Strengthening Financial Resilience to Disasters in Asia:
Exploring Regional Solutions

CATASTROPHE RISK MODELLING AND LIVE HAZARD DATA FOR PARAMETRIC RISK FINANCING IN ASIA

Disaster Risk Financing & Insurance Program
SUPPORTED BY WORLD BANK GROUP

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All the work related to this project can be found at www.financialprotectionforum.org/asiaregional

Abbreviations

ADB	Asian Development Bank
CCRIF	Caribbean Catastrophe Risk Insurance Facility
DRFIP	Disaster Risk Financing and Insurance Program
GFDRR	Global Facility for Disaster Reduction and Recovery
GVH	Global Vegetation Health
JAXA	Japan Aerospace Exploration Agency
NCEP	National Centers for Environmental Prediction
NCHMF	National Center for Hydro-Meteorological Forecasting
NOAA	National Oceanic and Atmospheric Administration
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
USGS	United States Geological Survey

Icons

DROUGHT FLOOD EARTHQUAKE CYCLONE

Executive Summary

This note is part of a program undertaken by the World Bank Disaster Risk Financing and Insurance Program in partnership with the Rockefeller Foundation to develop regional options for disaster risk financing for developing countries in Asia. Its findings are the product of technical work to identify, evaluate, and catalog catastrophe data suitable for disaster risk financing for selected Asian countries. Catastrophe data of appropriate quality and resolution are required to design financial policies, strategies, and mechanisms that respond effectively to disasters. Such data are typically available within catastrophe risk models for risk quantification, and as part of live data feeds on hazard occurrence for product structuring.

Fourteen Asian countries were selected for the exercise, and catalogs were produced to indicate where data can support near-term product development for parametric disaster risk financing, and where further investment is needed. Two catalogs were produced: one details available catastrophe risk models and one details available live hazard data sources suitable for parametric disaster risk financing.[1] Users can search the catalogs by peril and country to return a range of information:

- *Live hazard data available*. Information includes hazard intensity parameters, data provider details, strengths and weaknesses for use in parametric mechanisms, temporal and spatial resolution, and an overall rating for usability.
- *Catastrophe risk models available*. Information includes peril and secondary peril coverage, available model components, details of provider, and compatibility of the model for use with different types of live hazard data as inputs for parametric mechanisms.

These catalogs, the full technical report, and a set of index prototypes demonstrating how existing data sources and models could be used in the design of disaster-contingent parametric triggers can be found online.*

The exercise found that there are a number of options readily available to support developing Asian countries in designing and implementing parametric disaster risk financing mechanisms. However, some perils are better supported than others **Figures ES.1**, **ES.2**, and **ES.3** show coverage for tropical cyclone, earthquake, and flood, respectively. For tropical cyclone, development of probabilistic catastrophe risk models is identified as a priority for the Lao People's Democratic Republic and Myanmar. For

[1] Scope focused on *parametric mechanisms*, which use hazard parameters to infer event impacts, as the likely best option for implementation in environments of catastrophe data scarcity and low insurance penetration.

* www.financialprotectionforum.org/asiaregional

The exercise further showed that the entire region needs additional investment in high-quality exposure and vulnerability data, along with investment in local capacity for recording and reporting hazard information.

earthquake, work to supplement the global networks with local seismometer network information is identified as a priority, along with model development for Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal. For flood, the priority is research into the best method to derive a post-event flood footprint using the available live data sources for rainfall, river flow, and inundation extent; model development for Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal is likewise a priority. For drought, further research is needed into the ability of existing drought indices to capture event impacts of interest. A priority area of investigation for drought is how hindcast data sets or statistical extrapolation of historical time series for drought index could support an interim modeling approach. The exercise shows that even where live hazard data and models are available, live data outputs and model inputs are often not compatible. The issue can be resolved by adapting sources and models, but this work is not trivial. The index prototypes accompanying this work explore the issue further.[2]

The exercise further showed that the entire region needs additional investment in high-quality exposure and vulnerability data, along with investment in local capacity for recording and reporting hazard information. The high-quality exposure and vulnerability data that support the loss perspective relevant to governments are lacking across the region. Improvements to be considered for the local recording and reporting of hazard data include promoting data sharing and standards; standardizing observation types and formatting of local data sets to increase utility for parametric triggers; and increasing instrumentation in the long term.

Given regional interest in pooling of catastrophe risk, and the nature of the physical systems generating catastrophe events, a country-cluster approach to model development should be considered. Some options for coherent subclusters within the region are presented in the note. Regionwide consistency of models is important to prevent inequity between countries in the pricing and settlement of risk financing contracts. The development of a modeling platform to facilitate a regional, or subregional, approach to disaster risk financing could build on an existing platform from a single model provider, or use a regional multi-provider

[2] Ibid. www.financialprotectionforum.org/asiaregional

[3] World Bank, "Toward a Regional Approach to Disaster Risk Finance in Asia: Discussion Paper," 2016, http://documents.worldbank.org/curated/en/584961480930535198/Toward-a-regional-approach-to-disaster-risk-finance-in-Asia-discussion-paper.

platform (such as the OASIS framework which hosts models from multiple providers). The open framework approach provides longer-term flexibility to countries for model development. However, platforms supporting multiple provider components are a new phenomenon, and in the near future may still present a longer, more complex route to model development.

Any further development work based on the data and models identified as part of this exercise should be directed by country priorities. The investment and level of effort required to proceed with parametric disaster risk financing vary substantially by peril and country. However, country priorities need to be the determining factor in where to focus efforts. A review of country priorities and engagements in this area is available in the World Bank publication "Toward a Regional Approach to Disaster Risk Finance in Asia."[3]

FIGURE ES.1.
Probabilistic Model Coverage for Tropical Cyclone

Source: World Bank, *Catastrophe Risk Modeling and Live Hazard Data for Parametric Risk Financing in Asia: Final Technical Report* (Washington, DC: World Bank, 2017).

FIGURE ES.2.
Probabilistic Model Coverage for Earthquake

Source: World Bank, *Catastrophe Risk Modeling and Live Hazard Data for Parametric Risk Financing in Asia: Final Technical Report* (Washington, DC: World Bank, 2017).

FIGURE ES.3.

Probabilistic Model Coverage for Flood

Source: World Bank, *Catastrophe Risk Modeling and Live Hazard Data for Parametric Risk Financing in Asia: Final Technical Report* (Washington, DC: World Bank, 2017).

Note: Full probabilistic flood risk models are anticipated for Cambodia, Myanmar, and the Philippines for 2018. These three countries have hazard-only models at present.

Objectives, Outputs, and Scope

Although a number of Asian countries are already global leaders in developing policies, systems, and instruments for financial protection against disasters, a protection gap remains in Asia. According to an initial review by the World Bank Disaster Risk Financing and Insurance Program in partnership with the Rockefeller Foundation, some Asian countries have been working for several years on national strategies for disaster risk financing, but in general the use of such instruments is extremely limited across the region.[4] The review considered how a regional platform for disaster risk financing could contribute to resilience and determined that any such regional approach would have to accommodate countries' differing priorities, allow for the needs of both large and small economies, and allow for the heterogeneity of peril exposure across the region.

