ignores and fails to recognize the lack of understanding on the side of stakeholders and decision makers of the scope, limitations, and assumptions of the fully probabilistic risk assessment frameworks that already exist. This lack of understanding is the root of the obstacles to integrating the tools within comprehensive DRM schemes, and reducing that knowledge gap should be the priority; the relevance of this issue is evident in places where several risk assessments have been performed (at different resolution levels, with different tools and at different times), but concrete DRM actions beyond the risk identification never materialized.[6]

4 Julian J. Bommer, "Uncertainty about the Uncertainty in Seismic Hazard Analysis," *Engineering Geology* 70 (2003): 165–68.

5 Global Facility for Disaster Risk Reduction, *Review of Open Source and Open Access Software Packages Available to Quantify Risk from Natural Hazards* (Washington, DC: World Bank, 2014).

6 Omar D. Cardona, *La gestión financiera del riesgo de desastres. Instrumentos financieros de retención y transferencia para la Comunidad Andina* (Lima: PREDECAN, 2009).

FIGURE 1. Schematic LEC



Source: Author's calculations.

Concepts like mean return periods, mean damage rations, exceedance probabilities, AALs, and PMLs are not trivial, and understanding them properly requires a complete explanation, along with guidance that goes beyond academic papers and methodological technical reports. All these concepts can be misleading, and if understanding of the frameworks is lacking, the available tools may be erroneously blamed for any problems and classified as incomplete and/or unsuitable.[7][8] It is not easy for a non-expert to understand, without a detailed explanation, that a loss with a 10 percent probability of exceedance in the next 50 years has a mean return period of 475 years, which does not mean that it occurs every 475 years but accounts for its inter-arrival time or also why AAL's can be obtained from hazard maps with different mean return periods but PML's cannot and require an event-based hazard representation.

Also, we need to distinguish having a complete understanding of the underlying methodologies from simply using the risk assessment tools.[9] Although they are related, good practice follows a one-way road, where good use of the tools can only be achieved with a complete understanding of their assumptions, scope, and limitations. Knowledge of how to use tools in terms of which buttons to press but not in terms of the relevance and quality of the input data holds the potential for bad results, misinterpretation, and other problems that may undermine the credibility of the tools used, even if the methodologies incorporated in their creation are good.

Building capacity to obtain all the necessary knowledge must occur at different levels on the demand side, where the capacity building can take a different form than that targeted to technical experts—that is, those who are expected to perform the operational work with the tools. They need to be provided with a complete understanding of the whole framework, especially those issues related to the scope and limitations of the analyses (hazard, exposure, vulnerability, and loss assessment), as well as a comprehensive explanation of the existing uncertainties in terms of what they are, how they are treated, and how they can affect the final results.

The second level of capacity building is the executive one, where the stakeholders and decision makers usually are situated; they need to understand the need for probabilistic approaches, the advantages they provide compared with risk classifications that solely use historical data, and, most important, how to interpret and communicate the results (that is, how to differentiate between absolute and relative losses) to ensure DRM activities related to risk reduction, retention, and transference can happen. An example of the importance of learning to interpret the results is the question of how to read an AAL map at urban level, such as the one shown in figure 2 for Medellín, Colombia, when it is derived from a fully probabilistic risk assessment. The high resolution of the exposure datasets may mislead some users regarding accuracy in terms of location or with respect to the validity of reading the losses for only one building while ignoring others within the complete exposure database. Such mistakes are not obvious and require explanation.

Several capacity-building exercises on probabilistic risk assessment have been carried out and sponsored worldwide by different institutions, like the World

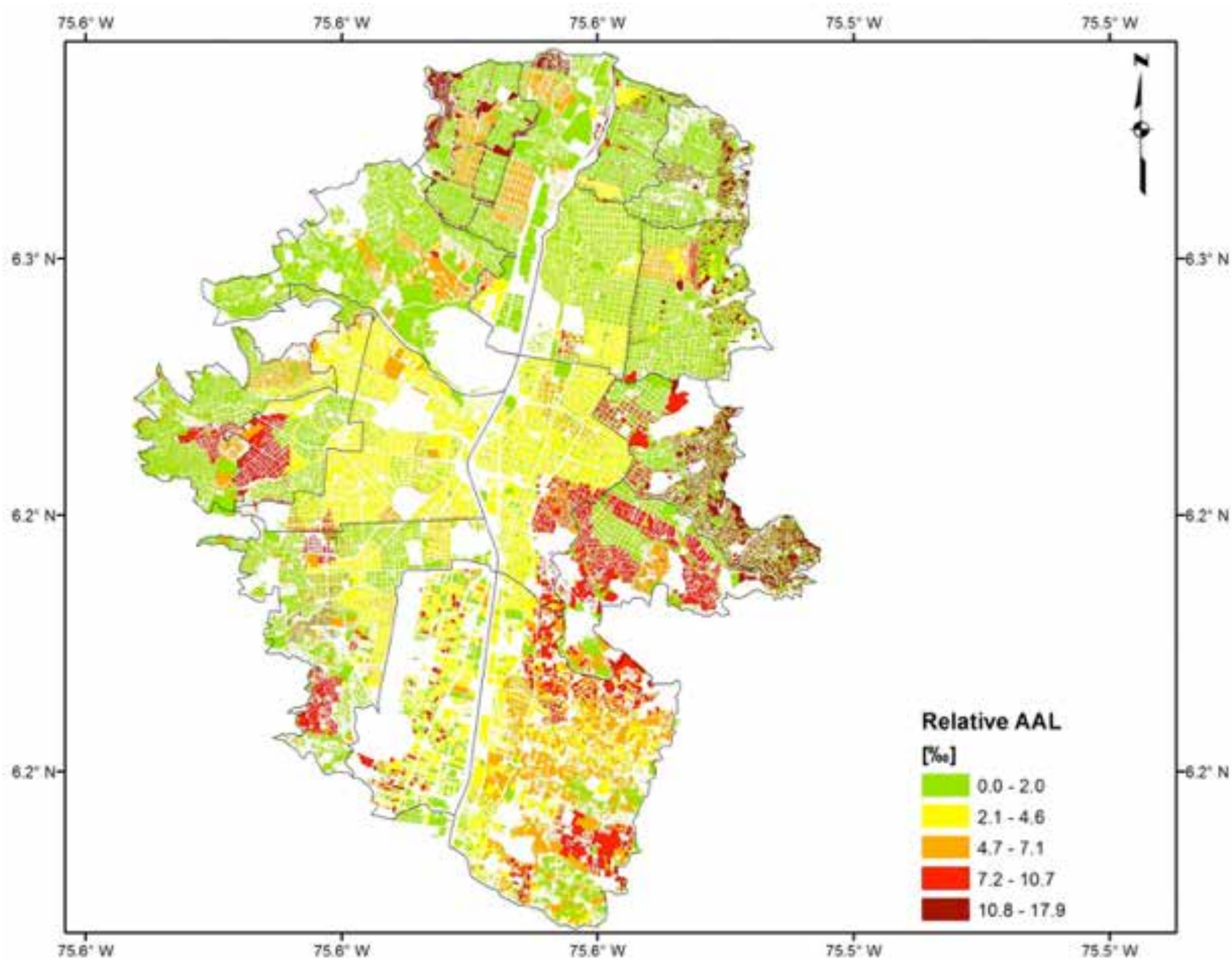
7 Helen Crowley, Peter J. Stafford, and Julian J. Bommer, "Can Earthquake Loss Models Be Validated Using Field Observations?" *Journal of Earthquake Engineering* 12 (2008): 1078–1104.

8 Mario A. Salgado-Gálvez, Alex H. Barbat, Martha L. Carreño, and Omar D. Cardona, "Real Losses Compared with Modelled Ones Using Probabilistic Approaches: The Lorca 2011 Case" (paper presented at the SECED 2015 Conference: Earthquake Risk and Engineering towards a Resilient World, Cambridge, United Kingdom, July 9–10).

9 Global Facility for Disaster Risk Reduction, *Understanding Risk: The Evolution of Disaster Risk Assessment* (Washington, DC: World Bank, 2014).

FIGURE 2. **Earthquake relative AAL map for Medellín, Colombia**

Source: Mario A. Salgado-Gálvez, Daniela Zuloaga-Romero, Gabriel A. Bernal, Miguel G. Mora, and Omar D. Cardona, "Fully Probabilistic Seismic Risk Assessment Considering Local Site Effects for the Portfolio of Buildings in Medellín, Colombia," Bulletin of Earthquake Engineering 12 (2014): 671–95.



Bank[10][11] and the United Nations Office for Disaster Risk Reduction (UNISDR),[12] with varying levels of success. In some cases, the continuity of the personnel enrolled in the participating institutions during not only the capacity-building process but in the medium to long terms proved more important than their initial technical knowledge in guaranteeing the sustainability of the process. Also, the selection of the participating institutions served as a basis for identifying and/or consolidating focal points where disaster risk data are to be stored at the national level.

These capacity-building exercises used a learning-by-doing approach, in which local probabilistic risk assessments were conducted using local data. Besides improving previous hazard, exposure, vulnerability, or risk models (where they existed), this approach encouraged the users to make their best efforts, since in many cases they had gathered the input data themselves in previous

10 Ministerio de Vivienda y Ordenamiento Territorial, Universidad de Panamá, Ministerio de Educación, Ministerio de Salid, Banco Mundial, Consorcio ERN-AL, *Modelación probabilista del riesgo sísmico para la Ciudad de David, Panamá*, Panama City, 2012.

11 Celina Kattan, L. Menijvar, R. Castellanos, J. Ramos, N. Ayala, and P. Méndez, *Modelación probabilista de escenarios de riesgo sísmico para el Área Metropolitana de San Salvador*, San Salvador, 2012.

