Strengthening Financial Resilience to Disasters in Asia

Prototypes for parametric disaster risk financing indices

Disaster Risk Financing & Insurance Program

SUPPORTED BY WORLD BANK GROUP

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The ROCKEFELLER FOUNDATION

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

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Contents

Flood (FL)

FL Index 1: High and medium resolution satellite-derived flood extent

DATA SOURCES:

- European Commission- Copernicus Emergency Management Service (EMS) flood activations [3],
- EarthLab Luxembourg- EarthLab Luxembourg FloodWatch® [4],
- MacDonald, Dettwiler and Associates (MDA)- in association with the Canadian Space Agency - MDA FloodWatch [5].

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Near Real-Time (NRT) Global Flood Mapping
- Global Flood Detection System (GFDS)
- National river gauge data

OVERVIEW:

High and medium resolution satellite-derived flood extent is captured from a number of satellite missions. The Copernicus EMS – following activations, the service produces free of cost maps of natural disasters, man-made emergency situations and humanitarian crises, with timely and accurate geospatial information derived from satellite remote sensing and augmented with available in situ or open data sources. The EarthLab Luxembourg FloodWatch® and the MDA FloodWatch also produce rapid snapshots of the observed flood extent, but the flood monitoring services are primarily target for commercial and the insurance industry, therefore any subscribe user of these commercial products can make activations for specific flood events.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam, but focus on Europe. Past activations include Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, Nepal, and Philippines.

POTENTIAL PERIL COVERAGE:

- Flood, Earthquakes, Severe Storms, Tsunamis, Volcanic Eruptions.
- Flood extent for a second generation parametric trigger if supplemented with exposure at risk to flood information.
- Flood extent for a third generation parametric trigger if supplemented with digital terrain data to derive depth information; as input to catastrophe model.

POTENTIAL IMPACT COVERAGE:

- The Copernicus EMS activations are based on a request from registered national focal points, European Commission Services, or the European External Action Service (EEAS) after the service request is reviewed and accepted by Copernicus.
- The MDA FloodWatch and EarthLab Luxembourg FloodWatch® activations can be defined by any users subscribed to their products. Different activation procedures are available.
- High and medium resolution flood extent products are provided based on satellite missions such as Sentinel 1-A (European Space Agency; 20 m; used by EMS and EarthLab FloodWatch®) and RADARSAT -2 (Canadian Space Agency; up to 3m resolution; used by all three data providers). However, not all satellites are available for all events, as it depends on the location, timing of the event, pre-planned acquisition of satellite segments, and availability of the satellite for a specific event.
- This data scope and resolution have the potential to capture the extent of flooding at administrative level 1, municipal level and potentially for individual assets.
- In modelled loss trigger form, the flood extent information could be supplemented with digital terrain data to derive flood depth which could be used as an input to a catastrophe model to capture the impacts on physical assets (encompassing residential, commercial and industrial and agricultural assets).

SUPPLEMENTARY DATA SOURCE OPTIONS:

- To give a continuous view of the flood footprint, satellite-derived flood extent from:
  - The MODIS flood extent products can be used to create a continuous daily flood footprint at lower resolution (250m) for the entire globe under cloud-free conditions and without a cost for the user associated with the acquisition of the dataset. However, under cover conditions MODIS will not be able to capture the full flood extent. Given the frequency of overpasses, MODIS is better suited to slow onset floods (days/weeks) rather than rapid onset events (hours).
  - The Global Flood Detection System (GFDS) can be used to create a daily continuous flood footprint at lower resolution (~10 km) for the entire globe under all-weather conditions and without a cost for the user. The GFDS system can complement MODIS as it is not affected by clouds though both systems have a low spatial resolution.
- Flood forecasting products (e.g. the Global Flood Awareness System; GloFAS) to trigger or prioritise the retrieval of satellite images in order to capture the best proxy for the maximum flood extent.
- National river gauge data can be used to validate the timing of the flood peak. If coverage is sufficient, the flood wave downstream could also be validated.
- Local water depth measurements could be used if available. However, these will typically cover specific point locations, and measurements will normally be done after the flood peak due to the risks associated with measuring during the event.

- High resolution Digital Terrain Model (DTM) (e.g. from Shuttle Radar Topography Mission (STRM) or Light Detection and Ranging (LIDAR)). Depth is a key parameter for most catastrophe models. As flood extent and depth varies across the flood duration, depth calculations using multiple extent estimates should be used to determine the maximum extent and depth across the event.
- Population / Infrastructure / Public assets to determine the numbers affected at risk of flooding within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the flood peril, full catastrophe models are available for the following countries: India (GC, JBA), Indonesia (ICRM and IF), Malaysia (IF, JBA), Sri Lanka (JBA), Thailand (CAT, IF, JBA) and Vietnam (IF, JBA).
- In addition, the following countries have hazard events sets available that form the basis of a model but would require further investment to produce a full model: Bangladesh (JBA), Cambodia (JBA), Lao PDR (JBA), Myanmar (JBA), Nepal (JBA), Pakistan (JBA) and the Philippines (JBA).
- Afghanistan does not have a probabilistic flood model (or hazard event set) available.

More detail is provided for the five focus countries of Bangladesh, Indonesia, Pakistan, Sri Lanka, and Viet Nam, as follows:

Bangladesh

- A probabilistic flood catastrophe model is not available.

Viet Nam

- The JBA Viet Nam probabilistic flood model is available for Viet Nam and can take raster flood depth footprints (m) as input data. An exposure database (residential, commercial and industrial lines) is available at commune resolution.
- The Impact Forecasting Viet Nam probabilistic flood model is available for Viet Nam and can take flood extent maps as an input. Economic (residential, non-residential, public buildings, public infrastructure, and population) and insurance industry (residential, commercial and industrial lines) exposure database are available.

Sri Lanka

- The JBA Sri Lanka probabilistic flood model is available for Sri Lanka and can take raster flood depth footprints (m) as input data.
- Exposure databases are not available.

Indonesia

- The Impact Forecasting Indonesia flood model is available for Jakarta state. The model can take flood extent maps as input. A Residential only insurance industry exposure database is available.

Pakistan

- A probabilistic flood catastrophe model is not available, although investment in this area is upcoming from the Asian Development Bank, so models may be available within the near-term time horizon.

POTENTIAL SETTLEMENT WINDOW:

Copernicus EMS

- Requests for satellite images are made based on specific contracts established for risk and recovery mapping or validation requests. The fastest delivery time (Service Level 1) is less than 1 day, but usually between 3 and 12 hours depending on the map type. Service Level 5 provide the map within 5 working days. Repetition (e.g. 3 maps in 2 weeks) can also be requested. Delivery Time is the time between receipt of satellite imagery by the service provider (for Rapid Mapping), or from the signature of the contract (Risk and Recovery Mapping), to the point at which the map(s) are delivered to the user.
- Authorised Users are public entities active in the field of disaster management in the EU Member States, the Union Civil Protection Mechanism, the Commission's Directorates General and the participating European Agencies. Authorised Users are the only entities authorised to trigger the service.
- The World Bank is currently an authorised user and have triggered Copernicus EMS in the past. Further discussion and formal agreement required to use Copernicus as a service for triggering transactions.

EarthLab Luxembourg FloodWatch and MDA FloodWatch

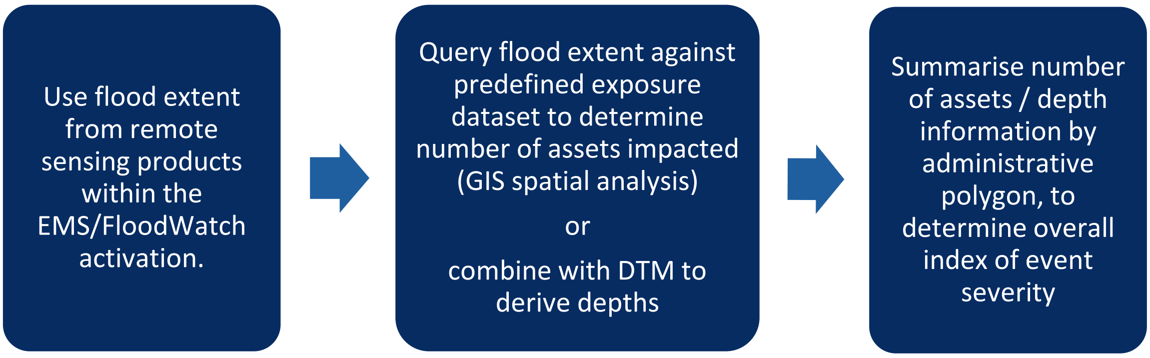
- Requests for satellite images are made based on specific contracts established for risk and recovery mapping or validation requests. Rapid Mapping consists of the on-demand and fast provision (within hours or days) of geospatial information in support of emergency response activities immediately following an emergency event. Note financial activities not related to immediate response may only be available weeks/months following the event.
- Clients can define Areas of Interest (AOI), triggers can be requested by customer and/or by EarthLab Luxembourg FloodWatch or MDA FloodWatch.

Common feature

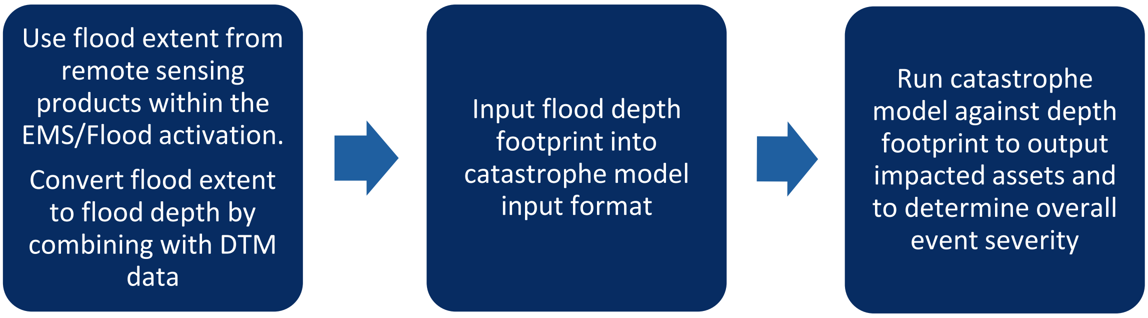
- In order to capture the event peak and maximum flood extent, several maps across the event duration are required. This could add several days to the settlement window, before the usual 1-3-week calculation process to determine any index and/or payouts.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

Copernicus EMS

- The activations have global coverage, but EMS does not make activations for all flood disasters as it is based on the request for activations they receive.
- Free and open licence. Under Copernicus Regulation (EU) No 377/20143 and Commission Delegated Regulation (EU) No 1159/20134, the information produced by the Copernicus Emergency Management Service shall be made available to the public on a full, open and free of charge basis (including commercial use). However, under exceptional circumstances, dissemination restrictions may be imposed for security reasons or the protection of third party rights. The information generated by the service can be used as supplied (e.g. as digital or printed map outputs). The data may also be combined with other data sources (e.g. as digital feature sets in a geographic information system). In both cases the data may support geospatial analysis and decision making processes of emergency managers.
- 4 years' historic data record on the EMS platform is relatively short, and poses challenges for structuring and pricing of any contract. Sentinel-1A was launched in 2014 and RADARSAT-2 in 2007. RADARSAT-1 was launched on 1995.