This note is part of a program of work to develop regional options for disaster risk financing for developing countries in Asia. It is being undertaken by the World Bank in partnership with the Rockefeller Foundation and seeks to examine opportunities and barriers to the development of disaster risk financing policies, strategies, and instruments. The approach includes three pillars:

01. Demand for disaster risk financing mechanisms
02. Availability of catastrophe risk modeling and live hazard data for the design and implementation of disaster risk financing policies, strategies, and instruments
03. Supply of disaster risk financing instruments

The objective and scope of the work undertaken and summarized in this paper pertain to pillar 2 above. Specifically, **this note seeks to evaluate available catastrophe risk modeling and live hazard data for the design and implementation of disaster risk financing policies, strategies, and instruments in selected Asian countries**.

To produce this note, technical work was undertaken to identify, evaluate, and catalog catastrophe data suitable for the development of disaster risk financing for developing countries in Asia. Suitable data must be of appropriate quality and resolution to quantify the potential losses to be managed, and to structure financial products and mechanisms that respond effectively to disasters.

The data that are appropriate for these tasks are typically available within catastrophe risk models for risk quantification, and as part of dynamic (live) data feeds on hazard occurrence for structuring products and determining parametric contract payouts when events occur. In order to be suitable to support the development of disaster-contingent financing instruments, models and data need to meet certain criteria. These are detailed in **box 1**.

[4] See World Bank, "Toward a Regional Approach to Disaster Risk Finance in Asia."

BOX 01

Prerequisite Features of Catastrophe Risk Models and Live Hazard Data for Financial Instrument Structuring

The volume and range of catastrophe risk data available to support disaster risk management for Asian countries is vast. However, only a small subset of these data will be suitable to support disaster risk financing, whether in the form of market-based instruments (such as insurance) or budgetary mechanisms (such as contingency funds).

Catastrophe risk models are used within parametric disaster risk financing for pricing and design of contracts (or contingent mechanisms), and for determining payouts after events in cases where the nature of the contingent trigger is "modeled loss." The PCRAFI Insurance Program provides such an example of a modeled loss trigger.[a]

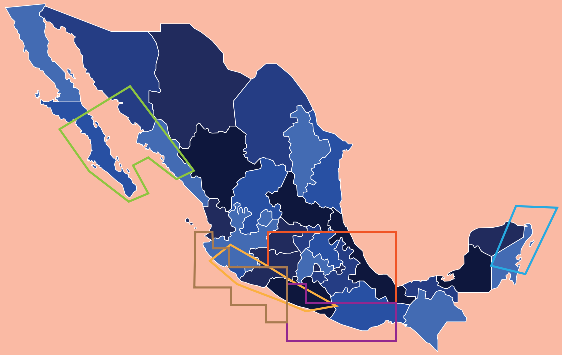
To fulfill these functions, models must contain a stochastic event set; these models are typically referred to as probabilistic catastrophe risk models, and their framework is outlined further in appendix A. Models of risk in the form of hazard maps or scenarios cannot be used to structure or price parametric disaster risk financing instruments because they do not include information on frequency of event occurrence or hazard information of specific individual disaster events. The team is aware of risk assessment platforms that do not fit the criteria and described framework applied for this exercise in their "off-the-shelf" form (and are thus not taken within scope), but that could still have utility for certain disaster risk financing purposes if adapted. One example is the Deltares Aqueduct Global Flood Risk Analyser.[b]

Live hazard data are used within parametric disaster risk financing to determine payouts after events. Under the Multicat Mexico catastrophe bond, for example, payouts were triggered based on United States Geological Survey (USGS) reporting of earthquake magnitude and depth and National Hurricane Center reporting of hurricane minimum central pressure within pre-specified zones (see figure B1.1).[c] To be useful for parametric contract settlement, hazard data must serve as the basis of an index, metric, or footprint that correlates with event impact. Data must also be

- Reported frequently (and soon after the event)
- Credible
- Transparent
- Independent
- Consistent/stable

Three different types of parametric payout triggers are described for the purposes of this report: first-generation "Cat-in-a-Box" structures that pay out if parameters exceed a threshold within a geographical region; second-generation index structures that comprise additional geographic information on hazard variability; and third-generation modeled loss structures where parameters are used within a catastrophe model to construct a footprint.

FIGURE 1:
Zones for 2009 Multicat Mexico Catastrophe Bond



[a] The PCRAFI (Pacific Catastrophe Risk Assessment and Financing Initiative) Insurance Program transferred catastrophic earthquake, tsunami, and tropical cyclone risk for five Pacific island countries via the World Bank to the international markets; see the PCRAFI website at http://pcrafi.sopac.org/. The program uses information on hazard parameters (e.g., earthquake magnitude, maximum sustained winds) to develop an event footprint within catastrophe risk models after the event. Estimated losses and payouts are then determined using the model.

[b] Information about this Deltares product is available at https://www.deltares.nl/en/projects/aqueduct-flood-risk-intervention-assessment-global-cities/?return_id=4196.

[c] In 2009, the government of Mexico transferred $290 million of catastrophe risk to the markets via the World Bank's Multicat Mexico catastrophe bond platform.

The emphasis of the work was on models and data suitable for *parametric* disaster risk financing, as these mechanisms are typically the only feasible option for establishing instruments in the near-term in environments of catastrophe data scarcity and low insurance penetration. Parametric disaster risk financing encompasses any contingent financial instrument that releases funds in the event of a severe disaster, where the severity of the disaster is determined by the physical parameters of the event. Parametric mechanisms offer both an efficient route to establishing a disaster risk financing instrument in the environments described above, and a rapid payout—typically within days or weeks of an event. They do, however, carry the significant downside of basis risk—that is, the risk that the payout made through the instrument is substantially different from the losses actually incurred. The models and data examined for this exercise could be used to design and implement a range of contingent financing instruments for disasters based on parametric triggers, including insurance, contingent credit, or budgetary mechanisms such as reserve funds. More information on the role of different financing instruments for post-disaster operational phases can be accessed in the World Bank publication *Financial Protection Against Disasters: An Operational Framework for Disaster* Risk *Financing and Insurance.*[5]

The scope of work covered a long-list of 14 Asian countries for which international or regional data sources were examined, and a short-list of five countries for which a deep dive into local data sources was conducted (table 1). The perils of drought, earthquake, flood, and tropical cyclone were taken within scope.

TABLE 1:
Country Scope

Long-list countries within scope	*Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, the Philippines, Sri Lanka, Thailand, Vietnam.*
Short-list countries selected for deep dive	*Bangladesh, Indonesia, Pakistan, Sri Lanka, Vietnam.*

The outputs of this exercise are intended to inform countries, their development partners, and technical practitioners on where data can support near-term product development for parametric disaster risk financing, and where further investment is needed. In addition to this note, two catalogs were produced, one detailing available catastrophe risk models and one detailing available live hazard data sources suitable for parametric disaster risk financing.[6] Users can search the catalogs by peril and country to return a range of information:

- *Live hazard data available.* Information includes hazard intensity parameters, data provider details, strengths and weaknesses for use in parametric mechanisms, temporal and spatial resolution, and an overall rating for usability.

[5] World Bank, *Financial Protection Against Disasters: An Operational Framework for Disaster Risk Financing and Insurance* (Washington, DC: World Bank, 2014), https://openknowledge.worldbank.org/handle/10986/21725.