12 United Nations Office for Disaster Risk Reduction, *Review of South-West Indian Ocean Region*, Working Papers on Public Investment Planning and Financing Strategy for Disaster Risk Reduction, Geneva, 2015.

work at their institutions. In addition to the hands-on sessions on the use of the tools, methodological lessons were developed for ample interactive and participatory sessions, complemented by remote assistance for at least the length of the project, which was usually between six and nine months. This proved more effective than merely using hypothetical and academic examples, which, although useful for a first approach to the tools, do not guarantee a proper replication process when other datasets are developed or used.

In terms of increasing the number of potential users of the existing tools, what is needed is enhancement of the tools, especially with regard to language-related issues. Some tools were developed under special conditions, and their modules' being in languages other than English hinders for many the use of the programs, as well as the accompanying manuals, tutorials, and user guides. Investment should be made in the short to medium terms in the translation of software tools and manuals that are not in English but rank well in the GFDRR review of open platforms; this would be relatively easy to achieve and would have a wide impact on the DRM community.

In summary, future investment should be in capacity-building processes, with the objective of providing a complete explanation to all participants of the underlying methodologies of fully probabilistic risk assessment frameworks without necessarily aiming to create a new group of expert modelers in a short time (although this may happen if some participants have prior knowledge of earth sciences, natural hazards, civil engineering, and probability and statistics, among other fields). Achieving this will open doors in different regions for use of the plethora of available tools, and the desired integration of outputs and formatting can be more easily reached. It will also increase the opportunity to integrate the results obtained with those tools into DRM activities, addressing the criticism that has arisen in many places where risk assessment studies have been developed and made available, but no real actions at any of the DRM stages have been derived from them.

Building Capacity to Use Risk Information Routinely in Decision Making across Scales

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Dominic Kniveton (University of Sussex)

Strengthening preparedness requires individuals and institutions to embrace the use of risk information in decision making. Risk information can benefit society only if it is relevant, accessible, and effectively used. Its uptake is not, however, a purely technological matter of how "accurate" it is and how easy to use; rather, it requires changes in the way scientists and decision makers interact. In particular, it requires the coproduction of knowledge and social learning.

Central to this interaction is how uncertainty is treated. Clearly, decision making under conditions of uncertainty opens the possibility of taking unnecessary actions when the potential hazard fails to materialize or failing to act when an unexpected hazard occurs. Decision makers need to be able to justify their decisions, and this, in turn, raises issues of accountability and consistency in acting on risk information.

The following, which is based on work carried out by the Adaptation Consortium in Kenya[13] and a number of complementary initiatives, outlines some practical steps for initiating and sustaining the processes of coproduction required to develop and support the use of risk information relevant to decision making.

Step 1: Establishing a common ground

Efforts to strengthen resilience in the face of risk involves bringing together groups who often have not worked together or have a limited understanding of each other's ways of working.[14] Decision makers may, for example, be largely unaware of the types of information available and the levels of confidence within it or of how to make appropriate use of uncertain information presented as probabilities or likelihoods. Meanwhile, scientists rarely have a deep appreciation of decision-making environments or the places within a decision-making process where externally sourced information can provide the most effective support.

Fundamental to supporting the development and use of relevant risk knowledge are the interlinked concepts of coproduction and trust. Efforts to strengthen risk communication often employ the terms "user" and "end user," failing to recognize that everyone is both a provider and user of risk information, as well as the two-way nature of the communication and coproduction essential to developing relevant risk knowledge. Coproduction consists of bringing together different knowledge sources and experiences to jointly develop new knowledge that is better able to support specific decision-making. Where historical disaster data are limited, for example, local knowledge about recurrence

[13] Financed by the UK Department for International Development, the Ada Consortium (Ada) aims to introduce a "combined approach" to adaptation in the arid and semiarid counties of Garissa, Isiolo, Kitui, Makueni, and Wajir. The approach consists of establishing county-level adaptation funds, integrating weather and climate information and resilience assessment tools into county and community planning, establishing adaptation planning committees, and implementing a robust monitoring, evaluation, and learning framework.

[14] C. Bene, "Resilience: New Utopia or New Tyranny? Reflection about the Potentials and Limits of the Concept of Resilience in Relation to Vulnerability Reduction Programmes," IDS Working Paper No. 405, 2012; K. Kniveton, E. Visman, J. Daron, N. Mead, R. Venton, and B. Leathes, "A Practical Guide on How Weather and Climate Information Can Support Livelihood and Local Government Decision Making: An Example from the Adaptation Consortium in Kenya," working draft, Met Office, Ada Consortium, University of Sussex, King's College London, 2015.

periods and the impact of extreme events can provide important information to complement scientific sources.[15]

Building trust involves recognizing different ways of working and different knowledge and value systems and agreement on the aims and principles of working together. Such principles have guided efforts to create frameworks for bridging scientists and decision makers at the regional level, including through forums held by the Association of Southeast Asian Nations (ASEAN) [16] and the Economic Community of West African States (ECOWAS),[17] and at the national, county, and local levels through the work of the Adaptation Consortium in Kenya.

To ensure effective communication between different groups, agreement on the use of key concepts and terminology is important. The process of coming to this agreement entails bridging linguistic and technical differences and identifying ways of translating key scientific terms into local languages. In support of the development of climate information services (CIS) in Kenya, for example, training in risk communication for county directors of meteorology involved an exercise in translating the terms "probabilistic" and "probability" into the more than twenty languages used across the country, while the development of a county CIS plan in Kitui included a workshop to agree on Kikamba definitions for key climate concepts.

Supporting the effective use of risk information also requires building an appreciation of its characteristics. Foundational training to promote the use of weather and climate information in Kenya, for instance, involved a series of exercises to develop this appreciation, among them the following:

- "Knowledge timelines" to compare the sources of and levels of confidence in local and scientific climate information
- "Probabilistic scenario exercises" to increase understanding of the uncertainty within forecasts
- "The archer" exercise, demonstrating variation in the uncertainty of forecast information with time and geographical scale
- "Participatory downscaling" to translate climate forecasts and scenarios to local scales[18]

While a need for more systematic assessment of mechanisms for supporting coproduction is recognized,[19] learning about those approaches most effective for helping decision makers appropriately use probabilistic information is still emerging.[20]

The establishment of common ground provides an opportunity to overcome perceptions that much risk information is inaccurate and to recognize, rather, that it is inherently uncertain and best represented by a spread of probabilities. Climate scientists, for example, have been reticent to include probabilities within the forecasts they provide, yet farmers and pastoralists can understand probabilities[21] and, after being introduced to probabilistic information, can integrate it into livelihood decisions.[22] Also vital, however, is that decision makers use accredited sources and have the ability to gauge

[15] E. Coughlan de Perez, B. van den Hurk, M. van Aalst, B. Jongman, T. Klose, and P. Suarez, "Forecast-based Financing: An Approach for Catalyzing Humanitarian Action Based on Extreme Weather And Climate Forecasts," *Natural Hazards and Earth Systems Sciences* 15 (2015): 895–904.

[16] ASEAN Capacity Building Forum on Risk Assessment Bridging Science and Practice in Disaster Risk Management towards Community Resilience, Bangkok, Thailand, March 19–22, 2013. See Association of Southeast Asian Nations, "Bridging Science and Practice in Disaster Risk Management to Build Community Resilience," *ASEAN Secretariat News*, March 26, 2013, (http://www.asean.org/news/asean-secretariat-news/item/bridging-science-and-practice-in-disaster-risk-management-to-build-community-resilience.

[17] ECOWAS Regional Workshop on Information Sharing and Early Warning Coordination Mechanisms for Disaster Risk Reduction, Niamey, Republic of Niger, November 11–14, 2013. See http://www.preventionweb.net/events/view/36258?id=36258.

[18] Kniveton, "A Practical Guide"; "D. Kniveton, E. Visman, A. Tall, M. Diop, R. Ewbank, E. Njoroge, and L. Pearson, "Dealing with Uncertainty: Integrating Local and Scientific Knowledge of the Climate and Weather," Disasters 39, no. S1 (2015): s35–s53. Also see Dialogues for Disaster Anticipation and Resilience, http://dialoguesforresilience.tumblr.com

[19] A. Meadow, D. Ferguson, Z. Guido, A. Orangic, G. Owen, and T. Wall, "Moving toward the Deliberate Coproduction of Climate Science Knowledge," *Weather, Climate and Society* 7 (2015): 179–91.

[20] J. S. Suarez, P. Suarez, and C. Bachofen, *Games for a New Climate: Experiencing the Complexity of Future Risks: Pardee Center Task Force Report* (Boston: Frederick S. Pardee Center for the Study of the Longer-Range Future, Boston University, 2012), http://www.bu.edu/pardee/files/2012/11/Games-for-a-New-Climate-TF-Nov2012.pdf .