EarthLab Luxembourg FloodWatch and MDA FloodWatch

- Global coverage but potential to target regions.
- Cost depends on datasets and frequency. Different forms of membership, according to the user requirements. Licence agreement to be reviewed.
- Rapid mapping and ready-to-use products.
- EarthLab Luxembourg FloodWatch has the potential of processing and quality check raw images from multiple Synthetic Aperture Radar (SAR) and optical sensors in order to provide the best estimate of the maximum flood extent.
- 9 years' historic data record since the RADARSAT-2 launch is relatively short, and poses challenges for structuring and pricing of any contract. However, this satellite product is based on experience from RADARSAT-1 which was launched on 1995.

Common features

- High resolution flood extent (up to 3 m) produced in all weather conditions and through cloud cover, smoke and haze.
- Sensors often fail to delineate full flood extent due to classification problems. This can lead to underestimation of the flood extent.
- Full geographic coverage of the event may not be available at high resolution; it may be limited to the peak areas of exposure.
- Ideally, flood depth is required to assess the full severity of the flood event. However, flood extent could be used to calculate the number of properties affected by flood water, although detailed exposure information may be difficult to obtain in some regions.
- Several images can potentially be obtained during the onset, peak, and recession of the flood which provide a full temporal evolution of the event. Satellite acquisition will be more successful for flood events lasting several days on large rivers with extensive floodplains. However, depending on the satellite cycle, the flood peak and maximum flood extent may be missed. For example, Sentinel 1-A has an exact 12-day repeat cycle, with a revisit frequency in Asia of 2-3 days, and RADARSAT-2 has a 24-day repeat cycle with an average cover of 2-3 days too. Flood forecasting systems are being tested as a trigger for prioritising retrieval of information from satellites.
- Potential failure of satellite missions or components within the satellite (e.g. antenna), but future RADARSAT constellation (planned launch in 2018) will reduce the revisit time.

SCOPE OF LIVE DATA:

Key attributes:

- Global coverage.
- High resolution flood extent (up to 3 m) under all weather conditions.
- Historical data availability depends on the satellite mission used.

Copernicus EMS

- Free-of-cost product, but availability of flood extent products is restricted to the Emergency Management System activations based on Authorised Users requests.
- Rapid mapping products (within 6 or 12 hours, or 5 days of activation), but inclusion and updates of the products are flood event specific.
- Activations for flood events might collect one or more satellite images.

EarthLab Luxembourg FloodWatch® and MDA FloodWatch

- Satellite-based flood footprints with proactive coverage of big flood events and possibility of on-demand mapping.
- Routine monitoring through systematic satellite acquisitions to detect the peak of flood events.
- Inclusion and updates of the products are flood event specific, however they can be tailored to client request.

FL Index 2: Low resolution satellite-derived flood extent

DATA SOURCES:

- NRT Global Flood Mapping (National Aeronautics and Space Administration; NASA) – MODIS Sensor [10]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Global Flood Detection System (GFDS)
- High resolution flood extent (e.g. Copernicus EMS, EarthLab FloodWatch®, and MDA FloodWatch)
- National river gauge data

OVERVIEW:

NASA Goddard's Office of Applied Science is working to operationalise near real-time global flood mapping using available satellite data resources. This currently includes the twice daily overpass of the MODIS instrument, on the Terra and Aqua satellites, providing flood extent mapping under cloud-free conditions. This product is based on collaboration with the Dartmouth Flood Observatory.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

POTENTIAL PERIL COVERAGE:

- Rapid mapping and continuous flood extent monitoring providing flood extent maps at the global scale. However, optical sensors cannot see through clouds, so the product is unable to determine surface water extent in cloudy conditions.
- Flood extent for a second generation parametric trigger if supplemented with exposure at risk to flood information.
- Flood extent for a third generation parametric trigger if supplemented with digital terrain data to derive depth information; as input to catastrophe model. However, this will be of low quality due to resolution of input data.

POTENTIAL IMPACT COVERAGE:

- The resolution of this product is 250 x 250m, provided on 10° x 10° degree tiles. The data scope and resolution have the potential to capture the extent of flooding at administrative level 1.
- In modelled loss trigger form, the flood extent information could be supplemented with digital terrain data to derive flood depth which could be used as an input to a catastrophe model to capture the impacts on physical assets (encompassing residential, commercial and industrial and agricultural assets).

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Due to cloud coverage the maximum flood extent might not be well captured. It is recommended that other satellite products which perform well under all weather conditions are used to supplement the data:
    - High resolution flood extent (e.g. Copernicus EMS, EarthLab FloodWatch®, and MDA FloodWatch)
    - Lower resolution (~10 km) flood extent (e.g. GFDS).
- National river gauge data can be used to validate the timing of the flood peak. If coverage is sufficient, the flood wave downstream could also be validated.
- High resolution DTM (e.g. from Shuttle Radar Topography Mission (STRM) or Light Detection and Ranging (LIDAR)) to determine flood depth from flood extent. Depth is a key parameter for most catastrophe models. As flood extent and depth varies across the flood duration, depth calculations using multiple extent estimates should be used to determine the maximum extent and depth across the event.
- Population / Infrastructure / Public assets to determine the numbers affected at risk of flooding within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the flood peril, full catastrophe models are available for the following countries: India (GC, JBA), Indonesia (ICRM and IF), Malaysia (IF, JBA), Sri Lanka (JBA), Thailand (CAT, IF, JBA) and Vietnam (IF, JBA).
- In addition, the following countries have hazard events sets available that form the basis of a model but would require further investment to produce a full model: Bangladesh (JBA), Cambodia (JBA), Lao PDR (JBA), Myanmar (JBA), Nepal (JBA), Pakistan (JBA) and the Philippines (JBA).
- Afghanistan does not have a probabilistic flood model (or hazard event set) available.

More detail is provided for the five focus countries of Bangladesh, Indonesia, Pakistan, Sri Lanka, and Viet Nam, as follows:

Bangladesh

- A probabilistic flood catastrophe model is not available.

Viet Nam

- The JBA Viet Nam probabilistic flood model is available for Viet Nam and can take raster flood depth footprints (m) as input data. An exposure database (residential, commercial and industrial lines) is available at commune resolution.
- The Impact Forecasting Viet Nam probabilistic flood model is available for Viet Nam and can take flood extent maps as an input. Economic (residential, non-residential, public buildings, public infrastructure, and population) and insurance industry (residential, commercial and industrial lines) exposure database are available.

Sri Lanka

- The JBA Sri Lanka probabilistic flood model is available for Sri Lanka and can take raster flood depth footprints (m) as input data.
- Exposure databases are not available.

Indonesia

- The Impact Forecasting Indonesia flood model is available for Jakarta state. The model can take flood extent maps as input. A Residential only insurance industry exposure database is available.

Pakistan

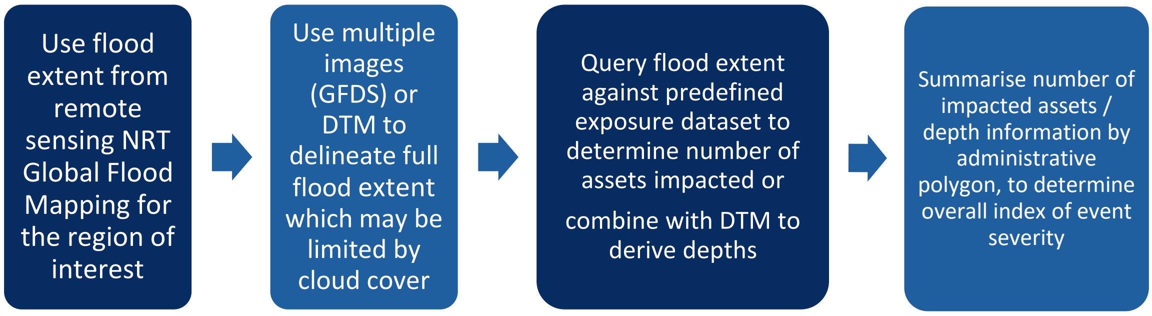
- A probabilistic flood catastrophe model is not available, although investment in this area is upcoming from the Asian Development Bank, so models may be available within the near-term time horizon.

POTENTIAL SETTLEMENT WINDOW:

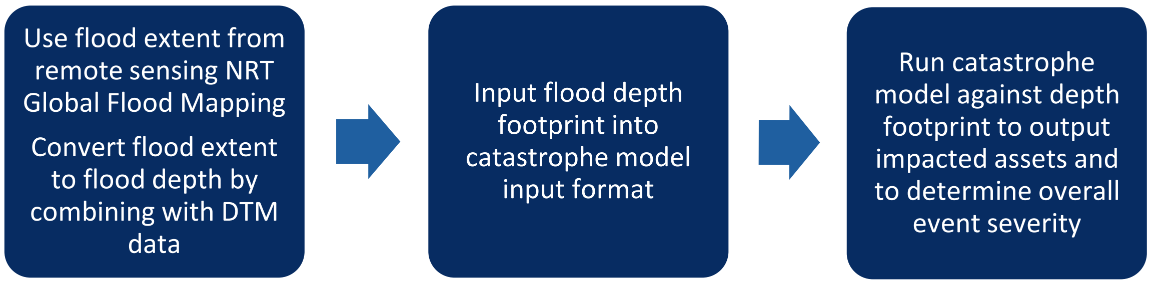
- The dataset is updated with each new satellite overpass. Most products are multi-day composites to minimize cloud cover issues: NRT Global Flood Mapping use optical sensors. Currently, three temporal standard products are produced daily: 2-day, 3-day, and 14-day. The 2nd order 14-day composite is a composite of the previous 14 days' 3-day product, to provide a recent-historical view of flooding and surface water extent, and it is generally the preferred product as largely overcomes the patchiness in 3 and 2 day products due to clouds. A single-day product is turned on for specific events of current interest, but is not (as of yet) run routinely.
- Still where the flood extent extends beyond the MODIS tile (10° x 10° tiles), cloud-free weather conditions have not been available or the event lasts longer than 14 days further multi-composition will be required. This could add several days to the settlement window, before the usual 1-3-week calculation process to determine any index and/or payouts.
- The client can access this dataset from different platforms: the NASA platform for visualization and download of individual tiles and products or though the Dartmouth Flood Observatory FTP site (http://csdms.colorado.edu/pub/flood_observatory/).