[6] Scope focused on *parametric* mechanisms, which use hazard parameters to infer event impacts, as the likely best option for implementation in environments of catastrophe data scarcity and low insurance penetration.

Parametric mechanisms offer both an efficient route to establishing a disaster risk financing instrument despite data scarcity and low insurance penetration and a rapid payout—typically within days or weeks of an event.

- *Catastrophe risk models available*. Information includes peril and secondary peril coverage, available model components, details of provider, and compatibility of the model for use with different types of live hazard data as inputs for parametric mechanisms.

These catalogs, the full technical report, and a set of index prototypes demonstrating how existing data sources and models could be used in the design of disaster-contingent parametric triggers can be found online.*

* www.financialprotectionforum.org/asiaregional

Availability of Catastrophe Risk Models in the Region

Thirteen model providers were identified with models, or model components, that fit the relevance criteria for parametric disaster risk financing for the perils and countries within scope. As explained in **box 1**, probabilistic models with suitably extensive stochastic event sets to support the design and pricing of parametric disaster risk financing mechanisms, or model components with the potential to be developed to serve this function, were taken within scope. Catastrophe risk models can be broken down into core components of hazard, vulnerability, and exposure. The hazard component gives a view of the occurrence of different levels of hazard and associated probabilities, but all components are needed to generate loss estimates. More details on the components of probabilistic catastrophe risk models can be found in appendix A and in the GFDRR publication *Understanding Risk: The Evolution of Disaster Risk Assessment*.[7] Twenty-one catastrophe risk modeling organizations/vendors with the capabilities to produce such models were identified and contacted as part of the project. Of these, 13 model providers were identified as having relevant models (**table 2**). Twelve in-scope providers gave information directly to the project team to support the catalog. Publicly available information was relied upon for the 13th identified provider.[8] *The team is aware that additional models may exist in the form of proprietary in-house models developed and used by risk carriers. However, only models made available to third parties (commercially or otherwise) were cataloged for this exercise.*

TABLE 2:

Model Providers Identified as Having In-scope Models

(given perils and countries within scope, and the parametric disaster risk financing focus)

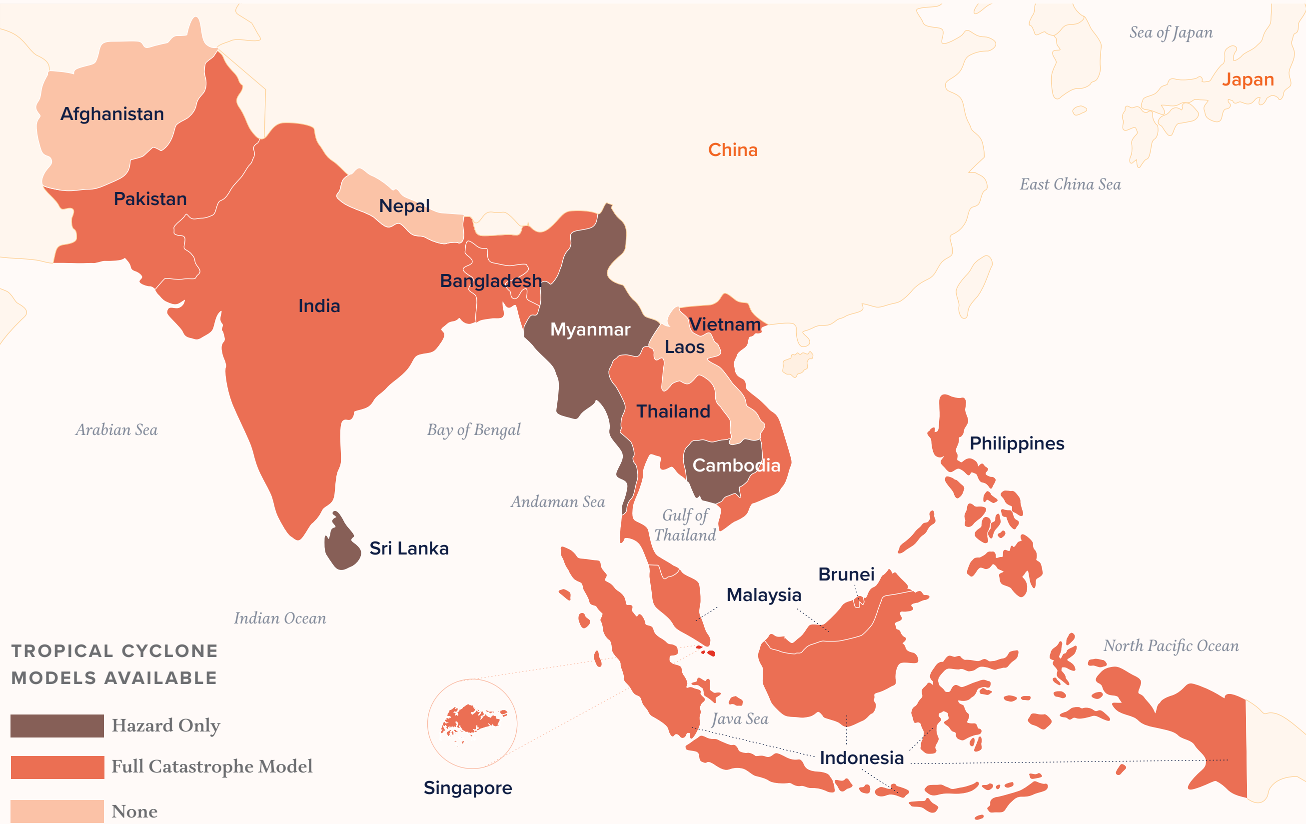
Model provider	Abbreviation
AgRisk	AGR
AIR Worldwide	AIR
Aon Benfield Impact Forecasting	IF
Applied Research Associates	ARA
Catalytics	CAT
CoreLogic	CL
Guy Carpenter	GC
Institute of Catastrophe Risk Management	ICRM
Imperial College	IMP
JBA Risk Management	JBA
KatRisk	KR
RMS	RMS
UK Met Office	UKMO

[7] GFDRR, *Understanding Risk: The Evolution of Disaster Risk Assessment* (Washington, DC: World Bank, 2014), https://www.gfdrr.org/sites/gfdrr.org/files/publication/_Understanding_Risk-Web_Version-rev_1.7.3.pdf.

[8] Only publicly available information was used for the Institute of Catastrophe Risk Management. For all other vendors with relevant models, information was provided through direct contact.

Tropical cyclone is the best-covered peril in the region, but Myanmar and Lao PDR face significant tropical cyclone exposure and lack catastrophe models. Lao PDR has no available model or relevant model components. A hazard-only model is available for Myanmar, but development of additional exposure and vulnerability components would be needed to support design and pricing of financing mechanisms. Full probabilistic catastrophe risk models are available for all other countries examined with material tropical cyclone exposure. Sri Lanka and Cambodia have hazard-only model components, but low peril exposure. See **figure 1**.

FIGURE 1:
Probabilistic Model Coverage for Tropical Cyclone



Source: World Bank, *Catastrophe Risk Modeling and Live Hazard Data for Parametric Risk Financing in Asia: Final Technical Report* (Washington, DC: World Bank, 2017).