[21] W. Luseno, J. McPeak, C. Barrett, P. Little, and G. Gebru, "Assessing the Value of Climate Forecast Information for Pastoralists: Evidence from Southern Ethiopia and Northern Kenya," final project report to the International Research Institute for Climate Prediction, Columbia University, USA, and to the Department of Range Management, University of Nairobi, Kenya, May 2002; CARE, *Facing Uncertainty: The Value of Climate Information for Adaptation, Risk Reduction and Resilience in Africa*, 2014, http://careclimatechange.org/wp-content/uploads/2014/08/C_Comms_Brief.pdf

[22] J. Phillips and B. Orlove, "Improving Climate Forecast Communications for Farm Management in Uganda," final report to the NOAA Office of Global Programs, Silver Spring, Maryland, 2004.

the quality of the risk information provided and the models, methods, and data used to produce it. Decision makers need to be able to assess, and scientists need to communicate routinely, the levels of confidence, reliability, and certainty associated with the risk information provided.[23]

Step 2: Identifying and meeting decision makers' risk information needs

If risk information is to be relevant, those producing it must understand the decision-making contexts they seek to support with it. Much humanitarian and disaster risk reduction planning does not make routine use of forecasts of heightened risk. A lack of accountability to act on early warnings is coupled with a lack of clarity on who is responsible for making decisions, what type of activities should be undertaken, and on what threshold of forecasted probability action is worth taking.[24]

Tools for mapping decision-making contexts, such as political economy analysis, adaptation use cases,[25] and stakeholder analysis, enable identification of the most appropriate opportunities and approaches for integrating risk information. A number of organizations are developing resilience assessment tools designed to identify the types of information and communication channels that can best support those whose lives and livelihoods are most directly affected by specific risks. Consortia led by Christian Aid, for example, have developed a participatory assessment tool tailored to identifying the information and interventions best able to increase resilience among communities at risk of climate vulnerability, extremes, and change in Burkina Faso and Ethiopia.[26] Forecast-based financing systems currently under development seek to combine existing methods for verifying forecasts with user-defined information on risk reduction costs and disaster losses.[27]

Contrary to scientific expectations, it is now widely accepted that decision makers do not always make what may be considered purely "rational" or independent decisions.[28] Where risk is high and situations are overly complex—where cognitive reflection cannot, or can only partly, inform decisions—individuals appear to rely on in-between strategies of heuristics and emotions to make their judgments.[29] Importantly, these in-between strategies are not just cognitive shortcuts; rather, they work in a different way and use a different logic than the processes of rational and analytical decision making. Embedded in specific social relations, these in-between strategies are influenced by thought, experience, and reflection, and they draw on feelings, personal preferences, and social norms. Understanding these influences on decision making processes is crucial for appreciating the role scientific information can play in risk management.

Step 3: Supporting appropriate application

Sustainable two-way communication channels are needed to coproduce information relevant to decision making and allow decision makers to provide the regular feedback providers must have to strengthen production further. Where currently weak, decision makers' access to technical expertise can be supported through knowledge exchanges, cross-organizational placements or secondments, and the development of channels for sustained engagement with relevant institutional expertise, as well as the establishment of new technical posts, as resources allow. The use of two-way channels like knowledge exchanges can result in individual and organizational change on the part of both the decision maker and the scientific organization and lead to the creation of additional channels for scientific research to be informed by decision-maker needs.[30]

[23] C. Roncoli, "Ethnographic and Participatory Approaches to Research on Farmers' Responses to Climate Predictions," Climate Research 33 (2006): 81–99.

[24] Coughlan de Perez et al., "Forecast-based Financing."

[25] J. Colvin and D. Amwata, "Developing an M&E System for Climate Information Services (CIS) in the Arid and Semi-Arid Lands (ASALs) of Kenya," Adaptation Consortium, 2014, unpublished.

[26] Consortia funded by the UK Department for International Development (DFID) Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) program and led by Christian Aid have developed the BRACED Participatory Assessment (BRAPA) methodology currently being piloted in projects in Burkina Faso and Ethiopia.

[27] Coughlan de Perez et al., "Forecast-based Financing."

[28] P. Palmer and M. Smith, "Earth Systems: Model Human Adaptation to Climate Change," Nature 512 (2014): 365–66.

[29] J. Zinn, "*Heading into the Unknown: Everyday Strategies for Managing Risk and Uncertainty,*" Health, Risk and Society 10 (2008): 439–50.

[30] E. Visman, "Knowledge Is Power: Unlocking the Potential of Science and Technology to Enhance Community Resilience through Knowledge

The co-development of monitoring, evaluation, and learning frameworks aids the recognition of shared and differing objectives, as well as enabling the monitoring of respective impacts on the part of all partners, both decision-maker and scientific collaborators. It is important that such frameworks emphasize regular review and ongoing learning and that monitoring applies to the stages in the process of enabling science to better support decision makers, and not just the resulting impact. In Kenya, for example, partners to the Adaptation Consortium are monitoring improvements in the development of decision-relevant climate information services by tracking the production, understanding, use, and impact of improved services and access to them.[31]

Equally important is that the framework be supported by systems of accountability on the parts of partnering decision makers, scientists, and funding agencies. While the instances in which scientists are held accountable for poor communication of probabilistic risk information have been increasing,[32] agreed-upon frameworks of accountability have yet to be finalized and put into operation.[33]

Efforts aimed at enabling increased use of risk information seek to identify ways of scaling up successful pilots. While many focus on the role of intermediaries and boundary organizations, a shared understanding of who they are, what their role is, and the capacity building they require to fulfill their translational role effectively is lacking. Investment in organizations that seek to interpret science on behalf of other organizations, as opposed to building the capacities of existing providers and users of risk information, has major implications for both the sustainability of the services created and the potential for integrating risk information into decision making. Increasingly, the benefits of working through existing networks with extensive reach, including livelihood groups, religious leaders, and extension services, are being recognized.[34]

Conclusion

The steps outlined above are intended to support social learning, encompassing behavioral change, and the building of trust between those on both sides of what was previously regarded as the science–policy divide. Ultimately, this capacity development is essential for the successful and appropriate use of improved risk data and modeling platforms.

Exchange," ODI HPN 76, January 2014, http://www.odihpn.org/hpn-resources/network-papers/knowledge-is-power-unlocking-the-potential-for-science-and-technology-to-enhance-community-resilience-through-knowledge-exchange; E. Visman, "Futures Group Briefing Paper: Exchange as a Tool for Science–Humanitarian Dialogue," Humanitarian Futures Programme, September 2009, http://www.humanitarianfutures.org/publications/futures-group-briefing-paper-exchange-as-a-tool-for-science-humanitarian-dialogue.

[31] See above.

[32] These include criticism of the Kenya Meteorological Services forecast in 2009, the sacking of the director of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) for provided inadequate warning about Typhoon Conson in 2010, and, following the earthquake in l'Aquila in 2009, the case against members of the National Commission for Forecasting and Predicting Great Risks for providing imprecise information.

[33] Examples of initiatives that seek to promote increased accountability in the use of risk information within disaster risk reduction and resilience building include the Partners for Resilience, Minimum Standards for Local Climate-Smart Disaster Risk Reduction, Policy Brief, 2012, http://cdkn.org/wp-content/uploads/2012/06/Policy-brief-and-MinStd-CDKN-PfR-_27SEP12_.pdf; Euporias 2014, http://www.euporias.eu/symposium; and the draft white paper of the Climate Services Partnership Working Group on Climate Service Ethics, "Toward an Ethical Framework on Climate Services." These are not yet systematically employed or monitored, however.

[34] R. Graham, E. Visman, S. Wade, R. Amato, C. Bain, T. Janes, B. Leathes, D. Lumbroso, R. Cornforth, E. Boyd, and D. I. Parker, "Scoping, Options Analysis and Design of a 'Climate Information and Services Programme' for Africa [CIASA]:Literature Review," Evidence on Demand, 2015, http://www.evidenceondemand.info/scoping-options-analysis-and-design-of-a-climate-information-and-services-programme-for-africa-ciasa-literature-review.

SOLVING THE PUZZLE

Innovating to Reduce Risk

WRITTEN CONTRIBUTIONS

Risk Communication

Visualizing Risk for Commercial, Humanitarian, and Development Applications

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Challenges in risk visualisation and communication

Identifying and visualizing risk (hazard, exposure to hazard, and vulnerability) is critically important to assessing risk, improving disaster risk reduction, and planning and implementing business decisions and disaster relief scenarios. Visualisations enable large amounts of data and information to be presented in one format. When it is done effectively, enables often complex data to be communicated quickly and effectively to multiple stakeholders. In many cases the different levels of stakeholder expertise, funding and time constraints mean that they are not able to create visualisations to help prepare for, or respond to disaster scenarios. An example of this, comes from humanitarian and development groups, who are commonly the primary external responder to different disasters. These groups collect valuable data on communities of interest, but may not have the training, or knowledge of specific software that would enable the data collected to be processed for visualisation and communicated effectively. In turn, academic and insurance communities may have expertise and access to a range of visualisation software, but require data to effectively represent risk.

To improve the visualization of risk, we undertook a unique collaborative pilot project through the Probability, Uncertainty, and Risk in the Environment (PURE) program of the UK's Natural Environment Research Council (NERC), involving the academic, insurance, and humanitarian and development communities. The main aim was to understand, adapt, and apply ImpactOnDemand,® a commercial software platform developed by Aon Benfield, to issues of disaster risk and relief faced by humanitarian and development organizations. To make the approach more widely available, the project also examined the use of freely available software packages (QuantumGIS, Google Earth) and less customized commercial packages (ArcGIS) for visualizing risk. The project highlighted the importance of collaboration for enhancing the effectiveness of disaster risk assessment and reduction, as discipline and sector boundaries must be crossed and knowledge, data, learning, techniques, and applications shared and jointly implemented.

Enhancing the visualisation of risk: Case study

Flood risk in Cambodia was chosen as the subject for the study, as the country is of interest to the business, humanitarian, and development sectors, and the Thai floods of 2010 highlighted the exposure and socioeconomic vulnerability of Southeast Asia to this type of hazard. As the primary objective of the project was to develop a tool for use by humanitarian and development nongovernmental organizations (NGOs), two workshops were held in Cambodia. The first was to learn about flood risk and work already undertaken and to gather data, and the second was to present visualizations to different stakeholders and experts working in disaster risk reduction and relief to gain feedback from them and make recommendations for future work.

