THE USE OF CATASTROPHE LOSS MODELLING METHODOLOGIES TO DESIGN AND MONITOR DISASTER RESILIENCE GOALS AND INDICATORS IN A POST-MDG FRAMEWORK

Robert Muir-Wood

December 6th 2012

Summary

The 2015 renewal of the Millennium Development Goals provides the unprecedented opportunity to incorporate goals around improved disaster resilience into the agenda for sustainable development.

The most powerful MDG goals have measurable outcomes: for example by 2015 - a reduction in annual maternal mortality in childbirth by three quarters and a reduction in deaths among children Under 5 by two thirds.

However, disasters, by their nature, are infrequent extremes for which it is not possible to identify the true average behavior from a single year or even a single decade. For example, between 1900 and 2009 no-one had been killed by an earthquake in Haiti.

This problem should not be used as an excuse to dilute the intent to ‘demonstrably reduce disaster impacts for all’ or to pursue initiatives that fail to have real impact.

The insurance industry has parallel problems around establishing the technical ‘average annualized loss’ price for catastrophe insurance, something that cannot be derived from the experience of losses alone.

In response, for the past twenty years, insurers and reinsurers have embraced the use of probabilistic catastrophe modelling, simulating the losses from 10,000-100,000 ‘versions of next year’ for the full geographical range of each insured peril.

The use of probabilistic catastrophe models can make it possible to design and measure development goals focused on ‘expected’ outcomes of disasters: such as the ‘expected average annual mortality rate’ from earthquakes.

Catastrophe models can be modified to generate the metrics most relevant for measuring resilience including: expected casualties, expected economic losses, and expected loss of houses and livelihoods.

The insurance industry integrates actuarial approaches for collecting and analyzing high frequency, low impact (so called ‘extensive’) claims, with modelling approaches for low frequency high severity ‘catastrophic’ (or ‘intensive’) events. The use of modelling for quantifying intensive catastrophic disaster risks needs to be allied with better data collection for assessing the high frequency extensive losses.

Metrics could be compared for different perils in the same country. Countries that share a similar hazard environment could be ranked for resilience.

In parallel with the expansion of catastrophe modeling for disasters, the function of ‘disaster risk auditing’ should be established. The disaster risk auditor will apply appropriate data on exposure and vulnerability, wherever possible within catastrophe models, to measure risk according to a set of international standards.

Risk auditing can also place all disasters into the context of their expected return periods and identify how risk is changing, whether from shifts in exposure, vulnerability or climate change. Risk auditing can also highlight when an intervention has prevented a disaster and enumerate ‘lives saved’.

Using consistent risk auditing methods, principally (but not solely) based on the use of approved catastrophe models, it becomes possible to frame a series of development goals that would be based on ‘expected’ (ie principally modelled) outcomes. For example by 2030:

- a 50% reduction in ‘expected fatalities’,
- a 50% reduction in ‘expected loss of homes and livelihoods’ and
- a 20% reduction in normalized ‘expected’ economic losses

Disaster catastrophe models and their outputs should be made available to developing countries to help design the policies and actions that would most cost-effectively achieve the biggest improvements in resilience.

Some of the catastrophe models covering the specific countries and perils that would be required for monitoring disaster resilience already exist, including within open access modelling initiatives.

Organizations such as the World Bank and the UN have recognized the importance of developing or commissioning their own catastrophe modelling capabilities.

There should now be focus on creating the budget and leadership to commission the development of catastrophe models for key unmodelled countries and perils presenting the highest risk of disasters, as for example drought in Africa.

New learning of relevance to improved modelling takes place after every disaster. Therefore catastrophe models need to be maintained and regularly updated.

Some extreme conditions, such as droughts, can be forecasted with long lead times, and again by employing probabilistic modeling it is possible to design the most appropriate interventions.

The full global disaster resilience agenda of catastrophe modelling, the dissemination of modelled outputs, the collection of baseline data and training in low income countries, is estimated to require a worldwide budget of $30-50M per year.

As with integrating catastrophe modelling into the insurance industry through the 1990s, for the disaster and development community there will be similar challenges relating to cost, data and culture.

The availability of catastrophe models will have many ancillary benefits for lower income countries, supporting the development of risk transfer instruments, and quantifying the outcomes of alternative disaster risk management options.

1.0 Introduction

The 2015 renewal of the Millennium Development Goals provides the unprecedented opportunity to incorporate specific goals around improved disaster resilience into the agenda for sustainable development. The renewal of the Hyogo Framework for Action, the global agreement to build resilience to disasters, also occurs in 2015. This coincidence adds to the opportunity to include improved disaster resilience as a key component of the renewed development goals.

In the 2010 Rio text 'The Future we Want' (UN, 2010)[1] Sustainable Development Goals are required to be: 'action-oriented, concise and easy to communicate, limited in number, aspirational, global in nature and universally applicable to all countries while taking into account different national realities, capacities and levels of development and respecting national policies and priorities'.

In reviewing options for development goals focused on disaster resilience Mitchell (2012)[2] identifies three classes of potential goals in terms of how their outcomes can be measured:

1. Those based on national policy actions. For example by 2030 to have:

    - A comprehensive disaster risk assessment embedded in sector-based development planning and for every community to have a risk register, or
    - Allocated 5% of annual national budgets to reducing disaster risk
    - Every community has an annually reviewed disaster risk reduction plan and has access to modern early warning systems

2. Those based on achieving reductions in the exposure and/or vulnerability of those people and communities exposed to disasters:

    - By 2030 to have halved the vulnerability and exposure of [the poorest quartile] and the infrastructure and services on which they rely.

3. Those based on actual outcomes:

    - Halving disaster mortality and the economic impacts of disasters by 2030

[1] UN (2012) 'The Future We Want'. Rio+20 Outcome Document http://www.un.org/en/sustainablefuture/

[2] Mitchell T. (2012) Options for including disaster resilience in post-2015 development goals, ODI Background Note, Sept 2012 12p

The most powerful of the original MDG goals are specific in their measurable outcomes: for example by 2015 - a reduction in annual maternal mortality in childbirth by three quarters, and a reduction in deaths among Children Under 5 by two thirds. Such simple goals are possible because progress can be monitored from annual mortality statistics. However, disasters, by their nature, are infrequent extremes for which it is not possible to identify the true average behavior from a single year, or even a single decade. Before the 2010 earthquake, in which 80,000-250,000 died, no-one had been killed by an earthquake in Haiti for more than a century.