Full probabilistic models are available for earthquake for 7 of the 14 countries examined, but gaps remain for some of the most exposed countries, notably Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal. Sri Lanka and Cambodia also lack earthquake models, but their earthquake peril exposure is substantially lower. It should be noted that secondary seismic risk from tsunami is present for all countries with coastal exposure, although this risk is mitigated for Cambodia due to its sheltered position. See **figure 2**.

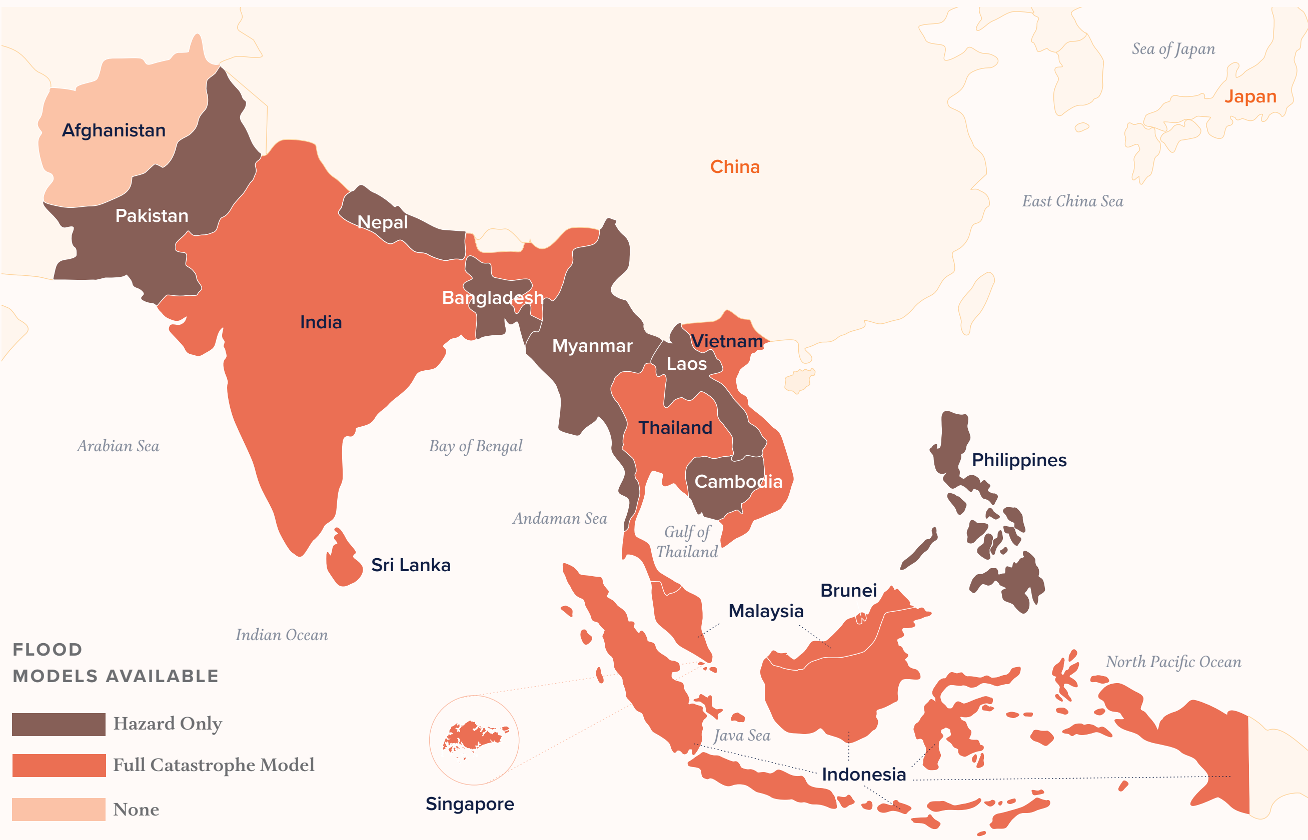
FIGURE 2:
Probabilistic Model Coverage for Earthquake

Source: World Bank, *Catastrophe Risk Modeling and Live Hazard Data for Parametric Risk Financing in Asia: Final Technical Report* (Washington, DC: World Bank, 2017).

Flood coverage across the region has improved significantly in recent years, and there is currently a substantial amount of development activity, with full probabilistic models available or forthcoming within the next year for 9 out of the 14 countries. Gaps remain for Afghanistan, Bangladesh, Lao PDR, Nepal, and Pakistan, although hazard-only models are available for all these countries with the exception of Afghanistan. As noted above, hazard-only models would require the addition of exposure and vulnerability components to fully support the development of financing mechanisms. See **figure 3**.

FIGURE 3:

Probabilistic Model Coverage for Flood



Source: World Bank, *Catastrophe Risk Modeling and Live Hazard Data for Parametric Risk Financing in Asia: Final Technical Report* (Washington, DC: World Bank, 2017).

Note: Full probabilistic flood risk models are anticipated for Cambodia, Myanmar, and the Philippines for 2018. These three countries have hazard-only models at present.

For drought, no catastrophe models of suitable scope were identified. However, an ensemble data set by the UK Met Office that may be useful for this peril was included in the catalog, subject to further analytical work. AgRisk is also known to have a crop model for India that incorporates drought in addition to other perils. In the absence of catastrophe risk models, a near-term option to support disaster risk financing could be to make use of the available time series for drought indicators or indices. For example, the National Oceanic and Atmospheric Administration (NOAA) Global Vegetation Health (GVH) composite global drought index has been produced since 1981,[9] so there is a 30-plus-year time series that could be built upon.[10] An alternative approach to the statistical extrapolation of indices based on available parameters is to extrapolate data using a modeled physical basis. For example, hindcast data sets based on metrics such as temperature and precipitation could be used. The UK Met Office and Global Parametrics are identified providers of promising hindcast data sets for drought for Asia.[11] Approaches using these time series of indicators would need to validate them against actual experience on the ground.

When considering priorities for improving regional model coverage, it important to consider cross-border consistency of models. Given the current interest in—and preliminary technical work on[12]— a regional risk pooling facility for Asian countries, there is a need for a catastrophe risk model or modeling platform that provides consistency across countries and potentially uses a single cross-country stochastic event set. Existing model coverage is split across a number of model providers. If countries opt for a collaborative approach to disaster risk financing, the catastrophe risk models to support any such approach should be produced using consistent methodologies to avoid inequity between countries in the pricing and settlement of any risk financing contracts. For example, models developed on the basis of differing hazard parameters (e.g., peak ground acceleration versus spectral acceleration for earthquake) will require a different process for determining any modeled-loss-type post-event payout. Cross-border consistency in models also facilitates better capture of correlation/diversification effects, which is important in determining the added value of a combined approach to disaster risk financing through a pool.

Given the physical characteristics of the systems in the region where hazard events take place, countries could be grouped into subregions for future model development; this approach would also mitigate the cross-border consistency issues raised above. For example, given the hydrological characteristics of this region, a Mekong River basin group (Lao PDR, Cambodia, Vietnam, Thailand, and Myanmar) could be approached collectively, and a Ganges and Brahmaputra basin group (India, Bangladesh, and Nepal) could be considered. For earthquake, a subregional source model covering Afghanistan, Pakistan, India, Nepal, and Bangladesh would be appropriate. Basinwide approaches for tropical cyclone are already standard in the development of catastrophe risk models for the region.