One main challenge for the project was to identify and obtain adequate hazard and socioeconomic—especially population—data of appropriate quality that could be plotted over base maps to produce the risk visualizations. For Cambodia, such data are described by Conrad.[1] Population data are available at increasing resolutions from the province down to the village levels from Open Development Cambodia (ODC)[2] and the Mekong River Commission (MRC)[3], although these two data sources are slightly discrepant in the exact locations of communities. Importantly, the ODC data also include 134 attributes that describe the socioeconomic state at the level of each community and thus provide important livelihood information, such as numbers of people within different age, employment, and education categories. Additional data at community level come from participatory vulnerability and capacity assessments (PVCAs) undertaken by NGOs. These provide useful hazard and vulnerability information on the communities the NGOs work with, but they have the drawback that they rarely cover all communities in a region and are, therefore, biased.

Flood hazard data were provided by the MRC, which produces outlines of individual flooding events based on satellite images of the extents of past floods. The MRC also produces estimates of minor, medium, and major flood extents for individual events, which can be used to develop scenarios and plans for future events. Additional information on durations and depths of floods were also available but were not used in this study.

Methodology

The methodology relies on the use of geographic information systems (GISs) to portray spatial information using a variety of GIS platforms. ImpactOnDemand® determines the exposure of communities by plotting their locations and investigating where they intersect with hazard footprints. This method can also be applied through more commercially common or freely available software by using the intersect tool within these packages. The data can also be transferred into Google Earth to make them more accessible to stakeholders who may not have any background in GIS. This is particularly useful because Google Earth is a tool often used by the general public for orientation and directions.

Using ImpactOnDemand® and other software, we have shown that available datasets in Cambodia can be used to identify and portray communities that are exposed to different estimated levels of flooding (see figure 1). To enhance these visualizations further, we have used the attributes of communities within the ODC census data to define vulnerability. Combined hazard and vulnerability data enable the creation of scenarios that permit prioritization of communities for relief efforts. We have implemented the social vulnerability index (SoVI) developed by Cutter and others, for which vulnerable groups are identified and ranked in the order of how they increase the vulnerability of a community.[4] For each village, this ranking is multiplied by the number of people within that particular group. The values are then summed to give an overall index for the village that describes its vulnerability. To define vulnerable attributes we have used PVCAs, in which the communities themselves define the attributes that make them vulnerable. In PVCAs obtained from other countries, such as Indonesia, vulnerable attributes are also ranked by the communities, providing a more accurate value for vulnerability.

The SoVI can be visualized as the aggregated index, providing a quick estimate of vulnerability that can then be interpolated and the level of detail altered to communicate data to different stakeholders. Using an aggregated value means that details within the community data are lost, however, so to examine vulnerability in greater detail the different attributes can be listed individually, allowing relief efforts to be tailored to different communities. One excellent method of visualizing the different vulnerable attributes is to export the shapefiles into Google Earth. Here individual villages can be highlighted and the vulnerable attributes listed in a table (see figure 2).

Combining values of hazard and vulnerability provides an estimate of risk that can be visualized within the different software packages, but because these values are derived from different sources they provide an uncertain

1 P. N. Conrad, "An Overview of Hazard Mapping in Cambodia," People in Need (PIN) Cambodia Phnom Penh, 2013.

2 Open Development Cambodia (http://www.opendevelopmentcambodia.net/)

3 Mekong River Commission (http://www.mrcmekong.org/)

4 S. L. Cutter, B. J. Boruff, and W. L. Shirley, "Social Vulnerability to Environmental Hazards," *Social Science Quarterly* 84 (2003): 242–61, doi:10.1111/1540-6237.8402002.

FIGURE 1. **Screenshots from ImpactOnDemand® showing villages throughout Cambodia (yellow circles) and the outline of a major flooding event (blue area), data provided by MRC and ODC. (Top) The red circles represent villages that are affected by this flood, and (bottom) the red circles surround exposed communities that have residents with reported disabilities. The reports generated for these communities show the statistics for the villages affected by this flood (that is, minimum, average, and maximum per village, total people and villages across flood zone, and so on).**

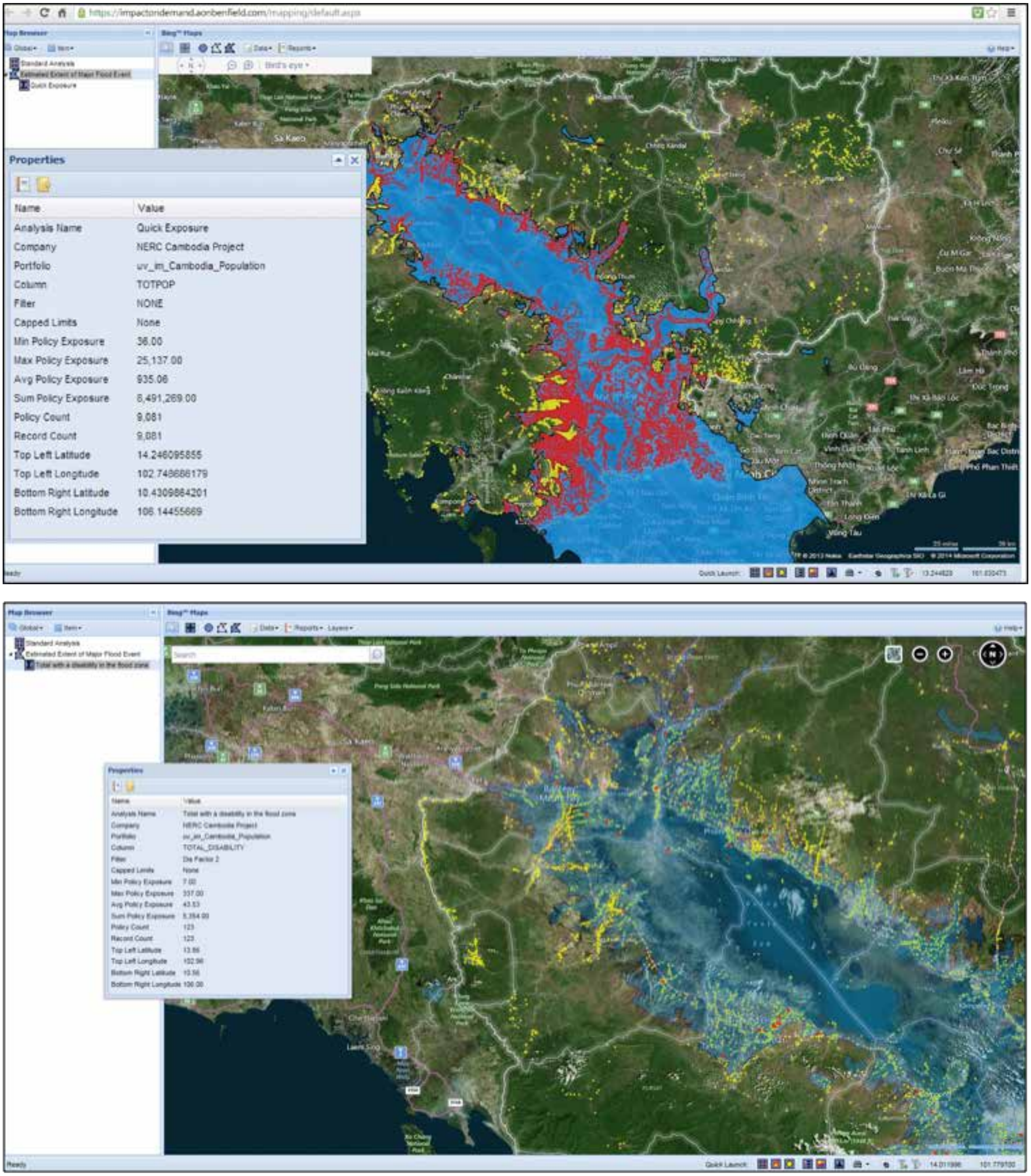
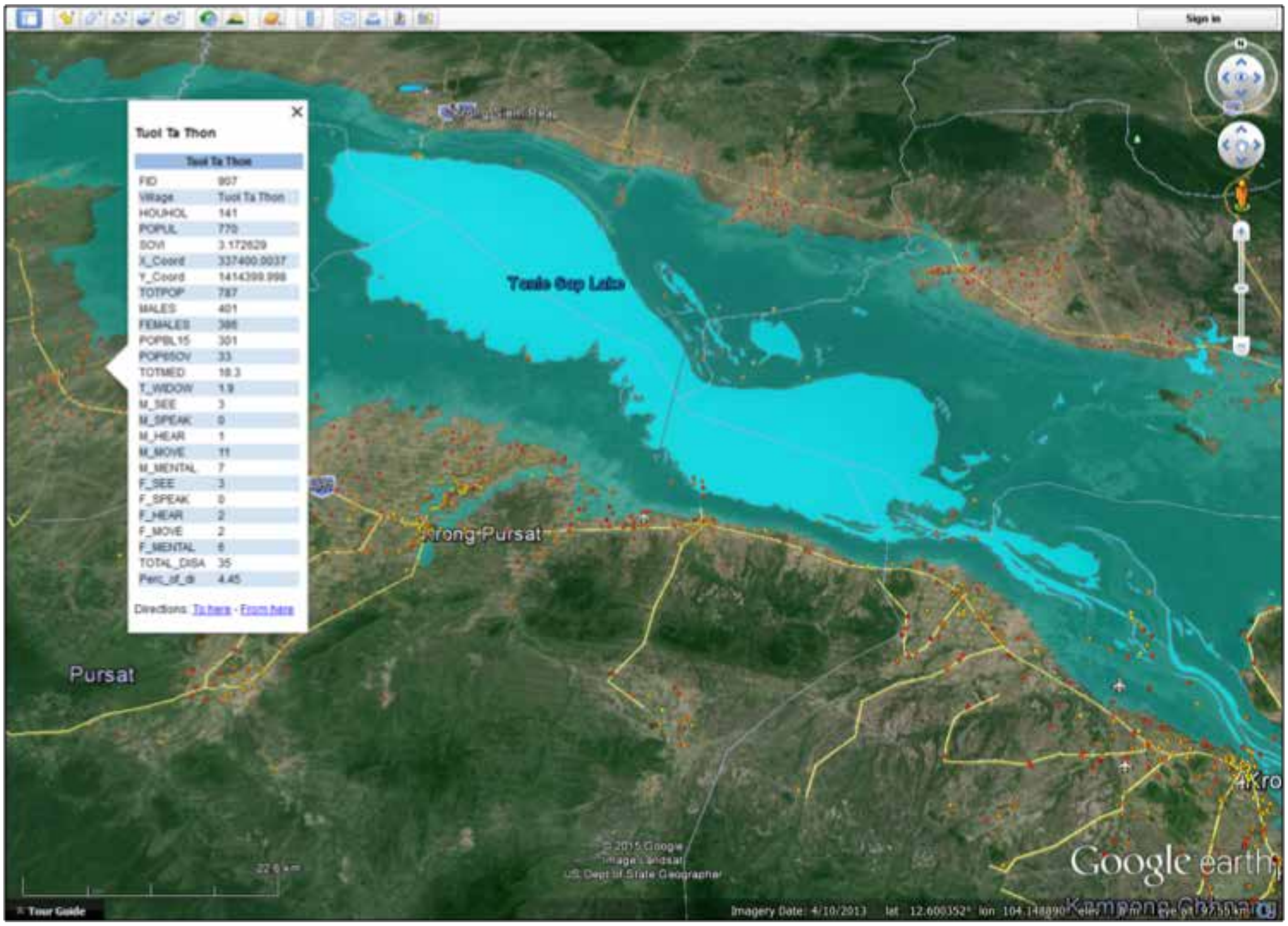