This difficulty in measuring outcomes could mean that disaster resilience goals focus on actions alone. However, focusing actions has the potential to dilute the power and efficacy of the goals. For example, 'having a disaster plan' is not the same as demonstrably halving disaster fatalities. A goal could be an action to extend the retrofitting of schools to be more earthquake resistant, rather than to achieve a measurable reduction in earthquake fatalities among children. In pursuit of the 'action' schools might be retrofitted in areas where there is very little prospect of earthquakes. Also the focus on schools might miss the point that children only spend one sixth of their time at school and are therefore more at risk from the collapse of their homes.

So how is it possible to maintain the idea of measuring outcomes and why is it so difficult to measure performance from disaster statistics?

2.0 The 'fat-tailed' distribution of extremes

Catastrophes, such as earthquakes, floods, volcanic eruptions, droughts and storms, occur as infrequent extreme events and can generate very large impacts. More frequent events tend to be relatively localized in their impacts. When plotted in terms of severity and frequency, statistically such a population is termed 'highly skewed', or 'fat tailed', in that there are more extreme events than would be expected in a normal statistical population distributed around a mean. (See Fig 1)

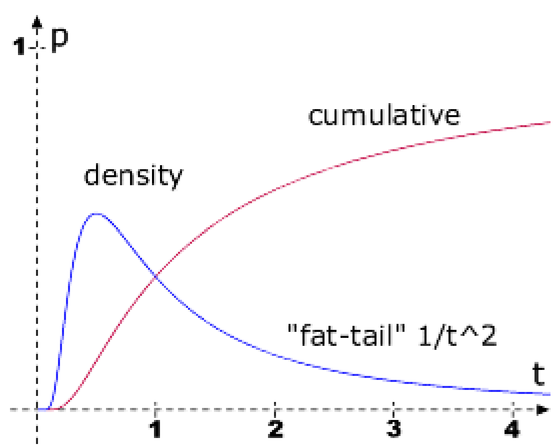

Figure 1: A fat tailed 'skewed' distribution expressed as both a probability density function (blue) and cumulative density function (red)

The extreme fat-tailed nature of disaster losses and casualties has significant implications in how to relate empirical experience and observations to evaluating the risk of catastrophes. In a normal statistical distribution the mode of a series of samples (ie the number for which half the samples lie above and half below) will be the same as the mean or average of the overall distribution. However for a highly skewed distribution, the mean may be many times higher than the mode of individual samples.

As a result, a few years or even decades of historical information on disaster casualties or losses will typically not capture a sufficient sample of extreme behavior to be able to identify the 'mean', such as the annual average fatalities from earthquakes in a particular territory. Most short-term samples will substantially under-report the true vulnerability of a population to specific threats from extremes. (In five decades of the past 100 years, earthquake casualties in Japan have been less than one hundred, although the decadal mean has been more than 18,000.)

On occasion a short time sample will include a rare and catastrophic extreme. It then becomes hard to interpret this observation, which may give the impression that the time averaged losses are exceptionally high, unless the true return period of that loss can be determined.

More than 30,000 people were killed in Sri Lanka in the 2004 Indian Ocean tsunami. If a starting date was selected at the year 2000 this could be taken to imply an average mortality of 2500 per year. However the return period of this extreme tsunami is now known to be more than 500 years. Tsunamis from other credible subduction zone plate boundary sources around the Indian Ocean would not be high enough to cause significant loss of life on the island. Therefore perhaps the true long term empirical annual average fatality rate from tsunamis is 30,000 divided by 500, which would be 60 per year. Since 2004, there has been a significant reduction in the exposure and vulnerability to tsunamis as well as the provision of early warning systems along the coast of Sri Lanka, so that a repeat of the 2004 tsunami today would result in much reduced life loss. We also know that the 2004 earthquake which generated the tsunami could not occur again until the plate boundary strain has re accumulated (a process that will likely take hundreds of years[3]), so as a forward looking modelled risk metric the annualized rate of tsunami casualties in Sri Lanka for the next few decades will be much lower than even the long term exposure and vulnerability updated average.

Simply extending the record of impacts further back into history cannot solve this problem alone, as the population, buildings or assets at risk, as well as the susceptibility or vulnerability to the extreme, are all likely to have changed over time. For many developing countries it may anyway not be possible to employ a historical record of extreme observations beyond a few decades.

This sampling problem presents a key challenge for measuring the outcome of interventions designed to reduce the impact of catastrophes, such as deaths in earthquakes. How can one know that specific interventions are 'succeeding' or that goals are being reached? An unusual large event may happen,

[3] **Jankaew K, Atwater BF, Sawai Y, Choowong M, Charoentitirat T, Martin ME, et al**. Medieval forewarning of the 2004 Indian Ocean tsunami in Thailand. Nature 2008;455:1228–31.

even while underlying levels of risk are being reduced. The absence of losses may appear to show risk is being reduced when in fact it is rising. Between 1900 and 2009 no-one had died from an earthquake in Haiti (although many had died in earthquakes in the 18th and 19th Centuries). Other drivers may also be modifying the level of underlying risk, whether from climate change or urbanization.

3.0 Probabilistic catastrophe loss modelling methodologies

The insurance industry likewise has to confront the challenge of establishing the technical 'average annualized loss' price for catastrophe insurance[4]**.** This cost cannot be derived from the experience of losses alone. In response, for the past twenty years, insurers and reinsurers have embraced probabilistic catastrophe modelling. This involves the simulation of 10,000- 100,000 'versions of next year' and is designed to capture the full range of potential events, along with the specific exposure at risk and the vulnerability of that exposure to loss. The sum of the loss from each modelled catastrophe, multiplied by that event's respective probability, is the annualized cost for that event. Adding together the annualized cost of all the simulated events provides the annualized cost of the risk from that class of catastrophes.