An additional gap in current models relates to their ability to capture the link between hazard and ultimate

[9]The NOAA GVH is a seven-day composite global drought index available in 1km, 4km, and 16km resolution that is based on several vegetation health indices derived from remote sensing. See "Appendix A. Live Data Source Catalog" in the full technical report more information.

[10]Both Exeter University and Imperial College London are developing statistical techniques to extend these types of data sets.

[11]The Global Parametrics hindcast data set in question was originally produced under a GlobalAgRisk-led Rockefeller Foundation grant.

[12]Under the South East Asia Flood Risk Assessment for Regional DRF Mechanism project, the World Bank is currently providing technical assistance to develop flood risk pool options for Cambodia, Lao PDR, and Myanmar.

> **Countries could be grouped into sub-regions for future model development, thereby mitigating cross-border consistency issues.**

loss; model development in this area would be required across all the countries examined. Although parametric triggers demand a particular focus on the hazard component of models, model components that capture vulnerability and exposure are also needed in order to determine the levels of loss that any financial instrument is seeking to cover. This ability to determine loss levels is a core part of product design, establishing accurate sources of exposure and vulnerability data is essential. Although these exist within the catastrophe models identified for the region, they are geared toward re/insurance industry use. Consequently, a government's contingent liability—what a ministry of finance and disaster risk management agency would be looking to manage—will not be explicitly modeled as a loss perspective. Exposure databases or vulnerability curves for infrastructure are also less likely to be included in models than those for more traditional commercial, residential, and industrial property stock. While some extrapolation of government losses is possible from traditional loss perspectives that are available, explicit (and hence accurate) capture of public contingent liability will require additional model development.

Availability of Live Hazard Data for Parametric Disaster Risk Financing

As box 1 details, live hazard data that can be used immediately after an event to give a view of its severity are critical for parametric disaster risk financing. It is on the basis of this information that contingent parametric financing instruments pay out. For example, the Caribbean Catastrophe Risk Insurance Facility (CCRIF) uses hazard information reported post-event by the USGS for its parametric earthquake insurance. Parameters such as latitude and longitude of event, depth, and teleseismic moment magnitude are downloaded from the USGS reporting sites and input into a catastrophe risk model to produce an estimate of loss and hence payout. The PCRAFI Insurance Program uses information on storm position (latitude, longitude) and wind speed (one-minute maximum sustained) reported by the Joint Typhoon Warning Center as inputs into catastrophe risk models to determine payouts for tropical cyclones. The scope of data and nature of use for triggering depend on the complexity of the parametric index:

- Simple event parameters such as moment magnitude are used “raw” for first-generation Cat-in-a-Box structures that pay out if parameters exceed a threshold within a certain geographical region (e.g., Multicat Mexico catastrophe bond).
- Geographic footprints of events, such as wind speeds reported by a network of anemometers, serve second-generation parametric index structures (e.g., Pylon II windstorm catastrophe bond for EDF)
- A range of parameters (simple single measures per event, or with the additional geographic information of footprints) is fed into catastrophe models to produce third-generation modeled loss structures (e.g., PCRAFI Insurance Program).

In order to design and price (and potentially determine payouts for) a contingent financing instrument, live hazard data sources need to be compatible with the catastrophe risk models being used. They must also fulfill certain criteria:

- *Credibility.* The data source must be a trusted one that produces reliable high-quality data.
- *Transparency.* The source must be accessible to all counterparties/stakeholders to the contingent financing contract or mechanism, and methodologies of production must be understood.
- *Independence.* The source must be objective, and cannot be influenced by any party with a stake in the contingent financing mechanism.
- *Consistency/stability.* The source must continue to report the same scope of data for the term of the contingent mechanism.

FLOOD

Flood presents the biggest challenge in the use of live hazard data for parametric disaster risk financing, as the significant spatial differentiation of hazard across flood events demands a high-resolution view of the peril. This issue is not limited to developing countries, but is also seen in the international risk transfer markets where parametric flood triggers are rare. Many of the live hazard data sources identified for Asia flood under this exercise were either indirect captures of the hazard (e.g., rainfall rate and river flow) or remote observation of flood extent via satellites. These sources are consistent with existing parametric triggers used for risk transfer (such as for CCRIF and the Pacific) where flood impacts post-event are estimated using rainfall data input into a catastrophe risk model. The use of (remote) earth observation data to capture flood extent is more "experimental" in this context. Given the limitations of identified sources, a combined approach may be most appropriate. Some options are given in appendix C of the full technical report, "Prototypes for Parametric Disaster Risk Financing Indices."

Seventeen regional sources of potential live hazard data suitable for disaster risk financing were identified for flood, covering the countries of interest. Of these sources, 12 were rated as medium or high for their usability in a financing context. All of the medium- and high-rated live data sources are satellite based. However, the spatial resolution and hazard parameters for each source vary. For example, the University of Maryland operates a Global Flood Monitoring System, which uses satellite-derived rainfall[13] as an input to a hydrological runoff and routing model. In contrast, the Asia-Pacific Regional Space Agency Forum provides earth observation–derived flood extent from the Sentinel Asia satellite constellation. For countries examined at the local level, a number of additional sources were identified, mostly gauge networks producing river flow or rainfall data. The density and usability of these local sources varied dramatically country to country. Three different hazard intensity parameters are available from the regional and local data sources: river flow, rainfall rate, and flood extent. Flood depth is the most direct intensity measure. However, the only live data set found to report flood depth had a spatial resolution of 0.125 degrees, which is too coarse to be useful for defining a footprint for disaster risk financing purposes. The sources identified are summarized by intensity parameter in **box 2**.

[13] Satellite-derived rainfall is based on NASA TRMM Multi-Satellite Precipitation Analysis.

BOX 02 Summary of Identified Live Hazard Data Sources for Flood

01. River flow

River flow data require a catastrophe model for a flood footprint to be produced. Most data sets are derived from gauges and managed by local entities. Therefore, only one regionwide data set was identified: satellite-derived streamflow from the **Dartmouth Flood Observatory**. At the local level, data suitable to capture river flooding for gauged catchments was identified from sources including the **Bangladesh Water Development Board; Tech4water Group** and **Balai Hidrologi dan** Air (Indonesia); the **Pakistan Flood Forecasting Division;** the **Sri Lanka Irrigation Department;** and the **National Center for Hydro-Meteorological Forecasting (NCHMF)** and the **Mekong River Commission** (for Vietnam).[a] The **Ganges-Brahmaputra Flood Awareness and Prediction System** also provides satellite-derived streamflow for Bangladesh. Gauge networks are subject to reporting gaps from poor spatial coverage, manual error from nonautomated reporting, and the overwhelming of gauges during flood. More information is available in the live hazard data catalog by source.