FIGURE 2. Google Earth visualization of villages in Cambodia that have high (red) to low (yellow) values of vulnerability, using the SoVI. Particular vulnerable attributes can also be displayed within this software to examine the needs of each village, as shown by the list to the left. Features such as rivers, lakes, roads, and infrastructure can also be added to this map, as well as flooding events.



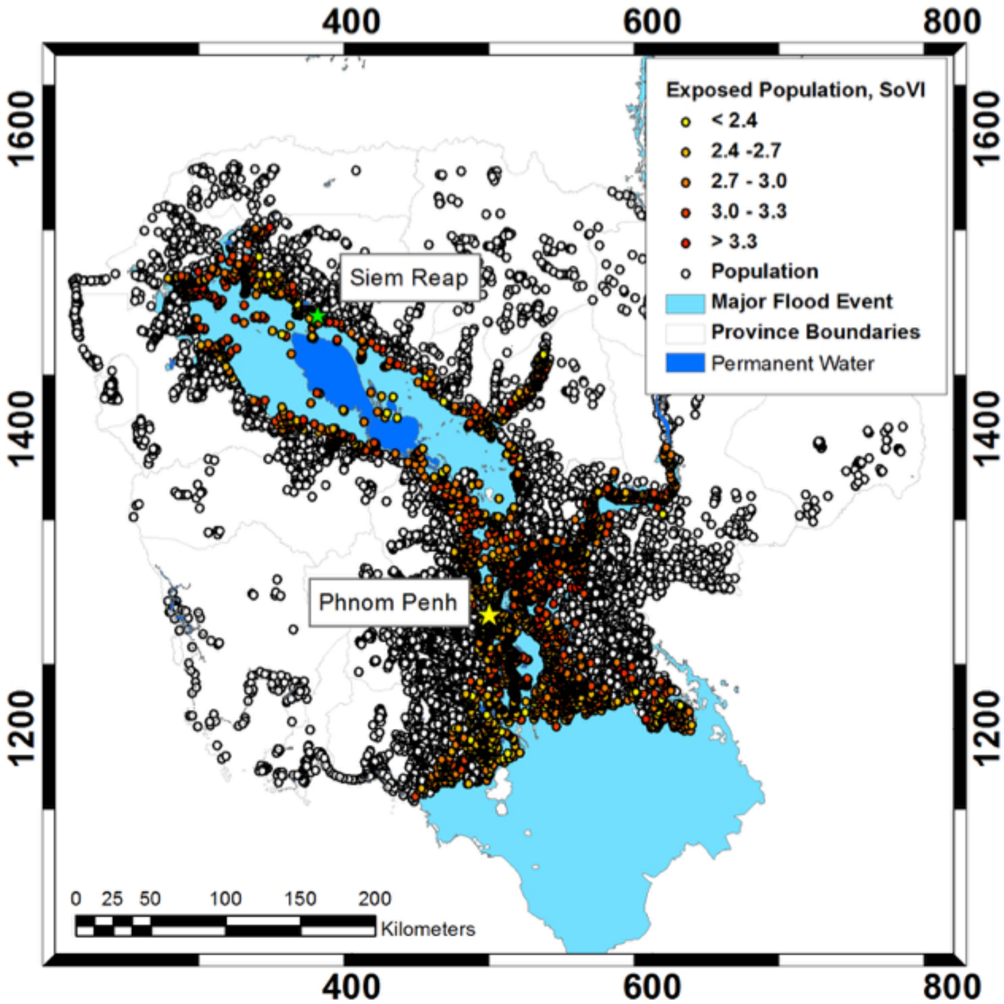
value for risk. Instead, we have plotted population vulnerabilities in relation to the hazard outlines, to show how the two are related spatially (see figure 3).

Challenges in visualising risk: Data and software availability

From this project we have shown socioeconomic vulnerability and natural hazards can be effectively visualized by using different software and datasets that are either freely available or can be purchased from different sources, however, in many cases users, depending on their requirements, may need guidance on the most appropriate software. The data required for risk assessments also pose a challenge as many are limited in their coverage and/or are presented in inconsistent formats. We call, therefore, for improved and systematized approaches to collection, storage, and accessibility of risk data. Ideally, a publicly accessible global risk database should provide standardized data that meet specific quality standards. In addition, an online directory similar to the *Understanding Risk* report, which describes a range of software packages,[5] should

[5] Global Facility for Disaster Risk and Recovery, *Understanding Risk: Review of Open Source and Open Access Software Packages Available to Quantify Risk from Natural Hazards,* International Bank for Reconstruction and Development/International Development Association or the World Bank, 2014, https://www.gfdrr.org/sites/default/files/publication/UR-Software_Review-Web_Version-rev-1.1.pdf.

FIGURE 3. **Communities in Cambodia exposed to a major flood (blue), where values of vulnerability have been calculated using the SoVI, from high (red) to low (yellow) values. Nonexposed populations are shown by the white circles, and main cities of Phnom Penh and Siem Reap are represented by yellow and green stars, respectively.**



be compiled, with links to open source and commercial risk visualization platforms available to enable users to choose the most effective ones for their requirements.

Related to the recommendation on data management, we highlight the importance of using the community-level data that are captured in PVCAs to help define vulnerability. Again, these need to be systematized in their definition of parameters and the rigor with which the data are collected, and they need to be stored in a central and publicly accessible database. Our study has highlighted the need for these assessments to contain accurate geographical information, such as coordinates of communities and essential infrastructure. A range of software currently exists for visualizing risk and enabling different users to apply these visualizations effectively, but training is needed to ensure users can understand the full potential of these visualizations and adapt and improve them for different scenarios. For this project, we have concentrated on socioeconomic vulnerability data, but software programs also exist (for example, Inasafe) that examine exposure to infrastructure, using OpenSource data and maps. By integrating both types of visualization, risk can be assessed more accurately and more effectively communicated to a range of stakeholders.

Recommendations for visualising risk

We have shown that combining the expertise from different stakeholders can lead to improvements in the visualization of risk. Insurance companies collaborating within this project benefited by having a better understanding of the available information, which could be utilized for risk mitigation and visualization to assist with industry developments concerning risk management. In addition, incorporating different types of information about vulnerable communities provided different ideas on how to use existing insurance-based data within the available visualization software. The project enabled NGOs to identify gaps and opportunities in existing risk assessment processes and gain feedback on data collection methods. It also provided a means of making NGOs aware of low-cost technologies for visualizing risk and how the application of these tools can aid local scenario planning.

Finally, we stress how essential it is to present and discuss risk visualizations with the different stakeholders and experts working in the area of interest. This allows the visualizations to be customized for the specific scenarios being investigated or prepared for. It should also reduce uncertainty and allow whatever uncertainty remains to be better understood and managed.

Improving Risk Information Impacts via the Public Sphere and Critical "Soft" Infrastructure Investments

Mark Harvey (Resurgence), Lisa Robinson (BBC Media Action)

A scoping of the possible need for a new open risk data and modeling platform is incomplete without an understanding of how best to move risk information beyond the disaster risk management (DRM) community. The exploration needs to be undertaken in ways that catalyze responses from the primary "owners of risk": communities throughout the world exposed to a range of natural hazards, including intensifying climate impacts, in increasingly urbanized environments.

Advances in technology (through remote sensing and surveying of the natural and built environments, advanced computer modeling, mobile internet–enabled crowd sourcing, and the maturation of "the Internet of Things") and the growth in open data release by government and scientific agencies are combining to support new, dynamic exposure modeling approaches. A further outcome of these twin trends is the generation of significantly increased volumes of risk information.

The expansion of risk information is occurring, of course, alongside well-documented challenges in data access, quality, standardization, and verification, and the capacity of end users to make use of existing modeling tools.

Our own experience in developed and developing countries alike, however, is of a growing discontinuity between the increased production of risk information and its use by communities at risk. One way of looking at this is as a disconnection between the *data sphere* (including "big data," which may contain both closed and open data) and a functioning public sphere, which we define broadly as the realm in which communities, families, and individuals reflect, debate, and, at times, demand responses and action from authorities and take action themselves.