Typically, the time horizon of these alternative futures is the 'next year' for insurance contracts (although catastrophe risk securitizations may require a 3-5 year perspective).

The catastrophe model comprises a set of five modules (Fig 2).

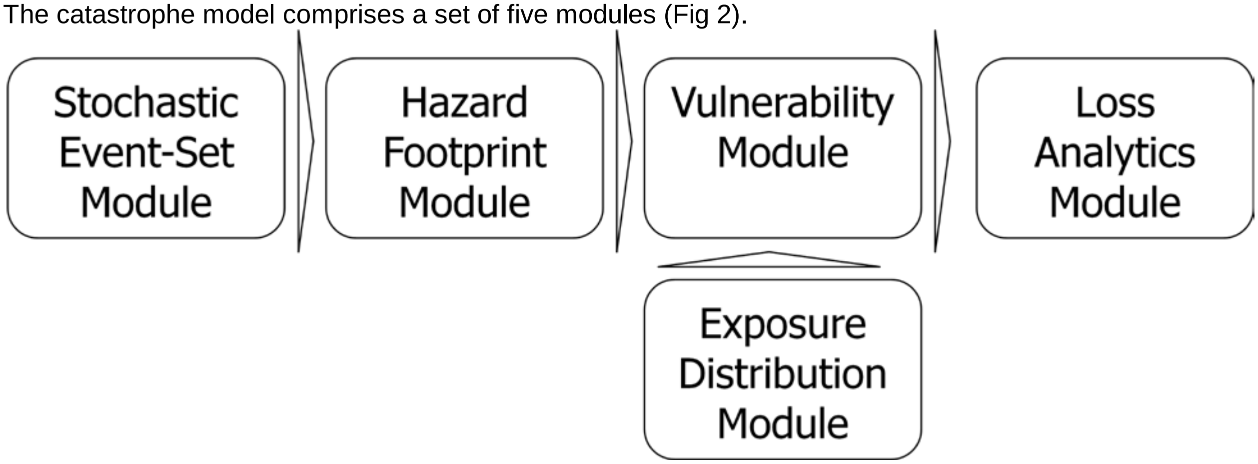

Figure 2: The five modules of the probabilistic catastrophe model

[4] http://www.rms.com/Publications/RMS%20Guide%202008.pdf

3.1 The Stochastic Module

The stochastic simulation procedure employs a range of physics-based modelling and statistical techniques, founded on the scientific understanding of the phenomenon in question, to generate a very large randomized set of potential extreme events. For example this could be an exhaustive set of tropical cyclone tracks, including the intensity and storm size at each point along the track. It could also be a set of potential earthquake locations and sizes, or a full range of potential floods or droughts, including very rare and intense events. If these events have been generated through a random stochastic process then they will have equal probabilities. However for computational efficiency it is preferable to 'importance sample' the event set, so that there are a smaller number of higher probability moderate severity events and a large and diverse number of low probability extreme events.

For some perils, such as earthquakes or tropical cyclones, there is a simple 'phenomenological' definition as to what constitutes an 'event' (ie. a mainshock earthquake or single hurricane storm structure and track). However, for other perils, such as flood and drought, the 'event' can only be defined in terms of the spatial and temporal extent of the extreme.

In generating a stochastic population of 'events', consideration also has to be given to all the different ways in which extremes may be interdependent. Raised groundwater levels and river flows can lead to multiple episodes of flooding. A drought can increase the potential for a heatwave. One earthquake may trigger another mainshock.

3.2 The Hazard Module

The '***hazard module***' comprises the high resolution spatial and temporal representation ('footprint') of each simulated event in terms of the specific agents that cause damage. This footprint could be the level of shaking at each location surrounding an earthquake source, or the maximum windspeed in the passage of a storm. While the earthquake is effectively instantaneous in time, for a windstorm or flood the footprint is the maximum windspeed or water height experienced at each location throughout the event. For long lasting hazards, as it would not be appropriate to collapse the whole phenomenon into a single footprint, the hazard can be characterized as a series of footprints through time: for example the daily extent of flooding, or the monthly spatial extent of drought, as represented by the soil moisture deficit or Palmer Drought Index[5].

Where there is more than one agent of damage, a single event will need to be represented as more than one hazard footprint. An earthquake, for example, could be represented by footprints for both ground shaking and tsunami flood depths. A tropical cyclone could be represented as three footprints:

---

1. [5] **Wayne Palmer**, "Meteorological Drought". Research paper no.45, U.S. Department of Commerce Weather Bureau, February 1965 (58 pgs). http://www.ncdc.noaa.gov/temp-and-precip/drought/docs/palmer.pdf

one of maximum windspeeds, another for the maximum flood heights from the storm surge, and a third for the consequences of inland precipitation.

3.3 The exposure module

The exposure module contains details of the location and the characteristics of the 'exposure' at risk. For insurance loss modelling, 'exposure' is typically the property at risk of damage, or the business at risk of interruption. Crops can be modelled as exposed to damage from weather or disease[6].

Insurance loss models have also considered human exposure to death or injury in both earthquakes and terrorist attacks. While building exposure remains fixed in the path of an extreme event, human exposure in homes, offices and industries is strongly a function of the time of day. For perils that cannot be forecasted, such as earthquakes, or terrorist attacks, the population can be mapped at two representative times (such as 'evening/ night' and 'workday'), and weights applied to the probability of outcome according to what proportion of the overall time these states represent.

3.4 The vulnerability module

For insurance loss modeling, *vulnerability* is the susceptibility to damage, or other forms of loss, as a result of the impact of the hazard. *Vulnerability functions* define the loss in terms of the % of the value expected to be lost for that property type at a defined hazard value, specific to the exposure category. For example the exposure could be a wooden single storey house in Barbados, built in 1972, for which the vulnerability would convert a peak gust windspeed of 210kph into a mean damage ratio of 15% of the property's value. For interrupted business activity, vulnerability is the % loss of business income in the month or year after the catastrophe. For casualties in earthquakes, % injury or % death to the human exposure will principally be a derivative of the level of damage and collapse of those buildings in which people were located. For crops, vulnerability is the % by which the yield is reduced.

3.5 The financial module

The financial module takes the outputs of the risk cost calculations and delivers them in the form of exceedance probability relationships and maps.