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

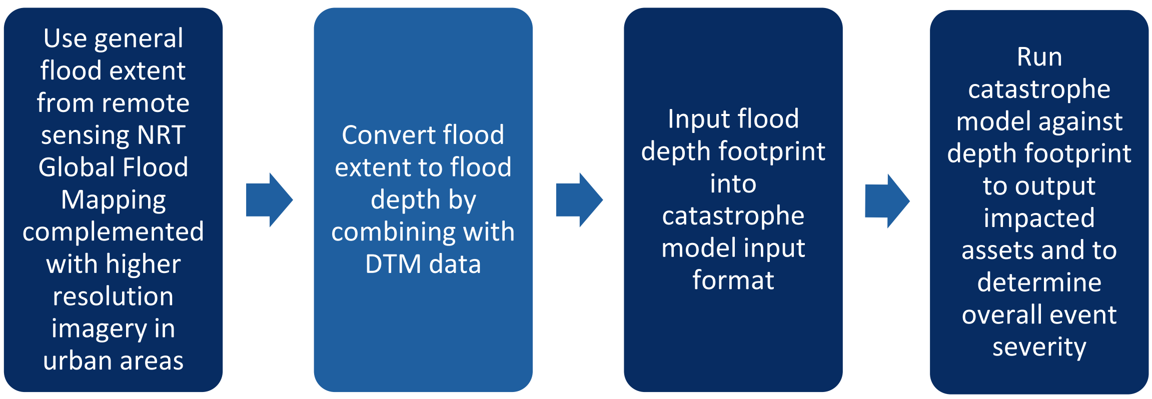
Second generation parametric trigger:



Third generation parametric trigger:



Third generation parametric trigger (enhanced):



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Global daily surface and flood water maps at 250 x 250m resolution, in 10° x 10° tiles means that due to the resolution, flooded features smaller than 250m will not be detected. This will be particularly problematic for any small areas of flooding where channels are constrained by topography (such as in mountainous areas) or urban features.
- Input data at 250m resolution will result in low accuracy flood depths and loss calculations which make this product unsuitable without supplementary data.
- The broad spatial coverage provided by this product may allow more complete capture of the flood extent, useful for calculating aggregated losses.
- Freely available under NASA licence.
- Automated global mapping started in Nov 2011.
- MODIS is an optical sensor and therefore unable to determine surface water extent in cloudy conditions. Their standard products are built using two (or more) days of data, with two chances per day to observe an area cloud-free. The graphic map products (MFM, MODIS Flood Map) show areas where with insufficient clear imagery for water detection.
- The twice daily satellite overpass enables several images to be obtained during the onset, peak, and recession of the flood during cloud-free conditions to provide a full temporal evolution of the event. MODIS has an exact 16-day repeat cycle, with a revisit frequency of 1-2 days. Multiple observations help eliminate false detections due to shadows (cloud, buildings and terrain). Therefore, satellite acquisition will be more successful for flood events lasting several days on slow flowing large rivers with extensive floodplains.
- 5 years' historic data record since the MODIS derived flood extent algorithm was automated is relatively short, and poses challenges for structuring and pricing any contract.
- Potential failure of satellites missions or components within the satellite (e.g. antenna).

SCOPE OF LIVE DATA:

Key attributes:

- Daily flood water delineation from MODIS sensor.
- NRT Global Flood Mapping produces automated global daily surface and flood water products. These products are:
    - MODIS Flood Water (MFW),
    - MODIS Surface Water (MSW) MFW before subtracting the reference water,
    - MODIS Water Product (MWP) combines both MFW and MSW, and
    - MODIS Flood Map (MFM) is the annotate 10 x 10-degree map/graphic product.
- 250m resolution.
- Continuous coverage. It does not provide product specific flood events.
- Automated global mapping available from November 2011.

FL Index 3: Real-time rainfall satellite estimates

DATA SOURCES:

- Real-time Rainfall Data - National Aeronautics and Space Administration (NASA) [15]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Flood footprint: Global Flood Detection System (GFDS), and FloodWatch products from the EarthLab Luxembourg and MDA.
- National river gauge data

OVERVIEW:

Real-time global rainfall data collected by satellites using the Tropical Rainfall Measuring Mission (TRMM)-based Multi-Satellite Precipitation Analysis (TMPA / 3B42) and the rainfall estimates combining data from all passive-microwave instruments in the Global Precipitation Mission (GPM) Constellation (IMERG). It provides descriptions and links for all of the primary sources available for downloading GPM and TRMM (discontinue since 2015) data. The products are first arranged by processing algorithm, and then by data processing level.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

POTENTIAL PERIL COVERAGE:

- Excess rainfall only, unless combined with other sources to capture fluvial or pluvial flooding. Rapid rainfall mapping at several accumulation times.
- Rainfall as a direct input, or combined with a hydrological model to derive flows which could be directly input to a catastrophe model and form a third generation parametric trigger.

POTENTIAL IMPACT COVERAGE:

- The resolution of this product is 0.1° x 0.1° grid over the latitude band 90°N-90°S derived from the Global Precipitation Mission (GPM) Level 3 and available since March 2015 in near-real time mode, and of 0.25 ° x 0.25 ° grid over the latitude band 60° N- 60° S from the Tropical Rainfall Measuring Mission (TRMM) available near-real time since 1997, and since 2015 using the GPM data with the same processing algorithm as with TRMM (3B42). Rainfall accumulation maps are provided at 30min (only GPM), 3, 24, 72, and 168 (7 Day) hourly totals with a delivery delay of 6 and 18 hours of observation time depending of the processing run. This data scope and resolution has the potential to capture the impacts of excess rainfall at administrative level 1.
- In modelled loss trigger form, rainfall information could be used to calculate pluvial flood extent and depth from modelled hazard maps. River flood extent and depth could also be calculated by linking through a rainfall-runoff model. Both could then be used to capture the impacts on physical assets encompassing residential, commercial and industrial and agricultural assets.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Analysis of the historical record in order to establish return period of rainfall.
- Precomputed extent of flooding for surface water by design return period (1 / 50-year, 1 / 100-year, etc.) by administrative boundary would allow rapid estimation of flood impact following return period calculation. Such datasets are available from companies such as JBA Risk Management, SSBN and KatRisk. Care should be taken to ensure these have been developed with consistent methodologies. Useful for secondary trigger.
- Provide complete flood footprint by including satellite-derived flood extent from:
  - The Global Flood Detection System (GFDS) to create a continuous flood footprint at lower resolution (~10 km) under all-weather conditions.
  - FloodWatch products from the EarthLab Luxembourg and MDA.
- National river gauge data to validate the timing of the flood peak and, if enough coverage, the flood wave downstream.
- Use of Digital Terrain Models (DTM) (e.g. from STRM or LIDAR) for a quick analysis on how the rainfall might be converted on runoff and flow to lower lying areas.
- Population / Infrastructure / Public assets to determine the numbers affected at risk of flooding within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the flood peril, full catastrophe models are available for the following countries: India (GC, JBA), Indonesia (ICRM and IF), Malaysia (IF, JBA), Sri Lanka (JBA), Thailand (CAT, IF, JBA) and Vietnam (IF, JBA).
- In addition, the following countries have hazard events sets available that form the basis of a model but would require further investment to produce a full model: Bangladesh (JBA), Cambodia (JBA), Lao PDR (JBA), Myanmar (JBA), Nepal (JBA), Pakistan (JBA) and the Philippines (JBA).
- Afghanistan does not have a probabilistic flood model (or hazard event set) available.

More detail is provided for the five focus countries of Bangladesh, Indonesia, Pakistan, Sri Lanka, and Viet Nam, as follows:

Bangladesh

- A probabilistic flood catastrophe model is not available.

Viet Nam

- The JBA Viet Nam probabilistic flood model is available for Viet Nam and can take rainfall (mm), river flow (m^3/s), return period (1/n-years) or raster flood depth footprints (m) as input data. Either rainfall data could be input directly to generate a surface water (pluvial) flood event and/or rainfall could be passed through a rainfall-runoff model to derive river flows.
- An exposure database (residential, commercial and industrial lines) is available at commune resolution.

- The Impact Forecasting Viet Nam probabilistic flood model is available for Viet Nam and requires flow or water level as input data (preferable) or flood extent maps derived from satellite imagery. Rainfall data could be passed through a rainfall-runoff model to derive river flows.
- Economic (residential, non-residential, public buildings, public infrastructure and population) and insurance industry (residential, commercial and industrial lines) exposure databases are available.

Sri Lanka

- The JBA Sri Lanka probabilistic flood model is available for Sri Lanka and take rainfall (mm), river flow (m^3/s), return period (1/n-years) or raster flood depth footprints (m) as input data. Either rainfall data could be input directly to generate a surface water (pluvial) flood event and/or rainfall could be passed through a rainfall-runoff model to derive river flows.
- Exposure databases are not available.

Indonesia

- The Impact Forecasting Indonesia flood model is available for Jakarta state. The model requires input rainfall (mm) for 6 gauges (preferable) or flood extent maps derived from satellite imagery.
- A Residential only insurance industry exposure database is available.