Arguably, this disconnection overshadows the important and inherent challenges to be addressed around communicating the outputs of probabilistic risk models and how they are to be interpreted and applied. For one salient example, the existence of flooding risk information for the city of Srinagar, India, and a major report by the city's Flood Control Department in 2010 predicting a major inundation within five years did not put a freeze on construction on wetlands and water bodies and the encroaching of flood spill channels. These areas suffered from the worst impacts in 2014 when the city was largely submerged by flooding, resulting in the loss of over three hundred lives and the inundation of six hospitals.[1] Building in these areas might, however, have been halted—and lives and critical public health infrastructure protected—as a result of informed public discussion to mitigate the risk more effectively and increased community-level preparedness. We consider the failure of the public sphere in this case to have been a contributor to the wider governance challenges that left Srinagar so exposed.

What strategies are relevant to future investments in data and modeling platforms to ensure communities can access the information they generate, debate them, and take action? Below are five approaches that can help

[1] S. A. Tabish and Syed Nabil, "Epic Tragedy: Jammu & Kashmir Floods: A Clarion Call," *Emergency Medicine* 5 (2015), http://www.omicsgroup.org/journals/epic-tragedy-jammu-and-kashmir-floods-a-clarion-call-2165-7548.1000233.pdf.

build connections between risk information providers and the communities that have the most to gain from using risk information.

1. Innovate to increase the overlap between the data sphere and the public sphere

Participatory mapping for risk assessment based on open data, as pioneered by the Global Facility for Disaster Reduction and Recovery (GFDRR) through its Open Data for Resilience Initiative in Sri Lanka and Nepal, and local ground truthing of natural hazard maps, as undertaken by Project NOAH of the Department of Science and Technology (DOST) of the Philippines, are good examples of initiatives that increase community ownership of risk information and help bridge the data divide by engaging community representatives as equal actors in the process of risk assessment. These practices can be reinforced by building local capacity in data visualization, not just for decision makers, but for citizens themselves. The emerging field of 3D visualization of natural hazard impacts can now allow community groups to view water levels against buildings and transportation and other vital infrastructure in their own districts in different flooding scenarios.[2]

Citizen-led sensor deployment initiatives to measure river levels and air or water pollution are increasing public engagement with data, in cities ranging from London and New Delhi to Ulaan Baator and on a range of chronic stresses. They may help create new channels into communities for risk information that can help them prepare for more extreme events.[3]

Civic facing applications are creating new ways for citizens to interact with risk-related information, particularly information related to early warning, as demonstrated by FloodAlert and Guagemap in the UK and by a number of applications developed through resilience challenges, such as Code for Resilience and the United Nations Office for Disaster Risk Reduction (UNISDR)/Esri Global Disaster Resilience App Challenge. The scaled adoption of many of these applications is being constrained in many instances, however, by challenges to developing sustainable operating models.

2. Engage in good media and communication practice

Effective practice in bringing risk information into the heart of communities includes having clear communication objectives, undertaking audience research and connecting with community interests, selecting appropriate and multiple channels, using creative, diverse formats, and developing strategic partnerships. The initiative *Showcasing Innovation: Media and Communication for Disaster Risk Reduction*[4] identified more than twenty media and communication projects from a pool of over forty submitted for presentation in Japan at the World Conference on Disaster Risk Reduction (WCDRR) that contained valuable lessons for the risk communication sector. These included the high value of engaging target communities themselves as investigators and communicators of risk information (The Youth Reporter Project of Plan International, the Philippines); creating family-level preparedness for flooding and landslides by focusing on evacuation plans for urban family pets (The Thunder Campaign of World Animal Protection, Costa Rica); and introducing technical risk–related information through "challenge" formats designed to mobilize initiatives and resources within the reach of vulnerable communities (the Amrai Pari TV series of BBC Media Action, Bangladesh). The vast majority of these initiatives not only used mass media, social media, or mobile phone platforms to reach key groups in interactive ways; they also deployed community-based, face-to-face communication elements as integral parts of their strategies.

Effective communication requires moving beyond risk "messaging." Our experience is that messaging should always be consistent and coordinated across agencies. When communication is too reliant on one-way, top-

2 Vizicities, a new company based at the Open Data Institute, is combining methods drawn from the Simcities game to allow city authorities and citizens to view flood impacts on buildings and visualize the carrying capacity and leakage points of sewer and underground water holding systems.

3 Kat Austen, "Environmental Science: Pollution Patrol," *Nature*, January 7, 2014, http://www.nature.com/news/environmental-science-pollution-patrol-1.16654.

4 Showcasing Innovation is a partnership led by BBC Media Action, the Red Cross Netherlands, Plan UK, the Global Network for Civil Society Organisations for Disaster Reduction (GNDR), and Resurgence (chair, independent jury process).

down "messaging," however, it can be ineffective and even counterproductive.[5] We all have complex ways of prioritizing (and deprioritizing) risk, and the importance of audience research, identifying the best channels to reach audiences, and creating space for listening to and engaging in dialogue with communities at risk cannot be underestimated.[6]

Transposing communication knowledge from other sectors is also important. Over the past decade, the climate science community has built up valuable but hard-won knowledge of how to communicate different levels of uncertainty relevant to conveying the results of probabilistic risk analysis; similarly, the fields of public health and governance have developed an evidence base on effective communication and the science of behavior change that underpins it. The DRM community has much to draw upon from these sectors, as well as effective communication practice from private-sector actors dealing more directly with risk—notably, the insurance industry and water and energy utilities.

3. Understand that DRR needs an open and enabled public sphere

Risk information is ignored or even suppressed in the absence of an open, vibrant media sector operating in a robust freedom of information environment. Communities cannot build preparedness and play an active role in reducing their own risk if critical information is withheld from them or they cannot voice concerns about their own vulnerability. The contrast between the government of Myanmar's failure to providing early warning and relief information in 2008 regarding Cyclone Nargis and its commitment to doing so in 2013 for Cyclone Mahasen and the summer of 2015 during the worst floods for many years provides a stark illustration of this.[7] Strategic investments in DRR and resilience building cannot be viewed, therefore, in isolation from governance support processes that relate to freedom of information, expression, and media.

A free media more literate in risk reduction and resilience issues can also reinforce public leadership in resilience building, support the process of public debate and dialogue on the tradeoffs involved in acting on risk information (particularly in urban and rural planning), and underline the accountability of public officials for protecting communities and assets. Likewise, building the capacity of community leaders and other key influencers to understand and communicate risk effectively will increase both the impact and, ultimately, the demand for risk information.

4. Invest in critical "soft" infrastructure for resilience

Given the current emphasis on "hard" infrastructural investments—in particular, in financing urban development needs—it is important when creating incentives for risk-sensitive investments (multilateral, bilateral, and private) to create the business case for investing in the "soft" but essential dimensions of community-oriented data and communication infrastructure that need to be developed in rapidly urbanizing economies. In our view, hard infrastructural investments cannot, in fact, be risk sensitive without parallel investment in capacity in these areas. In its revised Ten Essentials for City Resilience for its Making Cities Resilient Campaign, UNISDR recognizes this by calling for capacity building at the municipal level "in communication, data and technology management" and for "creating and implementing information and data frameworks for resilience and disaster risk reduction that build consistency in data capture and storage and enable data access, use and re-use by multiple stakeholder groups."

5. Support a community of practice in risk communication

Although a sector-wide advocacy and learning network is now well established in post-disaster communication through the Communicating with Disaster Affected

[5] See chapter 2 of Imogen Wall with Yves Gerald Chery, *Ann kite yo pale [Let Them Speak]: Best Practice and Lessons Learned in Communication with Disaster-affected Communities: Haiti* 2010, 2011, http://www.internews.org/sites/default/files/resources/IAA_Haiti_2010_0.pdf, on the challenges of messaging in responding to the cholera emergency in Haiti.

[6] See also the 2015 report by the ACAPS Ebola Project, *Ebola Outbreak, Liberia: Communication: Challenges and Good Practices*, http://acaps.org/img/documents/l-liberia-ebola-outbreak-communications-challenges-and-good-practices.pdf, which found disconnected top-down messaging ineffective.

[7] Palmstrom, B (2015): http://www.bbc.co.uk/blogs/bbcmediaaction/entries/5f1e8740-6a42-4a92-9f63-49c698104694

Communities (CDAC) Network, the architecture of the growing risk reduction and resilience practice area appears to have a major gap around communication. Further collaborative learning, piloting projects, joint research programs, and network building on effective predisaster risk communication are needed. Such a platform would bring together and document the disparate existing good practices in this area, as well as catalyze new initiatives that could strengthen, both directly and indirectly, the impact of current and future data and modeling platform investments.

Perceiving Risks: Science and Religion at the Crossroads

Ahmad Arif (Kompas)
Irina Rafliana (LIPI, Indonesian Institute of Sciences)

Do we perceive risk and hazard the same way others do? Do we react the same when facing a life-threatening event from nature? Indonesia has been known as one of the countries at highest risk for almost all kinds of natural disasters, including earthquakes, tsunamis, and volcanic eruptions, yet awareness of the risks and disaster preparedness in Indonesian communities are moderately low. In June–July 2011, the newspaper *Kompas* conducted a survey with 806 respondents in the cities of Banda Aceh (Aceh province), Yogyakarta (Yogyakarta Special Region), Sleman (Yogyakarta), Padang (West Sumatra province), Palu (Central Sulawesi province), Karangasem (Bali province), and Bengkulu (Bengkulu province), all of which experienced earthquakes, tsunamis, or volcanic eruptions. Among the respondents, only 8.4 percent believed disaster risks could be reduced through mitigation and preparedness.[1]

According to the study, the low levels of alertness are in large part the product of a perspective that tends to accept disaster as given by nature (48 percent). Others (43 percent) believe disasters are part of natural mechanisms, but nothing much can be done to avoid them because they are God's will. Most of the survey respondents were likely to see natural disasters as inevitable destiny to which they should resign themselves. Such beliefs contribute significantly to the decisions of survivors to return to residing in disaster-affected areas, as happened in Aceh after the 2004 tsunami, as well as in various other locations in Indonesia where natural disasters had taken place. These beliefs stand in contradiction to the scientific perspective, which holds that people can maintain some control over their destinies in the face of disasters and disaster risks.