The loss from each simulated event multiplied by its annual probability is the amount of money that would need to be set aside each year to pay for restoring the impact of that event. By summing the

[6] **Boissonnade A., Stojanovski P., Mortgat C.,** (2012). Designing And Implementing Weather Indices – Towards Resolving the Challenges of Weather Based Indices for Agro Risk, *The Challenges of Index-Based Insurance for Food Security in Developing Countries - Technical Workshop*, EC Joint Research Centre (JRC) and IRI (Earth Institute, Columbia University), JRC / Ispra, Italy.

loss multiplied by the probability for all the stochastic events we arrive at the 'average annualized loss': the amount that would need to be set aside each year to fund all future losses, also known by insurers as the 'technical premium'.

The loss exceedance probability ('EP curve') relationship represents the size of the loss vs the annual probability (see Fig 3). A point on the EP curve reveals the loss expected at a particular return period – for example the 1% annual exceedance probability - also known as the '100 year average return period loss'. The EP curve can be plotted in terms of the largest individual loss expected in a given year (the Occurrence Exceedance Probability – or OEP), or the sum of all loss events in the year (the Aggregate Exceedance Probability - AEP).

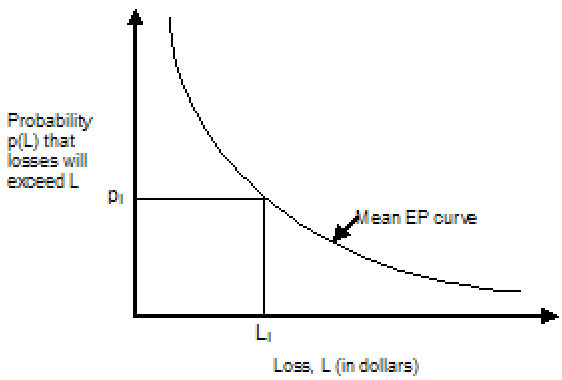

Figure 2: The Exceedance Probability (Risk) Curve

The outputs from risk models can also be displayed in the form of GIS (geographic information system) digital maps. These could be maps of the losses at each community from individual scenarios within the stochastic event set, or of metrics at some annual probability, such as the annualized loss cost, or the loss to be expected at the hundred year average return period. A map could show the expected loss of life (as numbers of the dead or percentage of the population) in each town or neighbourhood in a particular simulated earthquake, or the annual probability of life loss from all potential earthquakes. For crops the map could show the probability that the yield of a crop could be reduced by 50%.

The model is designed to provide great flexibility about what can be viewed in terms of outputs. Typically the model user will switch between the mapped risk perspective and that of viewing the overall exceedance probability of loss.

3.6 Model calibration benchmarks

The results derived from probabilistic catastrophe loss models can be very sensitive to variations in the input parameters. Typically the vulnerability function is a higher order function of the hazard values, so that a 10% increase in damaging windspeeds (for example) may give a 50-70% increase in modeled loss. Therefore, wherever possible, every component of the model needs to be independently calibrated. Calibrations should be from data sets independent of how the model has been developed.

A flood model would be expected to show consistency with river flow and flood height return periods for wherever there is gauged data, for the period of the record (which might be 20-50 years). For a drought model this could be the duration and severity of rainfall deficits at individual observing stations, for the length of their records.

Given that the purpose of the catastrophe model is to evaluate the potential spatial scale of extremes, calibrations should, where possible, include the return periods of extremes at widely separated locations within the same event – for example the probability that a ten year return period flood or drought will be experienced synchronously at separate cities at the same time.

Some of the most important calibrations concern the comparison of modelled and actual losses. To make data consistent past losses will have to be 'normalized': adjusted for both inflation and changes in exposure and wealth (and also potentially in vulnerability), so that the past losses are transformed into those that 'would have been experienced' today. The uncertainties of such normalization procedures limit the potential to employ loss data for calibration extending back more than 30-40 years. Where high quality loss data is available one will expect to see that the model shows consistency with the actual experience of normalized losses at short (ie. 2, 5 and perhaps 10 year) return periods.

As new disasters occur all the new information they reveal will need to be dissected and employed in testing and updating the components of the model. This could include new hazard data for defining return periods or event parameterization, and new loss data by which to adjust assumptions about vulnerabilities, or missing sources of exposure. By this means the model is always learning from all the relevant data that can be extracted from the latest catastrophe. (However given that in a 15 year period, the largest loss event experienced might reflect a '2 year return period' or a '100 year return period' it is the data on vulnerability or exposure extracted from the event, not the loss itself, that should be applied to the modelling.)

4.0 Metrics for Measuring Disaster Resilience

To extend the catastrophe modeling framework, models need to generate measures of relevance to disaster resilience. It is proposed that three metrics should be employed: a) economic loss, b) casualties and c) homes/livelihoods.

4.1 Economic loss.

The principal metric for current catastrophe loss modeling is the total cost of insurance claims, which can include: payments for the repair of damage to buildings; costs for replacing damaged contents; compensation for interrupted business income; payment for the costs of alternative accommodation while the insured's home of place of work is repaired; hospital payments for treatment to the injured, disability payouts for those left with permanent injuries and life payments to the relatives of the deceased.

Insurance loss is of course a subset of total economic loss and is simply the sum of all claims paid. There is no such formal accounting for economic loss, which may be distributed across many balance sheets, can include 'losses' that are never repaid with money, and inevitably blends into costs for reconstruction and the economic activity that reconstruction brings.

Therefore definitions are required around what constitutes economic loss[7] so that the modelling can be designed to output the same definitions. Damage to property and infrastructure is generally straightforward to define. It can be more of a challenge to define interrupted economic activity or the costs of deaths or injuries. For consistency across impacts reported in different countries, and at different times, as well as between empirical and modelled perspectives, what falls in and out of the definition of economic loss for a disaster will need to be standardized and clearly defined.

4.2 Casualties

Catastrophe loss models have already been adapted to output expected loss of life for perils such as earthquake with no prospect of a warning[8][9]. The population at risk is distributed into buildings according to the time of day. The number of casualties is based on what proportion of the buildings are in different damage states, with casualties concentrating where buildings collapse.