Pakistan

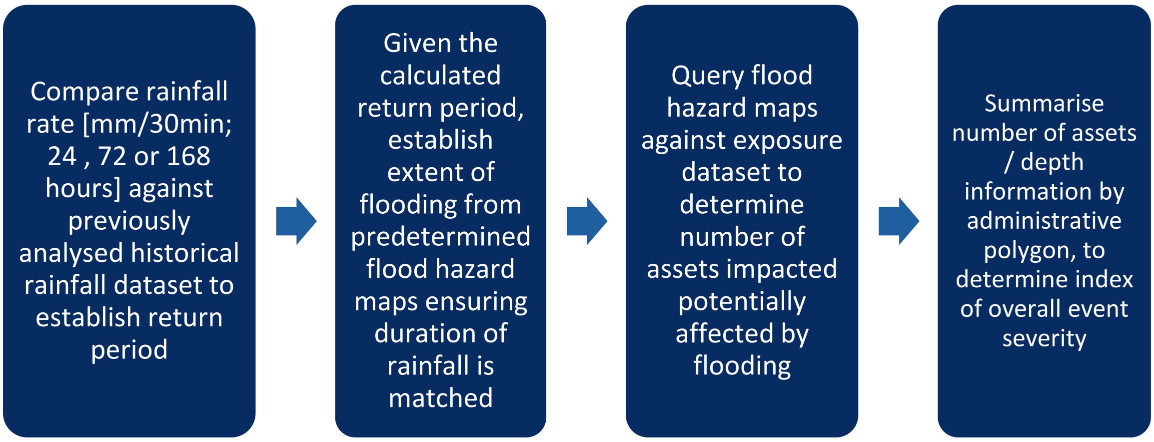
- A probabilistic flood catastrophe model is not available, although investment in this area is upcoming from the Asian Development Bank, so models may be available within the near-term time horizon.

POTENTIAL SETTLEMENT WINDOW:

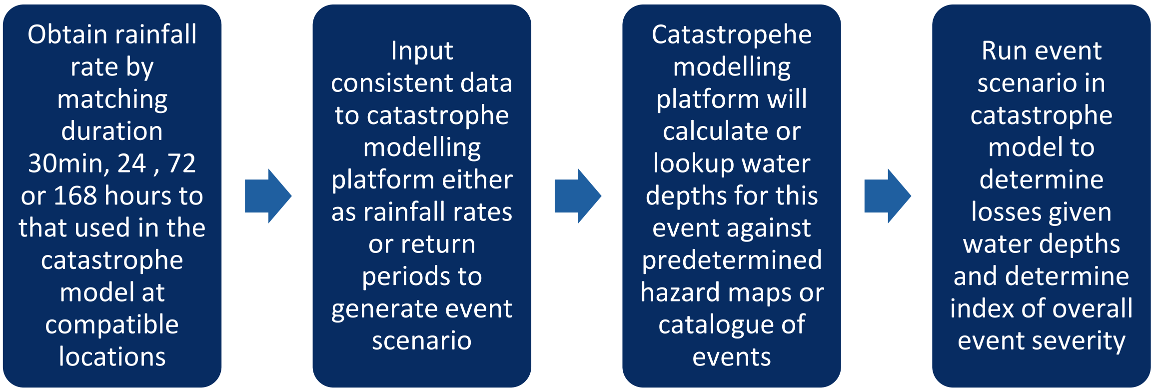
- The dataset is updated with each new satellite overpass. There is a 6 and 18-hour delay from satellite acquisition to data availability. Four months later the final product is deliver, but this will not be suitable given the settlement window.
- Rainfall accumulation maps: 30 minute (GPM/IMERG only), 3, 24, 72, and 168 (7 Day) hourly totals.
- Heavy Rain Areas Map based on the 3B42 algorithm: Areas with >35mm of rain in a day; >100mm of rain in 3 days; and >200mm of rain within a week. Data display via map and as text with country, rain amount, location name and latitude and longitude provided (http://trmm.gsfc.nasa.gov/publications_dir/potential_flood.html). At the moment of writing this report, not available for the IMERG algorithm.
- A modelled loss trigger could be generated within 2-4 weeks, although late corrections to some of the products leave the data open to change for up to four months after initial publication of data.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Rainfall information from the GPM [IMERG algorithm] and Real-Time TRMM Multi-Satellite Precipitation Analysis [TMPA/3B42 algorithm].
- Global (sub-) daily rainfall maps at 0.1° x 0.1° grid over the latitude band 90°N-90°S using GPM IMERG and at 0.25 ° x 0.25 ° grid over the latitude band 60 ° N-S using TRMM and GPM 3B42, within about six hours of observation time for the first run. Note that the Heavy Rain Areas Map product has a latitude band 50 ° N-S.
- Freely available under NASA licence.
- Global mapping started in 1998. 18 years' historic data record since the TRMM 3B42 derived rainfall estimation algorithm was automated is relatively short, and poses challenges to structuring and pricing of any contract. The IMERG GPM algorithm is even shorter with current availability since 2015, however it has been planned to reprocess the TRMM data using the IMERG algorithm for continuity of the dataset. Furthermore, this length may also be challenging for an accurate estimation of the rainfall severity.
- Frequent rainfall rates can be obtained during the onset, peak, and recession of the flood, which are useful to provide a full temporal evolution of the heavy rainfall event.
- Potential for failure for satellites missions or components within the satellite (e.g. antenna).

SCOPE OF LIVE DATA:

Key attributes:

- Automated gridded global coverage of rainfall at different accumulation periods: 30 minutes (GPM/IMERG only), 3, 24, 72, and 168 hours (7 Day) hourly totals from TRMM and GPM sensors.
- Automated mapping started in 1998 for TRMM/3B42 and 2015 for GPM/3B42 and GPM/IMERG.

FL Index 4: Water level and flow time series from National River gauge networks (local sources)

DATA SOURCES:

- Bangladesh Water Development Board (BWDB) (Bangladesh) [16]
- National Center for Hydro-Meteorological Forecasting (NCHMF) (Viet Nam) [19]
- Irrigation department (Sri Lanka) [22]
- Balai Hidrologi dan Tata Air (Center for Hydrology and Water System) (Indonesia) [25]
- Pakistan flood forecasting division (Pakistan) [26]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Rating curves at the gauge locations to convert water levels (m) into flow measurements (m3/s)
- Flood extent Earth Observations from available sources: e.g. NRT Global Flood Mapping, MDA FloodWatch
- Rainfall derived from local rain gauges or satellite products such as JAXA Global Rainfall Watch, Pakistan Meteorological Department (PMD) SYNOP/METARS.
- River flows derived from remote sensing such as the River Watch (Version 3) of the Dartmouth Flood Observatory to complement the flow time series if real-time data is not available.

OVERVIEW:

National river gauge networks measuring water level [m] and/or flow [m^3/s] at specific locations along rivers.

COUNTRY COVERAGE:

Other countries may have coverage but the following countries were examined: Bangladesh, Viet Nam, Sri Lanka, Indonesia, and Pakistan.

POTENTIAL PERIL COVERAGE:

- Limited to river (fluvial) flood events and areas along rivers with gauges only. Some of the catastrophe models will have the capability to interpolate information to adjacent ungauged catchments.
- Water level / flow severity for a first order parametric trigger where a measurement exceeds threshold at a pre-defined point.
- Water level / flow severity for a second generation parametric trigger where data can be linked to pre-computed flood hazard maps and further supplemented with exposure at risk to flood information.
- Water level / flow severity for a third generation parametric trigger where hazard parameters are reported by stations that are compatible with the catastrophe model.

POTENTIAL IMPACT COVERAGE:

- Used to ascertain flood severity at gauge locations across the country. This data scope and resolution has the potential to capture extent of flooding by administrative level 3 where sufficient spatial coverage is available (see below) and where can be linked with hazard maps.
- Data available as level (m) and/or river flow (m^3/s).
- In modelled loss trigger form, hazard intensity expressed either as a level, flow or return period can be input into the catastrophe model to capture impacts to physical assets (encompassing residential, commercial and industrial).

Spatial coverage by country:

- Bangladesh: 105 gauges recording water level. Good temporal coverage, but spatial coverage is poor from the WMIP (mainly restricted to Bay of Bengal) and HKH-HYCOS project. However, additional river gauges are maintained by the Bangladesh Water Development Board (BWDB) – their location was not provided.
- Viet Nam: 150 gauges that record water level and flow and 95 gauges that only record water level making a current total of 248 gauges. Excellent spatial coverage, relatively good temporal coverage.
- Sri Lanka: 33 principal gauges and 33 peripheral gauges. Relatively good coverage for the centre and southwest of the island, poor spatial coverage of the north, excellent temporal coverage. Kelani river flows through Colombo the capital and main exposure concentration is well captured.
- Indonesia: Tech4water group: 50 gauges. Balai Hidrologi dan Tata Air (Center for Hydrology and Water System): 240 gauges. Relatively good coverage for Java Island but poor spatial coverage for the rest of the islands within Indonesia, excellent temporal coverage.
- Pakistan: 22 inflow and outflow gauges on dams. Spatial coverage is confined to the upper catchments, where there is also a higher population density and few additional gauges along the Indus river on the middle and lower sections; temporal coverage is adequate, dependent on stations actually reporting.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Available catastrophe models require input hazard expressed as rainfall (mm), flow (m^3/s) or as return period (1/n-years) by gauge. Conversion between units may be required. In order to convert water level (where only level is available at some gauges) to flow, ratings curves are required. To convert flow to return period, prior analysis of the entire historical flow record will be required to establish a relationship between rainfall/flow and return period. It is suggested this is carried out by the modelling agent to ensure consistency with the catastrophe model.
- Surface water (pluvial) flooding following heavy rainfall is likely to be a considerable driver of loss in this region but is not captured by these sources. Rainfall measurements like the JAXA Global Rainfall Watch could be useful to assess the heavy rainfall extent and intensity. A number of the catastrophe models can consider surface water flooding as a secondary peril.

- Precomputed extent of flooding for both river and surface water by design return period (1/50-year, 1/100-year, etc.) by administrative boundary would allow rapid estimation of flood impact following return period calculation. Such datasets are available from companies such as JBA Risk Management, SSBN and KatRisk. Care should be taken to ensure these have been developed with consistent methodologies. Perhaps useful for secondary trigger.
- In Pakistan the problem of a poor distribution of river gauges may be overcome by deriving river flows from rainfall-runoff models. The Pakistan flood forecasting division has 7 stations providing rainfall data.
- Population / Infrastructure / Public assets to determine the numbers affected at risk of heavy rain within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the flood peril, full catastrophe models are available for the following countries: India (GC, JBA), Indonesia (ICRM and IF), Malaysia (IF, JBA), Sri Lanka (JBA), Thailand (CAT, IF, JBA) and Vietnam (IF, JBA).
- In addition, the following countries have hazard events sets available that form the basis of a model but would require further investment to produce a full model: Bangladesh (JBA), Cambodia (JBA), Lao PDR (JBA), Myanmar (JBA), Nepal (JBA), Pakistan (JBA) and the Philippines (JBA).
- Afghanistan does not have a probabilistic flood model (or hazard event set) available.