How people come to see and deal with disasters and other natural phenomena is a cultural process, with differing perceptions growing from different cultural constructions. If one accepts a rational explanation of the dynamics of nature as revealed through science, risk countermeasures or mitigation efforts may make more sense than if one sees disasters from a religious or faith perspective and concludes they are purely God's will. Nevertheless, we need to be careful not to automatically designate religion as the factor derailing risk reduction, nor should we see it linearly as the "answer" to the problem. The fundamental issue to be discussed here is how the scientific perspective of disaster risk reduction formulas needs to allow for an adequate discourse of the religious perspectives that are evidently closer to communities' daily lives.

The limited number of studies relating faith or religion to disaster risk reflects the minimal consideration given the subject in intellectual debates and among critics. At the same time, decision makers have different ideas on imagining the role of religion in disasters. A very interesting example was a speech given by Indonesian minister of communication Tifatul Sembiring during mass prayer on the important Islamic occasion of Eid Al Adha, shortly after the September 20, 2009, Padang earthquake. The minister attributed the earthquake to the consumption of entertainment that features indecent exposure, pornography, or morally questionable relationships.[2]

[1] *Kompas*, September 14, 2011, 24.

[2] BBC News, "Indonesia Minister Says Immorality Causes Disasters," November 28, 2009, http://news.bbc.co.uk/2/hi/asia-pacific/8384827.stm.

The accompanying table lists a few disasters occurring in Indonesia that were discussed in various media from a religious perspective.

The table illustrates how the understanding of risks and disasters is religiously driven throughout Indonesia. Meanwhile, the government at different levels presents disaster preparedness purely from the perspective of physical infrastructure. Policymaking in disaster risk reduction needs to pay more attention to the cultural aspects of disasters and recognize the importance of understanding communities' faiths and their religious views related to them.

Below are brief accounts of three of the many cases in which this challenge has been prominent. The cases will provide the main references for the subsequent discussion.

Case studies

The three cases described below are the eruptions that took place in Mount Agung 1963 and Merapi in 2010 and the major earthquake event in Aceh and Padang in 2012.

Agung eruption, 1963

On February 16, 1963, after having lain dormant for 120 years, Mount Agung on Bali Island finally woke up. On February 18, at around 11 p.m., residents on the northern slope of Mount Agung heard for the first time roars from inside the earth. The eruption itself was heard at 5:50 a.m. and was followed by a rain of small gravel and pyroclastic debris. The official death toll from the first cycle of activity, as released by the local government of Bali, was 1,700. Of those, 1,500 died because of the pyroclastic flow, coming mainly from a paroxysmal eruption on March 17. The other 200 were due more to the *lahar* (mud or debris flow), which hit Subagan on March 21. Most of the casualties fell in villages in the district of Selat on the southern slope, where 1,200 died from the *nuées ardentes* ("burning clouds"), which hit this area several times, but most casualties fell within the closed and danger zones.[3]

The reason for the high death toll from the Mount Agung eruption has been debated, but the most likely cause was given by Zen and Hadikusumo: "It can simply be explained by the reluctance of the people to move from the closed zone and from the danger area."[4] Kama Kusumadinata, a volcanologist from the Directorate of Geology in Bandung who came to Bali at that time, found some Balinese people believed the cause of the eruption was spiritual.[5] Every evacuation instruction from his office—a government agency responsible for all volcanoes in Indonesia—was ignored, despite its having established a danger zone at a five-kilometer radius from the mountain peak.

Kusumadinata's finding is consistent with the testimonies of survivors from Sogra and Badeg Dukuh, two villages separated by the Lengu River and only four kilometers from the peak of Mount Agung. Ketut Sudana, 73, a resident of Badeg Dukuh, said villagers on the southern slope did not move. Instead, they stayed in the temple and prayed while *gamelan* (traditional music) was played around them and hoped that the mountain gods would protect them.[6] Mangku Turut, 63, a resident of Sogra, was in the *gamelan* troupe, playing *ceng-ceng* (Balinese cymbals) in the temple every night. Since he was a child, Turut was told the volcano erupted because the people did not pray hard enough and make enough offerings. They believed no disasters would happen as long as they held ceremonies. So rooted in their minds was this tenet that even when Mount Agung started to show signs of dangerous activity, they did not rush to leave their villages. For them, the eruption was not only a matter of geology and geophysics; it was related to human behavior and depended on their developing and maintaining a harmonious relationship with the "master of the mountain."

Merapi eruption, 2010

The Merapi eruption of 2010 presented a situation quite similar to that of the Agung eruption. Located thirty kilometers north of the inner city of Yogyakarta, Merapi is one of the most active volcanoes worldwide, having erupted more than seventy times since 1548 and killed

3 M. T. Zen and D. Hadikusumo, "Preliminary Report on the 1963 Eruption of Mt. Agung in Bali (Indonesia)," (paper presented at the IUGG Assembly, IAV Scientific Session, August 30, 1963), Bulletin Volcanologique 27, no. 1 (1964): 269–99.

4 Ibid., 287.

5 K. Kusumadinata, *The Eruption of the Agung Volcano in Bali*, in 1963, Geological Survey of Indonesia, Bandung. Unpublished report.

6 Ahmad Arif, *Hidup mati di negeri cincin api* [To Live and Die in the Ring of Fire] (Jakarta: Kompas Book Publishing, 2012).

more than 7,000 people in sixty-one eruptions since the fourteenth century (Lavigne et al., 2000)[7]. Like those on and near Agung, people had been living with Merapi for centuries, always returning to reside in the danger zone on its slopes after its eruptions stopped. Attempts by the government to clear residents from the danger zone have always failed. In fact, evacuating people before and during eruptions has always been a huge challenge.

When Mount Merapi erupted in April 2006, its gatekeeper (the spiritual guardian of the mountain), Mbah Marijan, refused to evacuate, although he supported an evacuation for other villagers. He said he had connected with the spirits of ancestors (*pepundhen*) after three days of meditation to ask Mount Merapi to limit the amount of destruction.[8] A continuous parade of visitors sought information about the mountain from the nearly eighty-year-old man, who had been appointed by the sultan to carry annual offerings to the volcano in a century-old tradition, at his small home in the Kinahrejo village.[9]

In 2006, the eruption did not reach Mbah Marijan's home, and he became very famous throughout Indonesia as the spiritual leader of Merapi. When, in 2010, Merapi again erupted, Mbah Marijan again refused to evacuate. This time was different from the previous occasion, however; a large magnitude explosive eruption caused over 350 fatalities, including Mbah Marijan. The gatekeeper was found dead after the first eruption on Tuesday, October 26, 2010, along with at least thirty-two other Kinahrejo residents who had remained in the village.

Shortly before his death, Mbah Marijan explained why he was refusing to evacuate from Merapi: "If it goes down, many people will be laughing at me. [They] just want the good from Merapi, but [are] not willing to accept the bad. Good or bad, yes it's our own home." Still, when the situation became critical, Mbah Maridjan flatly refused to be called a role model. He asked his own family to flee and expected each person to be responsible for his or her own safety. As quoted by *Kompas*, he said, "If [you feel] compelled to evacuate, go evacuate. Do not follow a fool like me that was never taught in school."[10]

Unfortunately, many people misunderstood Mbah Maridjan's intentions, including some local residents, who thought he would sound the alarm if an eruption were imminent and a threat to their lives. But Mbah Maridjan would never have sounded the alarm, because he was ready to die on Merapi. When the eruption came, he prostrated himself to welcome the pyroclastic clouds, as would a person meeting the servant of his "lord"; and dozens of other people ended up being killed along with him.

These followers thought the 2010 eruption would be harmless as long as the gatekeeper was still living. They thought the good luck they had had in 2006 would be repeated. As the Agung volcano is for the Balinese, Merapi was—and still is—not just a natural phenomenon for the Javanese who live on the slopes of that mountain. Their culture and beliefs coincide there, and Mbah Maridjan still lives, in this cosmology, in a palace at the top of a mountain that is a living thing that can breathe, think, and feel.

Sumatera Outerise earthquake, 2012

The Indian Ocean 2004 event was a great shock to almost all of the communities in Banda Aceh, as the knowledge that scientists provided until that time on earthquake hazard and tsunami risk was insufficient. In the course of research on preparedness conducted by LIPI (Lembaga Ilmu Pengetahuan Indonesia, or the Indonesian Institute of Sciences) and UNESCO (United Nations Educational, Scientific and Cultural Organization) in 2006, some survivors shared their stories. According to one account, when the huge wave came through on the morning of December 26, 2004, a villager was seen to sit down in its path and recite the Quran rather than run away. The catastrophe was beyond comprehension based on what was known, and one could only assume it heralded the arrival of the apocalypse.

7 F. Lavigne, J.-C. Thouret, B. Voight, H. Suwa, A. Sumaryono, "Lahars at Merapi Volcano, Central Java: An Overview," *Journal of Volcanology and Geothermal Research* 100 (2000): 423–56.

8 F. Lavigne, B. De Coster, N. Juvin, F. Flohic, J.-C. Gaillard, P. Texier, J. Morin, and J. Sartohadi, "People's Behaviour in the Face of Volcanic Hazards: Perspectives from Javanese Communities, Indonesia," *Journal of Volcanology and Geothermal Research* 172 (2008): 273–87.