In many situations the same earthquake would give very different life loss according to the time of day at which it occurs. A Magnitude 7.1 earthquake in Puente Hills[10], Los Angeles was modelled to cause 500 fatalities if it occurred at night (when the large majority will be at home in their single storey wood frame houses) but more than ten times this number if it occurred in weekday daytime, when many people will be located in multi-storey office buildings most susceptible to collapse. To find average mortalities for this earthquake we would need to consider both time scenarios, and weight the outcomes according to their relative likelihood.

For forecastable perils, modelling fatalities will need to consider the process of evacuation[11]. As people evacuate, they will take with them (according to the lead time and their opportunities for evacuation) a proportion of moveable items such as cars, possessions or livestock. Not everyone will evacuate, and this proportion will be important to evaluate, based on: a) whether there have been evacuation drills, b) universal disaster education, c) previous ‘false alarm’, or successful, evacuations, and d) the level of assistance provided. Sometimes, an extreme turns out to be bigger than the planned scenario, when even evacuation destinations may be impacted (as happened in certain coastal towns in the 2011 Japan tsunami).

---

[7] Stéphane Hallegatte and Valentin Przyluski (2010) The Economics of Natural Disasters Concepts and Methods, World Bank, Policy Research Working Paper 5507

[8] S. T. Maqsood and J. Schwarz (2011) Estimation of Human Casualties from Earthquakes in Pakistan—An Engineering Approach, Seismological Research Letters, January/February 2011, v. 82, p. 32-41,

[9] Robin Spence, Emily So & Charles Scawthorn (2011) Human Casualties in Earthquakes, Progress in Modelling and Mitigation, Springer Publications 322p

[10] http://www.scec.org/research/050525puentehills.html

[11] Matthias MÜck (2008) Tsunami Evacuation Modelling Development and application of a spatial information system supporting tsunami evacuation planning in South-West Bali
Diploma Thesis, Institut fÜr Geographie an der Universitat Regensburg.

4.3 Housing and Livelihoods.

A third modelled resilience metric concerns ‘loss of housing and livelihoods’. For houses, this could be the point at which damage reaches a threshold at which the property can no longer be considered habitable, either for a period or permanently. Loss of livelihoods requires information on the exposure of people in their place of work, and the degradation of this workplace as a result of the extreme. For example in a flood this would be agricultural land that is no longer accessible, as well as houses and factories that are underwater. In a drought it would be the degree to which the productive capacity of the land had passed below the threshold where it could no longer feed or support the farmer.

5.0 Measuring resilience to the spectrum of disasters

‘Resilience’ is the capacity to withstand and recover from disasters. The IPCC SREX[12] definition is: ‘The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.’

Resilience can be linked to a particular class of extreme (such as earthquakes) or more holistically to all those classes of extremes (for example earthquakes, floods and droughts) expected at that location. Resilience is often found to be peril specific.

Over the past 50 years householders in Port au Prince, Haiti changed from building out of wood to constructing with concrete, in part to increase their resilience to hurricane wind and rain (as well as to termites) but also in response to the lack of local timber as the country had largely been deforested. The focus on reducing the impacts of hurricanes and storms meant the city unwittingly increased its vulnerability to earthquakes. The majority of casualties in the 2010 earthquake were in concrete buildings, constructed without proper reinforcing (or with any input from a structural engineer).

In testing disaster resilience we need to explore the full spectrum of extremes, to check whether resilience is in some way bounded or peril specific.

Along the Pacific coast of northeast Japan, up until 2010 the official earthquake and tsunami hazard models for Japan assumed that no earthquake would occur larger than those experienced in the previous 150 years: around Magnitude 8. The absolute certainty with which the upper bound magnitudes were decreed meant that it was possible to consider building tsunami defences (and

---

[12] **IPCC (2011).** Summary for Policymakers. In: Intergovernmental Panel on Climate Change Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C. B., Barros, V., Stocker, T.F., Qin, D., Dokken, D., Ebi, K.L., Mastrandrea, M. D., Mach, K. J., Plattner, G.-K., Allen, S., Tignor, M. and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

locate supplementary generators at the six Fukushima Daichi nuclear power plants) at an elevation that would not be affected by a tsunami from this ‘design earthquake’. When in March 2011 the offshore plate boundary megafault (where the Pacific plate dives down beneath Japan) broke in an earthquake almost twenty times larger than had been anticipated. The accompanying tsunami was also far larger than expected and the tsunami walls and gates at the coastal towns along the coast of northeast Japan and the diesel generators at the Fukushima nuclear power plants were over-whelmed. The tsunami walls were designed to survive moderate sized tsunamis, but were not able to withstand the largest of all tsunamis, as in 2011. Many people believed that the walls would protect them and therefore may not have evacuated[13]. Here was a situation in which the tsunami walls provided safety for some range of extremes, but offered no protection, or even ‘negative resilience’, for a more intense extreme.

Therefore measuring resilience to disasters requires that we should first identify the complete range of peril types that can affect that location. Then for each class of peril we need to investigate the full spectrum of potential severities and geographies, to see how a particular resilience strategy is expected to perform. As was the situation prior to 2011 for evaluating earthquake hazard along the Pacific coast of Japan, we need to be particularly careful to assume there is some arbitrary upper bound to the maximum size of earthquakes, tsunamis or tropical cyclones, simply because no larger extreme has occurred over the past 100-200 years.

We can measure resilience through seeing how the particular strategies would accommodate a wide range of potential extremes. We should explore where resilience has a ‘hard’ or ‘soft’ boundary: ie whether an event beyond the design level has catastrophic consequences, or whether, even in a more extreme event, the community sustains residual protection.

6.0 Integration of extensive and intensive risks

The insurance industry only employs catastrophe models for those perils and losses for which detailed claims data cannot provide a full understanding of the risks. For example losses in car accidents or house fires typically do not correlate with one another and statistics on these losses can best be collected and analyzed actuarially. For earthquakes and hurricanes, extreme events are rare and so the risk has to be quantified using catastrophe loss models.