More detail is provided for the five focus countries of Bangladesh, Indonesia, Pakistan, Sri Lanka, and Viet Nam, as follows:

Bangladesh

- A probabilistic flood catastrophe model is not available.

Viet Nam

- The JBA Viet Nam probabilistic flood model is available for Viet Nam and can take river flow (m^3/s), rainfall (mm), return period (1/n-years) or raster flood depth footprints (m) as input data. Where data is available only as water level, conversion would be possible where rating curves are available. An exposure database (residential, commercial and industrial lines) is available at commune resolution.
- The Impact Forecasting Viet Nam probabilistic flood model is available for Viet Nam and can take flow or water level as input data (preferable) or flood extent maps derived from satellite imagery. Economic (residential, non-residential, public buildings, public infrastructure, and population) and insurance industry (residential, commercial and industrial lines) exposure database are available.

Sri Lanka

- The JBA Sri Lanka probabilistic flood model is available for Sri Lanka and take can river flow (m^3/s), rainfall (mm), return period (1/n-years) or raster flood depth footprints (m) as input data. Exposure databases are not available.

Indonesia

- The Impact Forecasting Indonesia flood model is available for Jakarta state. The model requires input rainfall (mm) for 6 gauges (preferable) or flood extent maps derived from satellite imagery. A Residential only insurance industry exposure database is available.

Pakistan

A probabilistic flood catastrophe model is not available, although investment in this area is upcoming from the Asian Development Bank, so models may be available within the near-term time horizon.

POTENTIAL SETTLEMENT WINDOW:

Bangladesh

- Data are available daily (at 9am based on 6am measurements). For 7 out of the 105 river gauges, there is near real-time data updated every 2 hours.

Viet Nam

- Data are available twice daily (7am, 7pm). On hydrographs, measurements are plotted and are available every 6 hours.

Sri Lanka

- Data are available daily (at around 10am). Hourly water level and flow measurements are available at principal stations, and twice daily at peripheral stations, but these are not available online.

Indonesia

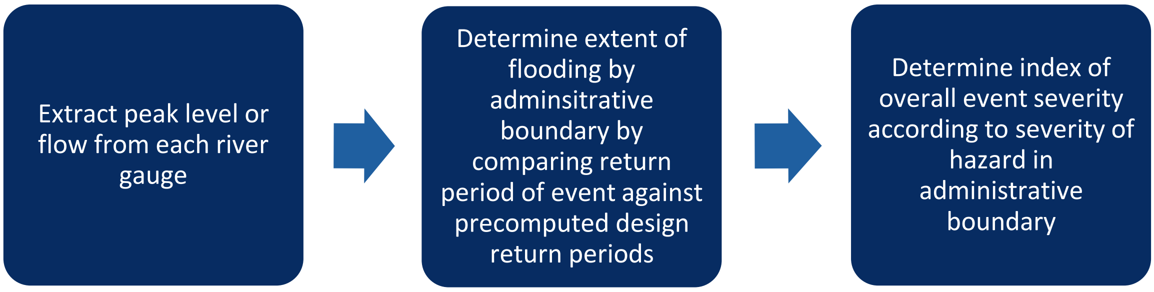
- Data are available at different temporal intervals: 5-minutely, hourly, daily, and monthly. Data are available a few minutes to a few hours after collection.

Pakistan

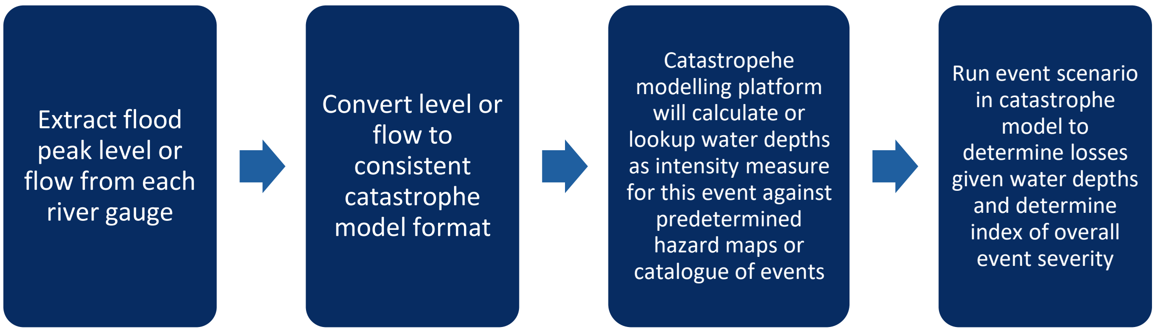
- Data are available daily. They provide the mean inflow and outflow at the dams calculated at 6am Pacific Standard Time (PST), and are available within a few hours after that time. Flood Bulletin B is usually available around 11am PTS. Rainfall measurements are reported real-time but there would be processing time required to generate river flows from rainfall-runoff models.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

Common features:

- The length of the historical hydrological record varies by country, and predictions of extreme flows based on short historical records are unlikely to be robust.
- Limited to river (fluvial) flood events and areas along rivers with gauges only. Some of the catastrophe models will have the capability to interpolate information to adjacent ungauged catchments.
- Could be combined with rainfall measurements as catastrophe models include both river and surface water hazard.
- River gauges may become inoperable during extreme flows and cease recording.
- Gauge data gathered by a government agency may raise questions of objectivity.
- River gauges operated by government agencies may raise questions of objectivity.
- River gauges may be supplemented or cross referenced with flows generated from rainfall-runoff models based on rainfall data, but this method has its own associated limitations.

Bangladesh

- Currently there are 105 gauges recording water level that offer limited spatial resolution across Bangladesh (See Appendix II. National meteorological gauges: Location maps). Gauges are sited to capture flow on the Meghna, Padma, Brahmaputra and Buriganga rivers, however there is a lack of gauges for the Shitalakshya river which would otherwise capture flow on the East site of the city of Dhaka. This may limit the ability to capture significant loss events. The location of additional gauges maintained by the Bangladesh Development Board is unknown.
- Free for real-time data access but historic time series datasets have an administrative cost.
- On the table display, it is only possible to access online water levels for the current day and the previous two days, plus the monthly (last 30 days) summary. On the hydrographs, it displays the last 7 days' measurements (plus the 5-day forecast).
- Data reporting began in 2012 or 2014 depending on the gauge.

Viet Nam

- There are currently 150 gauges that record water level and flow and 95 gauges that only record water level making a current total of 248 gauges (see Appendix II. National meteorological gauges: Location maps). Although this leads to limited spatial coverage, the gauges are, in general, located in highly populated areas. By 2020, the aim is to reach a total number of 337 river gauges. The current coverage is deemed sufficient to capture significant flood loss events.
- Only 68 river gauges currently available online. Near real-time from additional gauges needs to be requested.
- Free for real-time access; historic time series datasets have an administrative cost.
- Currently data is displayed as a hydrograph on a website. Not easy format to extract data.
- The observed system was set up on a large scale from after 1954 in northern Viet Nam, and was extended to the rest of Viet Name in 1976.

Sri Lanka

- There are currently 33 principal stations and 33 peripheral stations. The present hydrometric system is confined within the 24 major rivers (out of 103 rivers in total) and they convey 80% of total flows generated within the island and so are considered highly important from a hydrological point of view (see Appendix II. National meteorological gauges: Location maps). Gauges are available for the Kelani river which flows through the capital city Colombo. As this represents the majority of exposure this is deemed sufficient coverage.
- Daily reporting is available through a website. Hourly water level and flow measurements are shown at principal stations, and twice daily at peripheral stations.
- Historical hydrographs are available for display from 2010.
- Data reporting began on 1924 for the first gauge.

Indonesia

- Tech4water group: Currently 50 stations with a maximum of 8 parameters measured at each station, within a total of 44 catchments. Data are available from 2012. 5-minute, hourly, daily, and monthly data are available. Note that not all of the gauges shown on the map will be provided real-time data, but they still display the latest value collected.

- Balai Hidrologi dan Tata Air (Center for Hydrology and Water System): 240 gauges are currently operational, with some first installed in the 1970s.
- Free for real-time access and historic time series datasets through the Tech4water group website.
- The actual location of all gauges in Indonesia is currently unknown. However, the spatial distribution of those within the Tech4water group can be accessed on their website. There is a potential overlap with those maintained by the Balai Hidrologi dan Tata Air, but data are not available to confirm this. The highest concentration of river gauges is in Java island, but it still offers limited spatial resolution across Indonesia (see Appendix II. National meteorological gauges: Location maps). However, these measurements are useful along rivers where recent past data are available.
- Further investigation is recommended before determining whether this coverage is sufficient.

Pakistan

- The location of 22 inflow and outflow gauges on dams in Pakistan has been confirmed. These gauges are confined to the upper catchments and their artificial nature will prohibit their use for frequency and severity analysis. The location of additional gauges in Pakistan are show in the maps in Appendix I. These gauges show the potential to capture flows near the major areas of exposure however the precise all additional available location and nature of data reported has not been provided.
- Real-time data and data from the last two months are available free of charge on the website. The cost for historical data is unknown.
- Unknown start date of data reporting.
- An alternative approach would be to generate river flows from a rainfall-runoff model utilising the 97 rainfall gauges operated by the Pakistan Meteorological Department (PMD) SYNOP (surface synoptic observations). The temporal resolution of rainfall observations is good, but the Pakistan Meteorological Department has not responded to requests for information. Spatial extent of observation sites covers entire country, with stations concentrated near population centres with some additional stations near the coast.

SCOPE OF LIVE DATA:

Key attributes:

- Live river flow data represents direct measurements of hazard intensity and is therefore the measure most likely to correlate with loss.
- Conversion of a recording parameter (water level) to a parameter compatible with the catastrophe model (river flow) is expected to be straight-forward.
- Available historical time series and frequency of reporting might vary by gauge.