02. Rainfall rate

Rainfall data can be input directly for surface water models or be passed through a rainfall-runoff model to derive river flow. Most catastrophe model providers for the region have the necessary algorithms to do this. Frequently reported rainfall data are available, providing information for flood onset, peak, and recession. However, intense rainfall is not always correlated with flooding. Thus these data are best used in combination with a catastrophe model or other live data sources. Global providers of satellite rainfall data sets cover the countries of interest, including the **Japan Aerospace Exploration Agency (JAXA), NASA, and NOAA.** Gauged rainfall data are also available locally for the short-list countries, including from the **Bangladesh Water Development Board**, the **Vietnam NCHMF**, the **Mekong River Commission** (Vietnam), and the **Sri Lanka Irrigation Department**. The **Pakistan Flood Forecasting Division** and the **International Centre for Integrated Mountain Development** also report gauged rainfall, but spatial coverage is poor. Vietnam is well served with rainfall data due to its dense station network (of more than 700 stations) and availability of radar-based rainfall data **(NCHMF)**.

03. Flood extent

Flood extent from satellite observations can be combined with digital elevation models to derive flood depths. Longer satellite revisit times are an issue with higher-resolution sources, which may mean the peak flood extent is missed. Conversely, satellites with higher-frequency monitoring and wider spatial coverage have coarser resolution. This can be mitigated by using forecasting products to prioritize the retrieval of satellite images, and by using multiple satellites to produce composite flood extents. Another issue is lower accuracy in urban, forested, and mountainous areas and in cloud cover due to satellite sensor limitations. Cloud cover can be managed using synthetic aperture radar sensors that penetrate these conditions, but satellite revisit times are longer. Multiple providers have global coverage for date of this type (see catalog), although some noncommercial providers **(Copernicus Emergency Management Service** and **Sentinel Asia)** do not activate for all events.[b] Commercial providers **(EarthLab Luxembourg FloodWatch, MDA FloodWatch)** offer flexible activation, but at a cost.

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[a] Mekong River Monitoring System Forecast and Mekong River Real Time Water Level Monitoring.

[b] Rather, service activations are triggered by requests from "authorized users," which are public entities active in the field of disaster management in the European Union (EU) member states, the EU Civil Protection Mechanism, the Commission's Directorates General, and participating European agencies.

TROPICAL CYCLONE

The peril of tropical cyclone is well served for live hazard data sources for Asia; data from global providers already used in existing parametric insurance programs are available for the countries of interest. The sources identified for tropical cyclone fit within three categories: earth observation (satellite-based) sources, station data, and "assimilation" products that use numerical weather prediction models with station data inputs. The use of satellite-derived data for parameters is the most tried and tested method for parametric contract settlement. In addition to wind hazard, the incorporation of storm surge and rainfall-induced flooding impacts is also possible (the PCRAFI Insurance Program covers both these secondary perils), typically also using satellite-derived parameters. However, the capture of all these sources of impact requires the use of multiple sources; some options are presented in appendix C of the full technical report, "Prototypes for Parametric Disaster Risk Financing Indices." See **box 3** for a summary of sources by type.

Thirteen regional sources of potential live hazard data suitable for disaster risk financing were identified for tropical cyclone, covering the countries of interest. All of these sources were rated as medium or high for their usability in a financing context. In addition, a number of local sources were identified for the short-list countries exposed to tropical cyclone. These provide observations from station networks for wind and rainfall, and the density of stations varies from country to country. For example, the Vietnam National Center for Hydro-Meteorological Forecasting has over 200 stations for wind observations, while the Bangladesh Meteorological Department has around 70.

BOX 03 Summary of Identified Live Hazard Data Sources for Flood

01. The use of **earth observation data** to derive tropical cyclone hazard parameters and model losses for parametric contracts is well established. These sources report parameters such as storm location, wind speed, radius, and rainfall, and they provide a good basis for a hazard footprint. A large number of providers at the global level (e.g., **NOAA**) and the regional level (e.g., **Japan Meteorological Agency Regional Specialized Monitoring Center**) were identified for the range of parameters required to develop tropical cyclone products. Further details are available in the live hazard data catalog.

02. **Station-based observations** in the region are not suitable as primary sources for contract settlement due to the heterogeneous and sparse distribution of stations, and potential loss of data arising from extreme wind damage to stations during storms. However, these data provide the ability to "ground-truth" or calibrate the satellite-derived products for specific locations. The **UK Met Office** (**MetDB and MIDAS Global Weather Observation Data**) was identified as a global provider of station data. Locally, the **Bangladesh Meteorological Department**, **Vietnam National Center for Hydro Meteorological Forecasting** and **National Hydro-Meteorological Service** were identified and assessed. Local rainfall gauge networks as identified under the flood exercise (see box 2) are also relevant.

03. **Assimilation products** use numerical weather prediction models to interpolate station data in a physically consistent way, and thereby mitigate the sparseness of station data. However, the resolution of assimilation-based products is often not sufficient to fully resolve tropical cyclones, and there is a danger of smoothing extremes in hazard intensity through the interpolation process. Thus these products should be used as supplementary, rather than primary, sources. Potential assimilation data sources with coverage for the countries of interest were identified as the National Centers for Environmental Prediction **(NCEP) Global Data Assimilation System**, the European Centre for Medium-Range Weather Forecasts **(ECMWF) Single Level Analysis**, and the **UK Met Office Global Atmospheric Hi-Res Model.**

EARTHQUAKE

Multiple options are available for the development of contingent earthquake triggers for the countries of interest, but accuracy is restricted by the low density of seismograph networks. Live hazard data sources identified for the region can be broadly separated into those based on seismographs and those based on satellites. Some of the seismograph-based data come from sources widely used for the design and settlement of parametric earthquake contracts (for example, **USGS Shakemaps** or the **Global Centroid-Moment-Tensor Project**). However, the quality of hazard footprint that can be developed from these products depends on the density of station networks in the countries being covered, and this is known to be low for the countries of interest. For example, in the 2004 Indonesia earthquake, less than 100 recordings were used to create the Shakemap event footprint, compared to the thousands of recordings used to develop the same product for the 2011 Tohoku Japan earthquake and tsunami.[14] Indonesia has one of the denser seismograph networks among the countries considered for this exercise, as outlined in the live hazard data catalog. The use of satellite earth observation data to capture earthquake impacts within a financial instrument is a somewhat experimental approach; some of its advantages and disadvantages are outlined in **box 4**.

Thirteen potentially usable live hazard data sources were identified for earthquake at the regional level from global providers, with a further five sources identified at the local level and rated medium or high for use in a parametric disaster risk financing context. Local providers offer station-based observation data, and range from government-operated services (such as the **National Seismic Monitoring Center of the Pakistan Meteorological Department**) to academic institutions (such as the **Strong Motion Network of the Bangladesh University of Engineering and Technology**). In addition to damage from ground-shaking, data that could be used to develop tsunami footprints was considered. Catastrophe risk models developed with tsunami hazard components can be used with core earthquake parameters (those used to produce ground-shaking footprints) to produce an estimate of tsunami damage for modeled-loss parametric triggers. Additional sources identified as directly useful for tsunami estimates include the **National Research Institute for Earth Science and Disaster Resilience (NIED) tsunami SWIFT simulation system** for Indonesia and the Philippines, and the **Indonesian Tsunami Early Warning System** (InaTEWS). A summary of types of live hazard data examined is in **box 4**.

Live hazard data sources identified can be broadly separated into those based on ground measurements and those based on satellite imagery.