However some perils, such as windstorms and rainfall-related floods can exhibit both a high frequency of claims and rare extreme events. In such situations insurers employ a hybrid approach, taking the results of the catastrophe model down to a loss return period of once in every one or two years, and then analyzing actual loss experience for smaller more frequent losses.

---

[13] **Kenji Okazaki**, GRIPS (2012) April 01 Research on effective evacuation against the tsunami disaster **http://r-center.grips.ac.jp/ResearchProjectDetails/57/**

A similar approach will be required for integrating information on extensive and intensive risks where these apply to the same underlying peril. High quality data collection will be required to assess the loss distribution for extensive risks. Beyond one or two year return periods, the modelled losses should be more complete.

This will likely mean that data collection around extensive risks will need to be significantly improved. For the past 40 years in China, information has been collected at district and county level on every damaging natural event, with all information being centralized in a high resolution National Risk Atlas[14] of all the natural perils (geological, climatological and including animal and insect pests). The Atlas provides a useful overview of the relative levels of risk (although inevitably may give an imperfect picture of the most extreme and infrequent perils such as earthquake). The Desinventar Network[15] has also collected information on 'daily disasters' of small and medium sized impact in Latin America since the mid-1990s. There would be many benefits in establishing a comparable network of data collection procedures so as to create a 'Risk Atlas for Africa'.

7.0 Disaster Risk auditing

To measure disaster risk, a function of 'risk auditing' will be required to ensure that risk is assessed independently and consistently. Such risk auditing could be undertaken by an international agency or by a private auditing company. The Disaster Risk Auditor will need to check that catastrophe models meet the appropriate standards, check that the correct exposure data and relevant vulnerabilities have been collected and updated and thereby confirm the expected modelled outcome for the key resilience metrics. Where catastrophe models are not available, the Disaster Risk Auditor will assess these resilience metrics based on whatever information can be collected from recent losses, underlying exposures and vulnerabilities.

Disaster risk auditing will require establishing a consistent set of criteria – a risk auditing 'international standard'. If the scientific understanding of the hazard has changed – as a result of climate change for example - then the audit will need to separate out those changes in modelled outcomes that result from modifications to the hazard in the model from those relating to actual performance in that country.

Disaster risk auditing will also need to identify the inherent return period of recent catastrophes in that territory. (Such return periods are context-specific: for example winds from a hurricane may have '100 year return period' at a specific recording station, generate a '50 year return period' loss in the worst affected County, but only have a 5 year return period loss in the State.) The auditor could also usefully provide information on the numbers of lives and costs saved from situations where actions taken have averted a disaster, whether a successful evacuation, a flood defence that protects a city, or where buildings have been constructed to resist earthquake damages.

[14] **Atlas of Natural Disaster Risk of China** (2011) Science Press Publisher, 244p ISBN/ISSN : 9787030311696

[15] http://www.desinventar.org/

The auditor should have a particular focus on identifying the risk in those situations where a high loss catastrophe is anticipated but has not occurred for many decades, and hence the population is particularly unprepared. In the aftermath of a catastrophe, actions are typically taken to reduce risk. The actual risk in Port au Prince, Haiti was much higher in 2009 than it was in 2011 even though the risk perceived by the population was much higher in 2011 than in 2009. The key is to recognize the latent risk ahead of the catastrophe.

> For example, the objective might be to reduce life loss in earthquakes in Pakistani Kashmir by 50% over the next decade.
>
> We have an earthquake hazard catastrophe model for the potential sources, sizes, probabilities and footprints of earthquakes in the region. A disaster risk reduction project has been established to achieve a 50% reduction in earthquake casualties in a decade. We have details of the building exposure, all the houses and schools, as existed at the start of the project, characterized in terms of their locations, building types and vulnerabilities. We have a model for the distribution of the population at two representative times of day. We then run the catastrophe model to find the exceedance probability curve for life loss. We find that the ‘100 year return period’ ie 1% annual probability earthquake, is expected to kill 6000 people in this community. Meanwhile the average annual number expected to be killed in earthquakes is 90.
>
> At the end of the decade, we know the new distribution of building exposure and population as well as what proportion of buildings have been retrofitted, and which new schools and houses have been constructed in accord with a new earthquake resistant building code. We re-run our model for the new exposure and vulnerabilities. The number of expected casualties at the 1% annual probability has now reduced to 2500 while the annual life loss is 40. We have met our target.
>
> Meanwhile in the decade over which this project has run, there were no significant earthquakes, so the result is strictly a modelled one. However in a neighbouring province, there was a catastrophic earthquake, from which we have analyzed the detailed damage data and found that our estimations for collapse rates and casualties relative to the earthquake intensity can be refined relative to those that we were modeling. We revisit the original and updated analysis with our new information, so that we are using the best available science.

8.0 The setting of consistent baselines for disaster risk reduction across countries and perils.

If one can measure national risk in a consistent fashion with standard metrics then it becomes possible to make direct comparisons of disaster risk.

This comparison could be across different perils in the same country or region: for example we can compare the relative costs per capita of earthquakes and tropical cyclones in an island in the Lesser Antilles such as St Lucia. We want to measure the expected average annualized losses from each of the perils, as well as the magnitude of infrequent losses to be expected at return periods of 50 or 100 years or beyond. At return periods of 20 or 50 years, losses from tropical cyclones will dominate economic impacts, while at 200 year return periods earthquake may be the dominant peril. At even more remote probabilities, volcanic eruption could become the largest potential source of losses16. We may find that tropical cyclones dominate the annualized economic losses while earthquakes dominate the annualized casualties.

We can also compare risk metrics from one country to another. We could rank countries for expected annualized earthquake mortality statistics or for annualized losses as a percentage of GDP from catastrophes, based on a consistent modelling approach. In terms of comparison across countries, we can rank countries according to their modelled financial losses and human casualties expected at some key return periods – such as the '200 year return period' (ie 0.5% annual probability). Inevitably such a ranking would highlight both the level of the hazard to which a country is subjected as well as the level of resilience.

We can also compare risk metrics for the same country at different times in history (by varying the exposure and vulnerability), to show the progress being made to reduce the impacts of disasters. Again the modelling needs to be undertaken in a consistent framework to ensure the results are directly comparable.