Tropical Cyclone (TC)

TC Index 1: Global source TC locations with modelled wind field and satellite rain

DATA SOURCES:

- TC locations: US Joint Typhoon Warning Center (JTWC) Tropical Cyclone Warning Text [1] OR US Naval Research Laboratory (NRL) Tropical Cyclone Warning [2] OR Unisys Weather Hurricane / Tropical Data [3]

RELEVANT SUPPLEMENTARY DATA SOURCES:

Modelled wind field:

- US National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) [5]
- OR European Centre for Medium-range Weather Forecasts (ECMWF) Single level analysis [6]
- OR UK Met Office (UKMO) Global Atmospheric Hi-Res Model [7]

Satellite rain:

- Japan Aerospace Exploration Agency (JAXA) Global Rainfall Watch [8]
- OR National Aeronautics and Space Administration (NASA) Real-time 30 Minute, 3 Hourly and 1 Day Rainfall Data [9]
- OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS), Center for Satellite Applications Research STAR Satellite Rainfall Estimates - Hydro-Estimator [10]
- OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS), Office of Satellite and Product Operations Operational Hydro-Estimator Satellite Rainfall Estimates [11]

OVERVIEW:

This index uses the TC specifics information, including location, intensity and size, along with modelled TC wind field and satellite rain to determine the impact associated with exposure to strong winds and heavy rainfall.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

POTENTIAL PERIL COVERAGE:

- Tropical cyclone occurring anywhere on globe.
- Tropical cyclone impact for a second generation parametric trigger if supplemented with exposure at risk to strong winds and heavy rainfall, along with model TC wind field and satellite rainfall.
- Tropical cyclone impact for a third generation parametric trigger if supplemented with a model tropical cyclone (based model wind field) and satellite rainfall, as input to a catastrophe model.

POTENTIAL IMPACT COVERAGE:

- Damage from wind and rain is covered.
- Tropical cyclone location is supplied in source data every 6 hours, at a minimum. Supplementing with model surface wind analyses either 6-hourly (NCEP, ECMWF) or 12-hourly (UKMO) provides relatively high spatial resolution asymmetrical wind field to allow an estimate of the overall extent of possible damage based on TC impact location and extent of the damaging wind field.
- Supplementing with satellite rainfall estimates, as an event total or defined period rain depth from summation of appropriate 30-minute, 1-hourly, 3-hourly or 1-day rainfall totals (converted from rainfall rates, if necessary), provides additional information on the distribution of heavy rainfall. All suggested rainfall products have a spatial resolution of at least 0.1° (approximately 10 km).
- In modelled loss trigger form, the TC location and modelled surface wind field, along with the satellite rain depths, can be used as an input to a cat model, to capture impacts of strong winds and heavy rain on population and physical assets.
- Whilst the resolution of the modelled wind field is relatively high, the resolution of the captured impact is dependent on the output resolution of the selected cat model.
- The provision of flood extents will be dependent on the selected cat model; however, a TC rainfall footprint can be derived from satellite data for cat models without a flood model component.

SUPPLEMENTARY DATA SOURCE OPTIONS:

Modelled wind field

- NCEP GDAS provides global (90°N-90°S) 6-hourly surface (10 m) wind speed analyses at a spatial resolution of 0.25° (approximately 25 km) with a latency of approximately 6 hours. These data are archived by the US National Climatic Data Center (NCDC) through the NOAA National Operational Model Archive and Distribution System (NOMADS) project. The archive for the 0.25° dataset extends from 13 Feb. 2012. This dataset is free-of cost.
- ECMWF Single level analysis from the High Resolution (HRES) Model provides global (90°N-90°S) 6-hourly surface (10 m) wind speed analyses at a spatial resolution of 0.1° (approximately 10 km) with a latency of approximately 6 hours. The archive of this dataset at 0.1° resolution extends from 2016; older, lower resolution versions are available. This dataset has costs associated with it; archive items are available at additional cost.

- UKMO Global Atmospheric Hi-Res Model provides global (90°N-90°S) 12-hourly surface (10 m) wind speed analyses at a spatial resolution of 0.153° (approximately 15 km) with a latency of 6-12 hours. The archive length of this dataset at 0.153° resolution is unknown, but older, lower resolution versions are available from at least 2000. This dataset has costs associated with it; archive items may have additional costs associated with them.

Satellite rain

- JAXA provides global (60°N-60°S) 1-hourly rainfall estimates at a spatial resolution of 0.1° (approximately 10 km) with a latency of zero (since Nov. 2015) or 4 hours (since Oct. 2008). This dataset is free-of cost.
- NASA provides global (90°N-90°S) 30-minute (6-hour latency for early run since Mar. 2015; 18-hour latency for late run since Mar. 2015; 4-month latency for final run since Mar. 2014), 3-hourly (6-hour latency for early run since Apr. 2015; 18-hour latency for late run since Apr. 2015), 1-day (6-hour latency for early run since Apr. 2015; 18-hour latency for late run since Apr. 2015; 4-month latency for final run since Apr. 2015) rainfall estimates at a spatial resolution of 0.1° (approximately 10 km) through the GPM (IMERG) product. The GPM algorithm is being retrospectively applied to the TRMM (TMPA) dataset (global 60°N-60°S at 0.25°, approximately 25 km) to provide a consistent dataset extending back to 1997. This dataset is free-of cost.
- NOAA / NESDIS STAR Hydro-Estimator provides global (60°N-60°S) 1-hourly rainfall estimates at a spatial resolution of 0.057°x0.047° (approximately 5 km) with a latency of 2-hours since Jan. 2007. This dataset is free-of cost.
- NOAA / NESDIS Operational Hydro-Estimator provides global (60°N-60°S) instantaneous and 1-hourly rainfall estimates at a spatial resolution of 0.057°x0.047° (approximately 5 km) with a latency of 2-hours. This dataset is free-of cost.

Additional data sources

- Property / exposure information to determine the number of assets at risk to damaging winds or heavy rainfall within the extent.
- Additional historical TC track datasets (including the World Meteorological Organisation (WMO)-sanctioned International Best Track Archive for Climate Stewardship (IBTrACS) dataset) and synthetic TC datasets could be needed to estimate historical damage footprints to further assist in contract pricing and structure.
- Background mean environmental surface pressure in the region of interest as an input parameter for certain cat models. These data could be obtained from freely available mean sea level pressure analyses from global (e.g. NCEP or UKMO) or local / regional reporting agencies (e.g. in-country national meteorological services).
- Maximum water depth (surge) as an input for certain cat models. These data could be obtained from local tide gauges (if available) or from ocean model forecasts (e.g. NCEP Real Time Ocean Forecasting System (RTOFS) and NOAA WAVEWATCH III).

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the tropical cyclone peril, full catastrophe models are available for the following countries:
- Bangladesh (AIR, ARA), Cambodia (ARA), India (AGR, AIR, ARA, CL, IF), Indonesia (KR), Malaysia (ARA, CL, IF), Myanmar (ARA), Pakistan (ARA, CL), Philippines (ARA, CL), Sri Lanka (ARA), Thailand (ARA, IF, CL) and Viet Nam (AIR, ARA, IF, IMP, KR).
- Afghanistan, Lao PDR and Nepal do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Bangladesh, Viet Nam, and Sri Lanka.

Bangladesh

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution.
- The AIR Bangladesh Tropical Cyclone model requires 1-min sustained wind speed, track points and central pressure, environmental pressure, radius of maximum winds, maximum precipitation rate, precipitation radius, landfall time and location as input parameters. An insurance industry exposure database (residential, non-residential) is available. This model captures the impacts due to TC winds and rainfall at a spatial resolution of 5 km.

Viet Nam

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution.
- The KatRisk Indonesia and Viet Nam model requires 3-sec peak gust wind speed, cyclone track (location of landfall, direction at landfall, central pressure, radius to maximum wind, forward speed) as input parameters. Exposure including gridded economic and population datasets are available. This model captures the impacts due to TC winds rainfall at a spatial resolution of 1-5 km.
- The forthcoming Impact Forecasting Viet Nam Typhoon model requires 3 second peak gust wind speed; daily rainfall during storm (flooding), max water depth (surge), with track with central pressure at 6 hourly points as input parameters. Economic and insurance industry exposure databases are available. This model captures the impacts due to TC winds rainfall at a spatial resolution of 240 m.
- The AIR Viet Nam Tropical Cyclone model requires 1-min sustained wind speed, track points and central pressure, environmental pressure, radius of maximum winds, maximum precipitation rate, precipitation radius, landfall time and location as input parameters. An insurance industry exposure database (residential, non-residential) is available. An insurance industry residential buildings exposure database is available. This model captures the impacts due to TC winds and rainfall at a spatial resolution of 1 km.

Sri Lanka

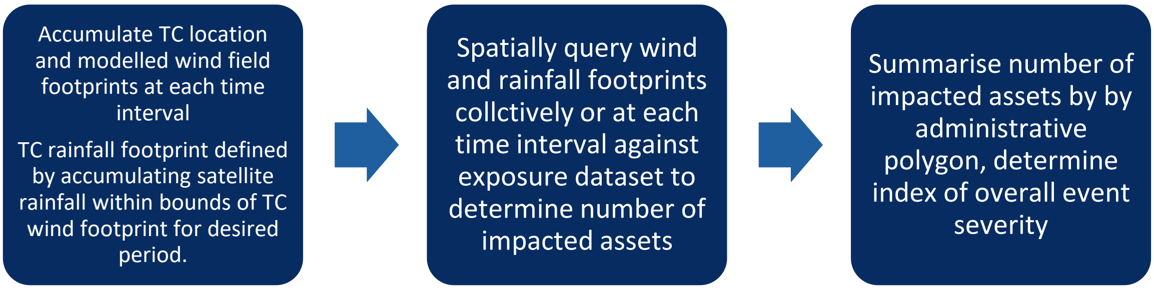
- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution. This model captures the impacts due to TC winds at a desired spatial resolution.