9 Lucas S. Triyoga, *Manusia Jawa dan Gunung Merapi: Persepsi dan kepercayaannya* [The Javanese and Merapi Volcano: Perceptions and Beliefs] (Yogyakarta: Gadjah Mada University Press, 1991).

10 *Menjemput Mbah Marijan* [Evacuating Mbah Marijan], *Kompas*, October 28, 2010, 1.

After the Indian Ocean tsunami in 2004, the Indonesian government put a lot of effort into establishing tsunami sirens and building tsunami shelters and related physical infrastructure. Immediately following the April 11, 2012, earthquake, however, the first ever Joint Rapid Assessment on the Effectiveness of the Indonesian Tsunami Warning System, conducted by LIPI and several national institutions, found that disaster mitigation using physical infrastructure had almost totally failed. Between the two events, communities had returned to reside in settlements in the high-risk zones, and during the 2012 earthquake, they evacuated using vehicles that caused severe traffic jams. Community members generally distrusted the built vertical shelters and avoided using them. If the event had been followed by a tsunami, the casualties might even have matched those of the 2004 event.

Event	Occurrences	Religious perspective on cause of disaster	Source
Earthquake events in Mentawai	Before and after 2004	Traditional *Arat Sabulungan* belief regards nature highly and welcomes earthquakes as blessing. Only after the 2004 earthquake in Aceh does the perception of risk change to fear of earthquakes and tsunamis.	I. Rafliana, "Imagining Risk: Social Construction of Tsunami Knowledge to Reduce Risks in Saibi Samukop Village, Mentawai, Indonesia" (master's thesis, University of Indonesia, 2015).
Mount Agung Bali eruption	February 16, 1963	Eruption occurs because of insufficient offerings and prayers to the mountain gods.	Based on interviews with Agung eruption survivors, in Ahmad Arif, Indira Permanasari, Agung Setyahadi, Aryo W. Genthong, and Aloysius B. Kurniawan, Merapi: Daya hidup di kerajaan gunung api [Merapi: Living in Kingdoms of Volcanoes] (Jakarta: Kompas, 2012).
Alor earthquake	November 12, 2004	The Alor earthquake is a form of punishment from God for the sins of the Alor people. It is a reminder and a message to people to be closer to God.	Nelson J. Campbell, "Religion and Disasters: A Critical Reflection Post Alor Earthquakes 2004," working paper 8, IITTS Publications, February 2008.
Indian Ocean (Aceh) tsunami	December 26, 2004	The entire impact of the tsunami disaster is solely God's will, and a message to the Acehnese to avoid moral hazards. Asy Ariyah theology (followed by most Aceh Muslims) concludes human beings are without free will, and all human conduct is dictated by God.	Affan Ramli, "Disaster Theology: Islamic Perspective," opinion, Serambi Aceh, October 10, 2007.
Merapi volcano eruption	October 26, 2010	Mbah Maridjan, defending his belief of being part of the cosmology of the Merapi volcanic "palace," is found dead after the first eruption.	Based on interviews with Agung eruption survivors in Arif et al., Merapi.
Padang earthquake	September 30, 2009	Minister of communication publishes announcement that the earthquake was caused by too much pornography presented by the media	BBC News, "Indonesia Minister Says Immorality Causes Disasters," November 28, 2009, http://news.bbc.co.uk/2/hi/asia-pacific/8384827.stm.
Raung volcano eruption	July 2015	The eruption is God's message to the (economic) elites that they must engage in introspection.	detikNews, "Raung Eruption, Major Anas: Elites to Introspect," detik.com, December 16, 2015.

In 2014, an interview was conducted with an elementary principal in Banda Aceh whose school had been designated as the school model for preparedness following intensive training that began in 2009.[11] She described how, during the 2012 event, teachers and children at her school had gone to the closest evacuation building, the Aceh Tsunami Museum. The principal herself had been personally involved in most of the trainings on preparedness and had conducted regular drills; yet, during the event, she went to pick up her family at her home, which was in the tsunami hazard zone near the coastline of the city. When asked why she chose to live in the area, she argued that it is up to God, not humans, to set up disasters.

In other words, despite her acceptance of the need for preparedness and intensive involvement in science-based preparedness measures, the principal's strongly held religious values overcame the motivation to act upon what scientists would refer to as "rational choice."

A 2013 article by Ahmad Arif in *Kompas* presented interesting findings on religious values and rational choices. Arman, a villager in Aceh Barat, rebuilt his home on the same spot where it had stood before the 2004 tsunami, even though half a dozen members of his family had been washed away and killed. Asked if he were anxious about living in the same area, he said, yes, of course; but, he continued, "We submit the decision to the Almighty (*pasrah*)." He believed God had decided it was not time yet for him and his wife to die, and that is why they had survived.[12] Arif's article examined the duality of the perception of risk, seeing it as greatly influenced by beliefs and faith. According to the author, the return of communities to danger zones is heavily influenced by *Asy Ariyah* theology, which suggests total submission to God's will; whenever and whatever disaster might occur, one has no choice as to whether to die or to live. The belief also shapes perceptions that "bad things" do not happen twice, at least in the same generation. On the other hand, during the 2012 earthquake, many ran away from the coastline, mostly in vehicles that ended up jammed in heavy traffic.

The *Asy Ariyah* theology is supportive to people after disasters, since it promotes the powerful mental strength communities need to accept the impact of disasters and move on. It may not, however, entirely support the idea of calculating and reducing risks in the future, although faith also requires humans to conduct all efforts (*ikhtiar*) before *pasrah*—that is, before giving in and leaving the final results to be decided by the Almighty.

Discussion

To obtain public compliance with disaster risk reduction efforts, those in the field need to look at different perspectives, including the way in which perceptions are socially constructed, that tend to be extremely divergent from scientific ideas on calculating risks. Agus Indiyanto and Argom Kuswanjono argued that the (structural) methodologies introduced by science are more favored in policymaking.[13] Anything other than the calculable or measurable is accounted as merely "illustration" of certain phenomena. Government, scientists, and disaster risk reduction practitioners predominantly adopt the perspective of calculable risks.

But time and again, communities have perceived and responded to disaster events in ways rooted in faith values they have held for generations, reflecting different ideas from or even resistance to the science more acceptable to government. Volcano hazards in the Merapi and Agung cultures, for example, are not seen as something bad or horrific. A blend of faith values and interventions by modern knowledge may also produce ambiguities in risk perceptions, as demonstrated by the fatalism expressed in Aceh in the face of the 2012 tsunami.

The experiences of the Mount Agung, Mount Merapi, and Aceh events provide valuable insights. In Agung and Merapi, deaths from volcanic eruptions are seen as given, which makes it reasonable for certain communities not to avoid them. Indeed, they even prepare themselves with ceremonies. The modern mitigation, meanwhile, emphasizes zero victims when a volcano erupts. Living within the communities on Mount Merapi and Mount

[11] Personal interview by Irina Rafliana, conducted during the ten-year commemoration of the Aceh tsunami, December 26, 2014.

[12] Ahmad Arif, "Kembali ke zona bahaya tsunami" [Return to the Tsunami Danger Zone], Kompas, March 7, 2013.

[13] Agus Indiyanto and Arqom Kuswanjono, eds., *Respons masyarakat lokal atas bencana* [Local Community's Response on Disasters] (Bandung, West Java: Mizan Pustaka Utama, 2012).

Agung, one may soon begin to appreciate the people's daily struggle to survive, which outweighs the less frequent risks emanating from the volcanoes. As the eruptions in these places have demonstrated, these people are extremely vulnerable, and their vulnerability is influenced by many variables as traditional beliefs become intertwined with social, economic, and political influences, creating complex scenarios at times of elevated risk. To understand the elements of their vulnerability, including cultural vulnerability, and so improve volcanic risk reduction, a new kind of interdisciplinary science is required.

Almost every year, people in Indonesia experience natural disasters, including volcanic eruptions, earthquakes, and tsunamis. In places like Mount Agung and Merapi, and even in Aceh, a mitigation approach relying on addressing the physical aspects of disasters will not be effective. The people who live on the mountain slopes or in coastal areas have their own ideas and opinions, which need to be thoroughly understood before risk reduction policies are made. In Aceh, for example, the perception of threats and hazards, including risks, evolved in ways that prompted the survivors to return to living along coastlines after disaster struck, and plans to move them away largely failed. It is important to understand the theology behind such responses, not merely emphasize the saving of lives from future threats.

Recommendation

From Agung, Merapi, and Aceh, we learn that volcanoes, earthquakes, and tsunamis are not only geological or geophysical phenomena; they are also cultural phenomena. For the people in those communities, natural disasters are often seen as failures in establishing harmony with risks, while—in the case of volcanic eruption, for example—prosperity and soil fertility are the fruits of a harmonious relationship with the "master of the mountain." In view of this, any mitigation strategy should be open and dialectical with local traditions, local knowledge, faith, and religions. Cultural dialogue should be encouraged to bridge the gap between policymakers who use modern mitigation plans and members of traditional society who still believe in the spirituality of mountains, and a social approach to disaster mitigation should be implemented, along with the provision of modern observation equipment.

Finally, all stakeholders should be humble, as the risk of disaster cannot be faced by modern knowledge alone or by the people's memory, which has proved too short for them to read all the patterns of volcanic eruption each time they recur. Memory and habits of disaster alertness should be continually renewed with humility, as nature's activities and human decisions always include some things that cannot be measured.

We see these actions as something that the community, as a whole, agrees upon. What is needed now is collaboration and investment to make progress on our broader goals of reducing disaster risk and loss in developing countries.

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