We can also compare risk metrics for the same country at different times in history (by varying the exposure and vulnerability), to show the progress being made to reduce the impacts of disasters. Again the modelling needs to be undertaken in a consistent framework to ensure the results are directly comparable.

Given that the hazard climate of different countries varies on a broad spectrum, we could place countries in 'leagues' which share a consistent level of hazard. We could then identify best in class and use that as a target for other countries in the same hazard league.

9.0 Targeting Resilience within Development Goals

Using consistent, internationally agreed disaster risk auditing methods, principally based on the use of appropriately designed and calibrated catastrophe models, it becomes possible to frame a series of development goals based on 'expected' (ie principally modelled) outcomes. This means that it

[16] **Michel-Kerjan, E., Hochrainer-Stigler, S., Kunreuther, H., Linnerooth-Bayer, J., Mechler, R., Muir-Wood, R., Ranger, N., Vaziri, P., and Young M**. 2012. Catastrophe Risk Models for Evaluating Disaster Risk Reduction Investments in Developing Countries **Risk Analysis *(in litt)*** http://opim.wharton.upenn.edu/risk/library/WP201207_EMK-SHS-HK-JLB_EvaluatingDisasterReduction.pdf

becomes possible to set targets for disaster risk reduction without concern for whether it is possible to measure their performance from empirical observations over short time-windows (such as a year).

A range of indicators are tracked which generate datasets that are then fed into the catastrophe modelling framework. These indicators would include detailed exposure data on buildings, infrastructure and people, the latest information that can be derived or inferred on vulnerabilities, as well as the state of evacuation planning.

Development goals could then be based on percentage reductions in expected outcomes relative to current (expected) levels. These percentages need to be set to be both realistic and but also substantial. For example by 2030:

- a 50% reduction in 'expected disaster fatalities'
- a 50% reduction in 'expected loss of homes and livelihoods in disasters'
- a 20% reduction in normalized 'expected' economic losses in disasters

Inevitably the focus on life safety in earthquake building codes has meant less concern among engineers to reduce the economic impacts of earthquakes. Buildings are expected to absorb strong shaking through suffering some internal damage to non-structural components but without collapsing and thereby imperiling their occupants. Therefore percentage targets for reductions in economic impacts will need to be set at lower levels than for life loss. However the next generation of buildings in high earthquake hazard locations will increasingly be designed to achieve the dual goals to ensure life safety and to avoid significant levels of damage, as has already been achieved for hurricane building codes[17]. Zoning of new development can be used to reduce exposure in tsunami zones, floodplains or locations prone to earthquake liquefaction and landslides. Even so a 20% reduction in normalized economic losses from disasters (ie after taking out the actual economic growth) over fifteen years is likely to prove challenging.

In setting targets we should acknowledge that some countries have already made significant progress in reducing the impacts of disasters and that beyond some level, there may be diminishing returns relative to the costs. However, as highlighted by the 2011 Japan earthquake, even the most advanced disaster management cultures may still have areas in which to focus to further reduce their disaster casualties.

[17] http://www.nist.gov/el/nehrp/program_earthquake.cfm

10.0 Use of modelling for planning resilience activities

Having set measurable resilience goals, catastrophe modeling outputs can be made available to support actions around risk communication and risk reduction and to enable countries to identify how best to achieve their targets.

Michel-Kerjan et al. (2012)[18] highlight applications of catastrophe models for measuring the benefits and cost of reductions in disaster exposure.

At a national level the model could be used for designing a flood insurance scheme. What would be the appropriate rating scheme for such a system? How would the scheme need to be structured in terms of capital and reinsurance to withstand losses at a range of return periods out to 200 years? What would be the impact of deductibles?

The modelling framework could also be used to measure the impact of any new development, such as a school, new housing or new infrastructure, in terms of the contribution the development will make to the three key resilience metrics. If the development is replacing a pre-existing housing settlement or school, the planners will need to show the degree to which the new building will reduce 'expected lives loss' and 'expected economic impacts'.

For local applications, the model outputs may need to be converted into formats that can be more easily understood and digested. Which flood alleviation scheme could achieve the greatest reduction in overall levels of risk relative to the cost? The modelled output would be used to identify the number of houses flooded with and without the scheme.

At a village level the model output might comprise flood hazard maps posted to inform people around the extent of flooding at a key return periods (such as the 1 in 100 year), so as to discourage new development inside the flood zones, and inform people where they should evacuate when a flood (or tsunami) is forecasted.

Drought risk information could be supplied in terms of the real time probability of experiencing a drought during this year's growing season.

11.0 The agenda for catastrophe modelling in support of driving improvements in disaster resilience.

The agenda for measuring disaster resilience requires that catastrophe models, outputting the three key resilience metrics, are expanded to cover those countries and perils for which there is the

[18] http://opim.wharton.upenn.edu/risk/library/WP201207_EMK-SHS-HK-JLB_EvaluatingDisasterReduction.pdf

greatest risk of disasters. In surveying the catastrophe modelling landscape, there are a number of commercial companies and agencies already involved in modelling.

Commercial catastrophe models

The three principal commercial modelling companies: Risk Management Solutions (RMS), AIR Worldwide and EQECAT, focus their modelling agenda on insured catastrophe perils (earthquake, tropical cyclone, windstorm, severe convective storm and flood) in those countries with a pre-existing, or emerging insurance sector.

The focus has been on property insurance, and therefore direct and indirect consequences of damage. Models have also been developed (by RMS) to output expected earthquake fatalities in the US and Japan, as well as casualties in a pandemic.

However commercial models are unavailable for the poorest countries or for most slow onset perils. There are no commercial models for drought or flood in Africa.

Beyond the commercial catastrophe models, a number of initiatives have begun to supplement the development of models for low income countries.

The Global Earthquake Model[19]:

The GEM initiative has set out to develop earthquake catastrophe models to cover the whole globe as well as to develop building inventory data and building specific vulnerabilities to support the modeling of earthquake casualties.

World Bank: CAPRA platform

In Central America, the World Bank has supported the development of the open source platform for disaster risk management: CAPRA[20], a Disaster Risk Information Platform for use in decision making, based on a unified methodology and tools for assessing disaster risk. The World Bank pioneered the sponsorship of catastrophe modelling capability to create a new catastrophe insurance facility in Turkey[21].