POTENTIAL SETTLEMENT WINDOW:

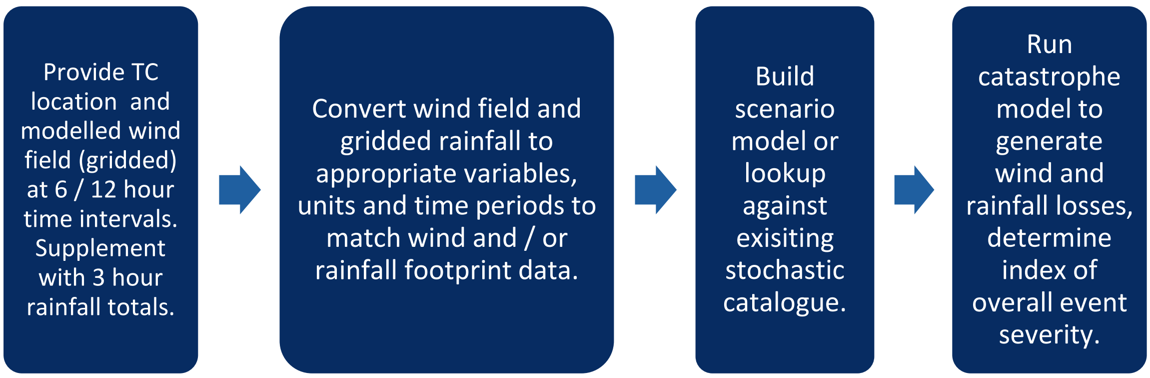
- All data is available as routine products with sub-daily updates (TC locations are 6-hourly; modelled wind field is 6- or 12-hourly, depending on source; rainfall is 30-minute, 1-hourly or 3-hourly, depending on source) available in real-time. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Global coverage.
- Some sources have free and open licence.
- All datasets are supplied by government supported agencies, providing very reliable product deliveries.
- Relatively high temporal resolution (sub-daily) allows for multi-scale assessment of damage throughout entire event.
- TC locations from all sources are usually based on satellite imagery and can be determined using polar-orbiting or geostationary satellite data; there is no reliance on a single source of imagery. When available, all sources will use "in-situ" data (station, ship, buoy or aircraft) to correct the satellite estimates.
- Historical TC location datasets are available from approximately 1945 (JTWC), 1997 (NRL) and 1845 (but depends on basin; Unisys) to allow contract to be priced and structured. Additional historical TC track and intensity datasets (including the World Meteorological Organisation (WMO)-sanctioned International Best Track Archive for Climate Stewardship (IBTrACS) dataset) and synthetic TC datasets could be used to estimate damage footprints to further assist in contract pricing and structure.
- Some cat models may not accept modelled wind fields as a direct input; however, desired inputs could be defined based on modelled wind fields.
- Archive lengths for model wind field products is short (maximum is a decade for NCEP); however, substitutions can be made with older, lower resolution versions, or by using appropriate reanalysis datasets.
- Resolution of satellite products is relatively high, city-scale.
- JAXA rainfall archive extends from 2008; NASA GPM archive begins in 2014 although TRMM rainfall is being reprocessed using GPM algorithm to extend archive back to 1997; NOAA / NESDIS STAR rainfall archive begins in 2007. These relatively short record lengths, given frequency of tropical cyclone impacts in the region, may pose challenges to structuring and pricing of contract.
- Potential for failure for satellites missions or components within the satellite (e.g. antenna) could impact all products was in this index.
- Some cat models require additional input data not explicitly discussed, however the listed sources which may limit the use of the cat model within this index formulation.
- All datasets are of global nature, with little scope for regional inconsistencies or local conflict of interest.

SCOPE OF LIVE DATA:

Key attributes:

- Global coverage.
- Sub-daily updates available with short (< 12 hours) latency for all listed data sources.
- Spatial resolution of wind footprint dependent solely on selected cat model.

NCEP GDAS modelled wind field

- Spatial resolution of 0.25° (approximately 25 km).
- Analyses available at 6-hourly intervals.
- Free-of-cost for real time and archive data.

UKMO modelled wind field

- Spatial resolution of 0.1° (approximately 10 km).
- Analyses available at 12-hourly intervals.
- Costs associated with both real time and archive data.

ECMWF modelled wind field

- Spatial resolution of 0.1° (approximately 10 km).
- Analyses available at 6-hourly intervals.
- Costs associated with both real time and archive data.

JAXA and NASA rainfall

- Spatial resolution of 0.1° (approximately 10 km).

NOAA / NESDIS STAR and Operational Hydro-Estimator rainfall

- Spatial resolution of 0.05° (approximately 5 km).

TC Index 2: Global source TC locations with satellite rain and local observations

DATA SOURCES:

- TC locations and intensity: US Joint Typhoon Warning Center (JTWC) Tropical Cyclone Warning Text [1] OR US Naval Research Laboratory (NRL) Tropical Cyclone Warning [2] OR RMSC Tokyo / JMA Tropical Cyclone Information [14]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- TC size: US Joint Typhoon Warning Center (JTWC) Tropical Cyclone Warning Text [1] OR US Naval Research Laboratory (NRL) Tropical Cyclone Warning [2] OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS) / Cooperative Institute for Research in the Atmosphere (CIRA) / Regional and Mesoscale Meteorology Branch (RAMMB) Dvorak Fix-Based Wind Radii OR RMSC Tokyo / JMA Tropical Cyclone Information [14]
- Satellite rain: Japan Aerospace Exploration Agency (JAXA) Global Rainfall Watch [8] OR National Aeronautics and Space Administration (NASA) Real-time 30 Minute, 3 Hourly and 1 Day Rainfall Data [9] OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS), Center for Satellite Applications Research STAR Satellite Rainfall Estimates - Hydro-Estimator [10] OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS), Office of Satellite and Product Operations Operational Hydro-Estimator Satellite Rainfall Estimates [11]
- National weather station wind and rainfall observations (global repositories – all countries): UK Met Office MetDB dataset of global weather observations [12] OR UK Met Office MIDAS Global Weather Observations dataset [13]
- National weather station wind observations (local sources):
  - Bangladesh - Bangladesh Meteorological Department (BMD) Automatic Weather Station (AWS) data [32, 33]
  - Viet Nam - National Centre for Hydro-Meteorological Forecasting Weather station data [31]
- National rain gauge observations (local sources):
  - Bangladesh - Bangladesh Water Development Board (BWDB) Flood Forecasting and Warning Centre – Rainfall [20] and Bangladesh Meteorological Department (BMD) Automatic Weather Station (AWS) data [33]
  - Viet Nam - National Centre for Hydro-Meteorological Forecasting (NCHMF) Weather station data [31], Mekong River Commission (MRC) Mekong river monitoring system – Forecast rainfall observations [23] and Mekong River Commission (MRC) Mekong River Real Time Water Level Monitoring (HYCOS) [24]
  - Sri Lanka - Irrigation Department (Sri Lanka) Hydro-meteorological Observation Network [21]

OVERVIEW:

This index uses the TC specifics information, including location, intensity and size, along with satellite rain and in-country observations of wind and rain to determine the impact associated with exposure to strong winds and heavy rain.

COUNTRY COVERAGE:

Other countries may have coverage but the following countries were examined: Bangladesh, Viet Nam and Sri Lanka.

POTENTIAL PERIL COVERAGE:

- Tropical cyclone occurring in Bangladesh, Viet Nam and Sri Lanka.
- Tropical cyclone impact for a second generation parametric trigger if supplemented with exposure at risk to strong winds and heavy rain.
- Tropical cyclone impact for a third generation parametric trigger if supplemented with a model tropical cyclone, based on TC intensity and size information combined with in-country wind observations (Bangladesh and Viet Nam only), and satellite rain combined with in-country rain observations (all named countries) as input to a catastrophe model.

POTENTIAL IMPACT COVERAGE:

- Damage from wind and rain is covered.
- Tropical cyclone location, intensity (maximum sustained winds) and size (radii of specific wind values in each quadrant) are supplied in source data every 6 hours, at a minimum. Combining the 6-hourly wind field extents provides an estimate of the overall extent of possible damage based on TC impact location and extent of the damaging wind field.
- Supplementing with satellite rainfall estimates, as an event total or defined period rain depth from summation of appropriate 30-minute, 1-hourly, 3-hourly or 1-day rainfall totals (converted from rainfall rates, if necessary), provides additional information on the distribution of heavy rainfall. All suggested rainfall products have a spatial resolution of at least 0.1° (approximately 10 km) except those products derived using the NASA 3B42 algorithm from TRMM or GPM data.
- In modelled loss trigger form, the TC location, intensity (maximum sustained winds) and size (radii of specific wind speeds in each quadrant) can be used to define and model TC. Empirically-based analytical relationships exist to derive central surface pressure, 3-second peak gust wind speed and radius of maximum winds from the TC location and intensity data from all sources. These data, along with the satellite rain depths, can be used as an input to a catastrophe model, to capture impacts of strong winds and heavy rain on population and physical assets.
- Whilst the resolution of the modelled wind field is relatively high, the
- The resolution of the captured impact is dependent on the output resolution of the selected cat model.
- The TC wind field distribution used in the cat model may be prescribed as axisymmetric or asymmetric (and usually more realistic), dependent on the selected cat model.
- The provision of flood extents will be dependent on the selected cat model; however, a TC rainfall footprint can be derived from satellite data for cat models without a flood model component.

Bangladesh (local sources)

- In-country observations of wind (at sub-hourly timescales) and rainfall (at daily and sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind data is moderately good. Stations are primarily located near the population centres of Rajshahi and Sirajganj, and in the coastal Noakhali district. Isolated stations are dotted around the rest of the country; notable gaps in coverage are present around the capital, Dhaka, and near the coast.
- The gaps in station wind observation coverage near the coast are particularly problematic for validating and / or enhancing wind footprints which may impact population and assets in Barisal, southern Chittagong divisions.
- Coverage by rainfall gauges, for combined data sources, is reasonably good, with most of the major population centres in relatively close proximity to at least 1 rainfall gauge. A few gauges are present near the coast, generally near population centres.
- Validation and / or enhancement of rainfall footprints should be achievable with the available gauge network.

Bangladesh (global repositories)

- In-country observations of wind (at daily / sub-daily timescales) and rainfall (at daily / sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind and rainfall data is good with fairly even coverage across the country, including a number of stations along the coast and in close proximity to Dhaka.
- Validation and / or enhancement of wind and rainfall footprints should be achievable with the available station network.

Viet Nam (local sources)

- In-country observations of wind (at hourly to sub-daily timescales) and rainfall (at daily and sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind data is excellent. The coast line, except for the extreme southern tip of Viet Nam has excellent coverage, as do the large population centres.
- Validation and / or enhancement of wind footprints should be achievable with the available station network.
- Coverage by rainfall gauges, for combined data sources, is excellent. The extreme southern tip of Viet Nam has no coverage by rainfall gauges; there are no large population centres here.
- Validation and / or enhancement of rainfall footprints should be achievable with the available gauge network.

Viet Nam (global repositories)

- In-country observations of wind (at sub-daily timescales) and rainfall (at sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind and rainfall data is sparse but reasonable. Stations are relatively evenly, but widely, spaced along the coastline, including the extreme southern tip of Viet Nam, and also located at the major population centres.
- Validation and / or enhancement of wind footprints may be possible, but limited, with the available station network.