[14] See "Live Data Source Catalog" at www.financialprotectionforum.org/asiaregional

BOX 04

Summary of Identified Live Hazard Data Sources for Earthquake

01. **Raw waveform data**. These station-based data can be used to derive shaking intensity parameters, such as moment magnitude, peak ground acceleration, or spectral acceleration close to recording sites. For example, USGS incorporates data of this type into its Shakemap product, derived from the recorded time history from local seismic networks, to define the shaking intensity footprint at or near places of recordings. Indonesia has the most promising coverage for this type of trigger due to the **GEOFON global seismological broadband network** operated by the German GeoForschungsZentrum (GFZ).

02. **Event source parameters**. These data provide event source information such as magnitude, epicenter, hypocenter depth, and focal mechanism.[a] These are the sources typically used for Cat-in-a-Box parametric structures, or as inputs into catastrophe risk models for modeled-loss triggers. As with all other station-based data sources, the sparsity of local recording networks limits the quality of derived footprint products. A number of these sources are detailed in the catalog.

03. **Ground motion maps**. These data can be used with catastrophe models to generate modeled loss. The USGS Shakemap product, for example, has been used widely for parametric contract settlement in the developed alternative risk transfer markets. One significant limitation is the limited amount of local seismometer information included in the product for this region. For places where recordings are not available, empirical ground-motion prediction equations derived from local historical events or similar tectonic settings are used instead. These introduce additional uncertainty into the intensity footprint.

04. **Estimated economic damage and fatalities derived from estimates of ground shaking**. While sources of this type can provide useful early estimates, they are not suitable for parametric financing triggers as a stand-alone product, and should be considered only as a supplement to an alternative primary data source. These sources can shortcut the standard post-event process for modeled loss trigger transactions by including some of the usual post-event processing steps within their estimates. However, they carry the major challenges of off-the-shelf data, namely methodological inconsistency with the catastrophe risk models available to design and price the contingent financing trigger, and inability to incorporate specific national data sets on exposure and vulnerability that may be available locally. The **USGS PAGER** product is one example covering the countries of interest, as is the **International Centre for Earth Simulation QLARM system**.

05. **Satellite imagery (earth observation sources)**. These sources estimate damage based on "before" and "after" satellite images, offering a rapid visual assessment of heavily damaged and destroyed buildings. However, they carry a number of disadvantages, including lack of consistency with the catastrophe risk modeling estimates needed to design and price any financial instrument, possible delays in acquisition, and subjectivity or errors in the production of damage-grade assessments derived from the images. Identified sources of this data type for the countries of interest are the **European Commission Copernicus Emergency Management Service**, the **Asia-Pacific Regional Space Agency Forum Sentinel Asia** service, and the **International Charter for Space and Major Disasters**.

[a] See "Live Data Source Catalog" at www.financialprotectionforum.org/asiaregional

DROUGHT

The large spatial scope of catastrophic drought events means that lower-resolution data options can still perform well within a parametric index, making a number of satellite-derived options from global providers suitable. The drought live data sources identified are all predominantly satellite derived, comprising indices of vegetative condition, precipitation, temperature, or soil condition. However, the drought parameters/indices available are indirect measures, and each has limitations for capturing drought impacts in a footprint. For example, indices based only on precipitation measurements lack information on soil condition, evaporation rates, and the ultimate impact of rainfall deficit on crops and livestock.[15] A composite/hybrid indicator approach can help mitigate this issue. Six global/regional data sources were identified with the potential to support parametric disaster risk financing instruments for the countries of interest. Additional local gauged data on river flow and precipitation noted under the flood exercise could also support the basis of drought estimates—although significant additional work would be required to develop these, and the limitations arising from sparsity of networks and basis risk would apply. Vietnam is taken as a local example in the catalog, due to its high drought exposure[16] and relatively high density of rainfall recording stations (more than 700 stations managed by the National Center for Hydro-Meteorological Forecasting). **Box 5** summarizes available sources.

Only six regional/global live data sources with medium- or high-rated usability were identified. The limited number of drought sources presented in the catalog largely reflects the restricted scope of the exercise undertaken. A specific subset of available data was taken within scope focusing on physical hazard data rather than food security estimates. Work was therefore not carried out to examine direct in-country sources (such as crop yield statistics) or indicators of food security (such as FEWSNET). There are precedents for using such information as the basis of index insurance triggers, such as the Mongolian Index-Based Livestock Insurance Scheme.[17]

BOX 05

Identified Drought Indices from Regional or Global Providers for Countries of Interest

01. **International Water Management Institute, Global Water Partnership, and World Meteorological Organization South Asia Drought Monitoring System.** This eight-day composite drought severity index combines information on vegetation condition, temperature, precipitation, and soil condition. Data are satellite derived. The index and its reporting system are still under development at time of drafting, but will ultimately cover Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

02. **NOAA (Global Vegetation Health) Drought Index.** This seven-day composite drought index is based on a satellite-derived Vegetation Health Index, Vegetation Condition Index, and Temperate Condition Index. The latest iteration of the product is available at 1km resolution, and covers the countries of interest. Data are freely available, with a back catalog of over 30 years for the (earlier) lower-resolution version.

03. **UN Flood and Agriculture Organization Global Information and Early Warning Systems on Food and Agriculture (GIEWS) Agricultural Stress Index**. This 10-day composite drought index is based on satellite-derived remote sensing data to detect agricultural areas with a high likelihood of water stress. The index is a composite drought indicator based on a spatiotemporal analysis of the Vegetation Health Index, and is freely available at 1km resolution. The current format of data provision (image only) poses challenges for post-processing for use in a contingent financing instrument. However, development work is ongoing, and new products are anticipated in the near term, including more refined national versions to complement the existing global index.

04. **NOAA Standard Precipitation Index**. This monthly meteorological drought index is based on precipitation only. The index combines rain gauge data and remote sensing data at 1 degree spatial resolution. The index is freely available and offers global coverage. Because it is a precipitation-only measure and thus captures meteorological drought only, basis risk is an issue with respect to actual impacts experienced on the ground. The incorporation of station data will lead the product quality and accuracy to vary country by country, subject to the density of station networks to complement the satellite data.

CSIC Spanish Research Council Standardized Precipitation-Evapotranspiration Index (SPEI) Global Drought Monitor. This monthly composite index combines satellite-derived precipitation and temperature measures to capture meteorological drought. The CSIS index uses NOAA NCEP temperature data and monthly precipitation data from the Global Precipitation Climatology Centre as its basis. Resolution is 0.5 degrees, and data are available at no cost. Basis risk issues (associated with using a measure of meteorological drought only) apply to this index, limiting its effectiveness in capturing ultimate impacts on the ground.

06. **Asian Development Bank (ADB) and Japan Aerospace Exploration Agency drought monitoring system**. This 15-day composite index combines satellite data on temperature and precipitation and is available at 0.1 degree resolution for specific countries in Asia (Indonesia, Thailand, the Philippines, Vietnam, and Japan available from JAXA at time of drafting; Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam forthcoming from the ADB). The modified Keetch-Byram drought index forms the index basis, which estimates the dryness of the soil. The index is suitable for capturing persistent drought events at the provincial level. Basis risk issues (associated with using a measure of meteorological drought only) apply to this index, limiting its effectiveness in capturing ultimate impacts on the ground.

[15] The timing and duration of rainfall deficits with respect to growing seasons has a huge impact on basis risk within the index. Seasonal crop calendars combined with temporal information on the meteorological drought are therefore important components in producing a useful measure of impact.