Caribbean Risk Reinsurance Facility Loss Model

The Caribbean Catastrophe Risk Reinsurance Facility, set up in 2007 with backing from the World Bank and donor countries to provide a parametric insurance facility for governments in the Caribbean,

---

[19] http://www.globalquakemodel.org/landing/index.html
[20] http://www.ecapra.org/
[21] http://webarchive.iiasa.ac.at/Research/RAV/conf/IDRiM06/pres/tabuchi.pdf

has now developed its own ‘Facility Loss Model[22]’ capability to quantify the risk posed by hurricanes (from wind and rain) and earthquakes in the Caribbean.

UNISDR

The UNISDR[23] has a program to develop basic catastrophe modeling capabilities for a wide range of countries and perils.

Asia Risk Center

The Asia Risk Center[24] was established to develop high resolution models of agricultural risk in Asia to support the development of index based risk transfer products.

Catastrophe models now need to be commissioned and developed where there is the greatest concentration of disaster risk: in particular life loss and homes/livelihoods. For applications around disaster risk reduction, models will need to be maintained for the long-term and regularly updated, requiring that they have a sustained budget and remain the responsibility of enduring commercial companies, international institutions or national development agencies.

For Africa, the principal perils of concern will be flood and drought.

A typical drought catastrophe model might represent tens of thousands of potential droughts, each different in their spatiotemporal extent and severity and each weighted for their annual probability. As part of the analysis it will be important to identify the degree to which droughts can be linked in their probabilities to the El Nino Southern Oscillation signature, or other climatological indicators that could be employed in long term drought forecasting.

Having established the modelling framework for considering the spatial extent and duration of potential droughts under today’s climatology, the hazard parameters could be modified by employing the output of climate models run at suitable resolution for some period later into the 21st Century. Such a climate change modified drought catastrophe model could then be employed to explore the consequences of anticipated changes in the duration, intensity and spatial scale of drought hazard.

---

[22] http://www.ccrif.org/

[23] http://www.unisdr.org/

[24] http://www.asiariskcentre.com/content/publications/ARC%20Press%20Draft.pdf

12.0 Summary

Catastrophe loss models have become invaluable to the insurance industry. What began in the late 1980s as university research projects rapidly grew into a commercial modelling industry that today is worth around $600M each year. Although events such as the New Zealand and Japan earthquakes of 2011 revealed missing elements of modelling (as around tsunami and earthquake liquefaction impacts), catastrophe models today provide an essential risk management framework for the reinsurance industry.

Catastrophe loss modelling is now breaking out of its focus on current insurance markets to be employed for measuring disaster risk more widely. In Mexico, catastrophe loss models are employed for quantifying national economic disaster risks, and to provide the analysis for calculating the costs of transferring some part of this risk in the form of catastrophe risk securitization[25]. In the future there will be increasing diversity of sources of modeling, with commercial modelers building 'industrial strength' models used for demonstrating the critical solvency for insurers and reinsurers as well as a wide range of academic, UN/World Bank and open source modeling initiatives.

Models to be employed for risk auditing for future development goals will need to be of sufficient standard for performing this function. According to the level of funding, it might take at least five years before the models cover the majority of the world's disasters. Risk auditing (see Section 7.0) will need to employ simpler methodologies where models are not yet available.

So what lies in the way of developing and making available such models?

We can identify three principal barriers:

1. Availability of data

There will be many challenges around the availability of hazard and loss data for building and calibrating catastrophe models for developing countries. There will be a scarcity of long term weather observations, and river gauge flow data. There may be no national dataset on the population and location of buildings. However these challenges should not be considered a barrier to modelling. Climatological Reanalysis datasets (going back to at least 1950) infer daily weather data (from satellite imagery and surrounding measurements) for regions without observations. There is also significant experience (as employed by hydraulic engineers) for deriving extreme flow curves for unmonitored rivers based on catchment geology, topography and climatology. Satellite imagery has proved very powerful for developing datasets on human population and building exposure.

2. Cost

[25] http://www.gfdrr.org/gfdrr/sites/gfdrr.org/files/Chapter_13-Mexico-Disaster_Risk_Management_in_Mexico-from_response_to_risk_transfer.pdf

Robust, high quality catastrophe models are relatively expensive to develop and deliver. A typical catastrophe model is developed by a team of 3-6 scientist/modellers working for 12-18 months. Modellers working for catastrophe modeling companies almost all have PhDs in relevant areas of science, applied mathematics, statistics and engineering. Product managers are required to understand the client needs around catastrophe models. Design specifications and model development are complex and iterative and require strong project management. Modellers need to access powerful computing resources and may have significant data costs. There may however be opportunities to extend capabilities available on open source platforms such as CAPRA or GEM. Accessing commercial models may prove the best option for those regions in which these have already been developed, and commercial agencies that already have teams of modellers in place, could prove the most efficient place in which to commission certain new catastrophe models. Modelling for measuring development goals will need to be institutionalized in international development agencies, or private companies, to ensure that models are maintained and upgraded for the long term. The cost for developing a full suite of catastrophe models, covering all the principal perils to support the worldwide disaster resilience agenda, along with the collection of detailed data on extensive risks and the dissemination of modelled outputs, training and support would require a budget estimated at $30-50M per year. (A lower budget would achieve a reduced agenda, or a longer time period for obtaining full coverage.) An initial focus could be to develop models for Africa covering drought and flood.

3. Culture

The disaster risk community has not previously engaged with a scientific modelling community. This will require cultural adjustment, in particular to get scientists to understand how the disaster risk reduction community defines vulnerability and then how this definition can be mapped to specific metrics on modelled resilience, as set out in this report. This transformation will also require programmes of education in developing countries, to understand how catastrophe models works, what data they require and how a new generation of model users can be trained to understand how to explore the costs and benefits of alternative national and local actions around disaster risk reduction.

Yet as with the world of insurance, which also did not employ any research scientists until the advent of catastrophe models, the entry of scientifically trained individuals into the field is likely to create many benefits beyond the specific modelling applications.