[16] According to the methodology applied to assess country-peril exposure in the full technical report from which this note is derived, Vietnam has the highest ratio of economic loss per capita due to drought.

[17] GFDRR, "Index-based Livestock Insurance in Mongolia," https://www.gfdrr.org/sites/gfdrr.org/files/DRFI_Mongolia%20IBLIP_Final.pdf.

Conclusions

Developing Asian countries have a number of readily available options to support the design and implementation of parametric disaster risk financing policies, strategies, and instruments. However, some perils are better supported than others. Further details are given below, along with some priority areas for action. The scope of the exercise is reiterated here, given its impact on the identified priorities for future action: *only models and data with the potential to support parametric disaster risk financing have been taken within scope.* The criteria defining such suitable models and data are outlined in **box 1**. Even where live hazard data and models are available, live data outputs and model inputs are often not compatible. This issue can be resolved by adapting sources and models, but the work is not trivial. The index prototypes accompanying the full technical report explore this issue further.[18]

For tropical cyclone, development of probabilistic catastrophe risk models for Lao PDR and Myanmar is identified as a priority for action. Live hazard data are available to support the development of high-performing parametric triggers—in forms already tried and tested for financial instruments—for all the countries examined for tropical cyclone. Investment to further develop live hazard data sources for tropical cyclone is therefore not identified as a priority. However, data availability is not matched by model availability for Lao PDR and Myanmar; improving model availability for these countries would require developing catastrophe risk models for tropical cyclone for any parametric disaster risk financing to be developed.

For earthquake, the priorities for action are incorporating local seismometer network information to supplement the global networks when defining ground motion footprints, and developing probabilistic catastrophe risk models for Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal. Live hazard data are available for all the countries examined, and in forms already used within financial instruments in the alternative risk transfer markets. However, in the case of earthquake, the sparsity of local seismograph networks in the countries of interest would result in much lower-quality triggers than exist in the developed markets. This limits the accuracy of outputs from global agencies such as the USGS. Earth observation options could also be examined as an innovative (though untested) option for capturing event impacts in parametric triggers. The limitations in using these sources would need to inform the types of financial mechanism for which it would be worthwhile to undertake such an investigation. Data availability is not matched by model availability for some of the most exposed countries in the region, namely Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal. Model development would be required for these countries in order to proceed with any parametric disaster risk financing mechanism. In the longer term, investment to improve local networks for recording and reporting earthquake hazard could be considered. Some initiatives of this type already exist for the region, and they are detailed further in the full technical report to this note.

For flood, there are two priorities: research into the best method to derive and validate a post-event flood footprint

[18] See "Prototypes for Parametric Disaster Risk Financing Indices" at www.financialprotectionforum.org/asiaregional

Developing Asian countries have a number of readily available options to support the design and implementation of parametric disaster risk financing policies, strategies, and instruments.

using the different available live data sources for rainfall, river flow, and inundation extent, and development of full probabilistic models for Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal. There are various live hazard data options for parametric triggers for flood, but all carry significant limitations due to their indirect measures of impact capture and their comparatively low-resolution view of the event. Mixed approaches could be considered, such as those combining more established techniques (e.g., use of satellite rainfall data sets with rainfall-runoff models) with more novel techniques (e.g., satellite flood-extent estimates), or those with enhancements from on-the-ground recording networks. Although probabilistic catastrophe risk modeling for flood shows substantial gaps in the region, almost all the countries of interest have at least a hazard model component that could be built upon. Further model development work for Afghanistan, Bangladesh, Lao PDR, Myanmar, and Nepal would be required.

For drought, further research is needed into the ability of existing drought indices to capture event impacts of interest (given national priorities for disaster risk financing). A priority for drought is examining how hindcast data sets or statistical extrapolation of historical time series for drought index could support an interim modeling approach. Some promising satellite-derived indices based on composite assessments of vegetative condition, precipitation, temperature, and soil condition are available as live hazard data options for the countries of interest. No catastrophe risk models are available to support implementation of parametric disaster risk financing mechanisms. However, statistical extrapolation of the established historical catalogs of available drought indices, or the use of physically modeled hindcast data sets, could form the basis of an interim modeling approach. It is important to note again the specific scope of the exercise: *the focus is on physical hazard data rather than food security estimates.* A broader exercise to look at the quality and availability of alternative types of data for index triggers, such as crop yield estimates, could be undertaken.

Any further development work based on the data and models identified as part of this exercise should be directed by country priorities. Given the findings above, the investment and level of effort required to proceed with parametric disaster risk financing mechanisms vary substantially depending on the peril-country combination. However, country priorities need to be the driving factor in determining where countries and their development partners can best focus efforts. For the countries of interest, a brief review of country priorities and engagements in this area is available in the 2016 World Bank publication "Toward a

Regional Approach to Disaster Risk Finance in Asia." The peril of flood was identified as a particular area of priority across the region, along with options for countries to work in subclusters to pool risk. However, given extensive engagement already underway at the national level, priorities for near-term action can be best defined at the national level.

In addition to addressing the peril- and country-specific gaps identified, additional investment in high-quality exposure and vulnerability data across the region could be considered, along with investment in local capacity for recording and reporting hazard information. High-quality exposure and vulnerability data, to support a loss perspective relevant to governments, is a gap across the region as a whole. A number of potential ways to improve local recording and reporting of live hazard data have been identified. These include

- Promoting data sharing and standards protocols
- Improving methods for disseminating meteorological station data for most countries, and standardizing the types of observations and formatting of local data sets to make them more useful as parametric triggers
- Increasing instrumentation in the long term

Further details on country-specific gaps are given in the full technical report.

Given regional interest in pooling of catastrophe risk, and the nature of the physical systems generating catastrophe events, a country-cluster approach to model development should be considered. There is a difference between having regionwide coverage of models and regionwide consistency of models. Existing model coverage is split across a number of model providers, and methodological differences can therefore be expected. These differences could lead to inequity between countries in the pricing and settlement of any risk financing contracts. Particular areas of concern are

- Difficulty in accurate capture of diversification benefits due to a lack of consistent event sets that span the region
- Differences in the way different countries model risk, resulting from inconsistency in the treatment of secondary perils, demand surge, and other model aspects, and potentially leading to inequity in contract pricing and settlement
- Different levels of basis risk due to different levels of model effectiveness for each country
- Differences in model compatibility with live hazard data sources, which prohibit the use of certain triggers across sets of countries

The chapter "Availability of Catastrophe Risk Models in the Region" in the full technical report details options for coherent subgroups of countries that could form the basis of a cluster approach to model development.

The development of a modeling platform to facilitate a regional or subregional approach to disaster risk financing could build on an existing mature platform from a single model provider, or a regional multi-provider platform could be considered. For example, where a single model provider already had extensive coverage for countries/perils of interest, its modeling platform could be built out to cover additional countries. Alternatively, a regional platform on which multiple suppliers build models (consistent within each subregion peril) could be considered. The OASIS Loss Modelling Framework provides an existing example of an open platform, where models from multiple providers are hosted within a consistent framework. The more-open framework approach provides longer-term flexibility to countries in how they select and develop models. However, the decision by companies to develop probabilistic models on other companies' platforms is a relatively new phenomenon, and in the near future may still present a longer, more complex route to model development. This issue is discussed further in the full technical report.

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