Sri Lanka (local sources)

- In-country observations of rainfall (at daily and sub-daily timescales) may allow validation and / or enhancement of rainfall footprints.
- Coverage by hydro-meteorological stations collecting rainfall data is relatively good. Stations are concentrated near population centres, mostly on the eastern half of the island; relatively few stations are located on the south eastern portion of the island; however, population density is very low here.
- Validation and / or enhancement of wind footprints should be achievable, with limitations, with the available station network.

Sri Lanka (global repositories)

- In-country observations of wind (at sub-daily timescales) and rainfall (at sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind and rainfall data is sparse but reasonable. Stations are relatively evenly, but widely, spaced along the coastline, with several stations near the middle of the island and near the major centre, Colombo.
- Validation and / or enhancement of wind footprints would be limited but achievable, with the available station network.

SUPPLEMENTARY DATA SOURCE OPTIONS:

TC size

- JTWC provides estimates of TC size in terms of the radii of specific wind speeds referenced to the windspeed thresholds of the Saffir-Simpson Scale categories (i.e. 34kn for Tropical Depression, 50kn for Tropical storm, 64kn for Category 1 Hurricane, etc.). These data are available alongside the TC location and intensity information on which this index is based, at least every 6 hours, for every TC that occurs in the Indian and Pacific Oceans, with a latency of less than 3 hours. The archive of TC locations and intensity for this dataset extends from 1945; however, TC size estimates will only be recorded for the more recent post-satellite era. This dataset is free of cost.
- NRL provides estimates of TC size in terms of the radii of specific wind speeds referenced to the windspeed thresholds of the Saffir-Simpson Scale categories (i.e. 34kn for Tropical Depression, 50kn for Tropical storm, 64kn for Category 1 Hurricane, etc.). These data are available alongside the TC location and intensity information on which this index is based, at least every 6 hours, for every TC that occurs across the globe, with a latency of less than 1 hour. The archive of TC locations and intensity for this dataset extends from 1997; however, TC size estimates may not be available from this date. This dataset is free of cost.
- NOAA / NESDIS / CIRA / RAMMB provides estimates of TC size in terms of the radii of specific wind speeds referenced to the windspeed thresholds of the Saffir-Simpson Scale categories (i.e. 34kn for Tropical Depression, 50kn for Tropical storm, 64kn for Category 1 Hurricane, etc.). These data are available alongside the TC location and intensity information on which this index is based, at least every 6 hours, for every TC that occurs across the globe, with a latency of less than 2 hours. The archive for this dataset extends from 2006. This dataset is free of cost.
- RSMC Tokyo / JMA provides estimate of TC size in terms of the radii of specific wind speeds (e.g. 30, 50 knots, etc). These data are available alongside the TC location and intensity information on which this index is based, at least every 6 hours, for every TC that occurs within the RMSC Tokyo reporting area (0-60°N, 100-180°E), with a latency of less than 12 hours. The archive of TC locations and intensity for this dataset extends from 1951; however, TC size estimates may not be available from this date. This dataset is free of cost.

Satellite rain

- JAXA provides global (60°N-60°S) 1-hourly rainfall estimates at a spatial resolution of 0.1° (approximately 10 km) with a latency of zero (since Nov. 2015) or 4 hours (since Oct. 2008). This dataset is free-of cost.
- NASA provides global (90°N-90°S) 30-minute (6-hour latency for early run since Mar. 2015; 18-hour latency for late run since Mar. 2015; 4-month latency for final run since Mar. 2014), 3-hourly (6-hour latency for early run since Apr. 2015; 18-hour latency for late run since Apr. 2015), 1-day (6-hour latency for early run since Apr. 2015; 18-hour latency for late run since Apr. 2015; 4-month latency for final run since Apr. 2015) rainfall estimates at a spatial resolution of 0.1° (approximately 10 km) through the GPM (IMERG) product. The GPM algorithm is being retrospectively applied to the TRMM (TMPA) dataset (global 60°N-60°S at 0.25°, approximately 25 km) to provide a consistent dataset extending back to 1997. This dataset is free-of cost.

- NOAA / NESDIS STAR Hydro-Estimator provides global (60°N-60°S) 1-hourly rainfall estimates at a spatial resolution of 0.057°x0.047° (approximately 5 km) with a latency of 2-hours since Jan. 2007. This dataset is free-of cost.
- NOAA / NESDIS Operational Hydro-Estimator provides global (60°N-60°S) instantaneous and 1-hourly rainfall estimates at a spatial resolution of 0.057°x0.047° (approximately 5 km) with a latency of 2-hours. This dataset is free-of cost.

National weather station wind and rain observations (global repositories)

- UKMO MetDB provides nominally 6-hourly rainfall accumulation, mean wind speed and direction and maximum gust wind speed with latencies between 20 minutes and 1 day, depending on the station. Some stations may report more or less frequently. Data undergo basic quality control before entering the repository. Length of historical archive varies by station. Approval for use must be sought from each respective country to use that country's data; these data may have costs associated with, dependent on the country.
- UKMO MIDAS provides nominally 3-hourly rainfall accumulation, mean wind speed and direction and maximum gust wind speed with a latency of up to 1 month. Some stations may report more or less frequently. Data undergo more rigorous quality control before entering the repository. Length of historical archive varies by station. Approval for use must be sought from each respective country to use that country's data; these data may have costs associated with, dependent on the country.

Bangladesh

- BWDB provides daily rainfall for 58 gauges across Bangladesh with a latency of 1 day. This dataset is free of cost. Historical data, with costs associated, are available from 2012 or 2014 onwards, depending on the gauge.
- BMD provides AWS 1-minute rainfall, 1-minute average and maximum wind speed and 1-minute average, maximum and minimum wind direction for up to 73 climate stations across Bangladesh, and 1-minute and 10-minute average, minimum and maximum wind speed and direction for 1 airport station (Jessore). This data is provided with a latency of up to 30 minutes. Costs associate with using this data are unknown. Historical data is available from at least 2014 onwards.
- MetDB and MIDAS provide wind and rainfall for up to 54 stations.

Viet Nam

- NCHMF provides 1-, 3- or 6-hourly wind and rainfall for up to 234 stations around Viet Nam. The majority of these stations are manual and hence data must be obtained directly from NCHMF. These data have costs associated with them. Historical records are also available at additional costs; most station records extend from 1976 onwards, however 50-80- year records exist for some stations.
- MRC Monitoring – Forecast provides daily rainfall for 2 stations in southern Viet Nam with a latency of 1 day between June and October and 1 week outside of that period. These data are free of cost; historical data, available from 2008 onwards have costs associated with them.

- MRC HYCOS provides 15-minute rainfall for 12 stations with a latency of 2 hours. These data are free of cost; however, they are only provided in graphical form; digital data is recorded and may be available by contacting the agency. Historical record lengths are unknown at present. lengths are unknown at present.
- MetDB and MIDAS provide wind and rainfall for up to 19 stations.

Sri Lanka

- The Irrigation Department collects rainfall information for at least 1882 sites in Sri Lanka, with the first gauges installed in the 1970s. Obtaining the data requires a login, presumably this can be provided through contact with the data source, although they have not responded to requests for information.
- MetDB and MIDAS provide wind and rainfall for up to 22 stations.

Additional data sources

- Property / exposure information to determine the number of assets at risk to damaging winds or heavy rainfall within the extent.
- Additional historical TC track and intensity datasets (including the World Meteorological Organisation (WMO)-sanctioned International Best Track Archive for Climate Stewardship (IBTrACS) dataset) and synthetic TC datasets could be needed to estimate historical damage footprints to further assist in contract pricing and structure.
- Background mean environmental surface pressure in the region of interest as an input parameter for certain cat models. These data could be obtained from freely available mean sea level pressure analyses from global (e.g. NCEP or UKMO) or local / regional reporting agencies (e.g. in-country national meteorological services).
- Maximum water depth (surge) as an input for certain cat models. These data could be obtained from local tide gauges (if available) or from ocean model forecasts (e.g. NCEP Real Time Ocean Forecasting System (RTOFS) and NOAA WAVEWATCH III).

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the flood peril, full catastrophe models are available for the following countries:
- Bangladesh (AIR, ARA), Cambodia (ARA), India (AGR, AIR, ARA, CL, IF), Indonesia (KR), Malaysia (ARA, CL, IF), Myanmar (ARA), Pakistan (ARA, CL), Philippines (ARA, CL), Sri Lanka (ARA), Thailand (ARA, IF, CL) and Viet Nam (AIR, ARA, IF, IMP, KR).
- Afghanistan, Lao PDR and Nepal do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Bangladesh, Viet Nam, and Sri Lanka.

Bangladesh

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution.
- The AIR Bangladesh Tropical Cyclone model requires 1-min sustained wind speed, track points and central pressure, environmental pressure, radius of maximum winds, maximum precipitation rate, precipitation radius, landfall time and location as input parameters. An insurance industry exposure database (residential, non-residential) is available. This model captures the impacts due to TC winds and rainfall at a spatial resolution of 5 km.

Viet Nam

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution.
- The KatRisk Indonesia and Viet Nam model requires 3-sec peak gust wind speed, cyclone track (location of landfall, direction at landfall, central pressure, radius to maximum wind, forward speed) as input parameters. Exposure including gridded economic and population datasets are available. This model captures the impacts due to TC winds rainfall at a spatial resolution of 1-5 km.
- The forthcoming Impact Forecasting Viet Nam Typhoon model requires 3 second peak gust wind speed; daily rainfall during storm (flooding), max water depth (surge), with track with central pressure at 6 hourly points as input parameters. Economic and insurance industry exposure databases are available. This model captures the impacts due to TC winds rainfall at a spatial resolution of 240 m.
- The AIR Viet Nam Tropical Cyclone model requires 1-min sustained wind speed, track points and central pressure, environmental pressure, radius of maximum winds, maximum precipitation rate, precipitation radius, landfall time and location as input parameters. An insurance industry exposure database (residential, non-residential) is available. An insurance industry residential buildings exposure database is available. This model captures the impacts due to TC winds and rainfall at a spatial resolution of 1 km.

Sri Lanka

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution. This model captures the impacts due to TC winds at a desired spatial resolution.

POTENTIAL SETTLEMENT WINDOW:

Bangladesh

- All TC location, intensity and size data, along with satellite rainfall and wind and rainfall observations from local sources and MetDB are available in real time, with a maximum latency for these data sources of 1 day. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.
- Wind and rainfall observation data retrieved from MIDAS has a latency of 1 month; if this data source is used, settlement would be delayed by at least 1 month, subject to the standard timelines for actual performance of the calculation.

Viet Nam

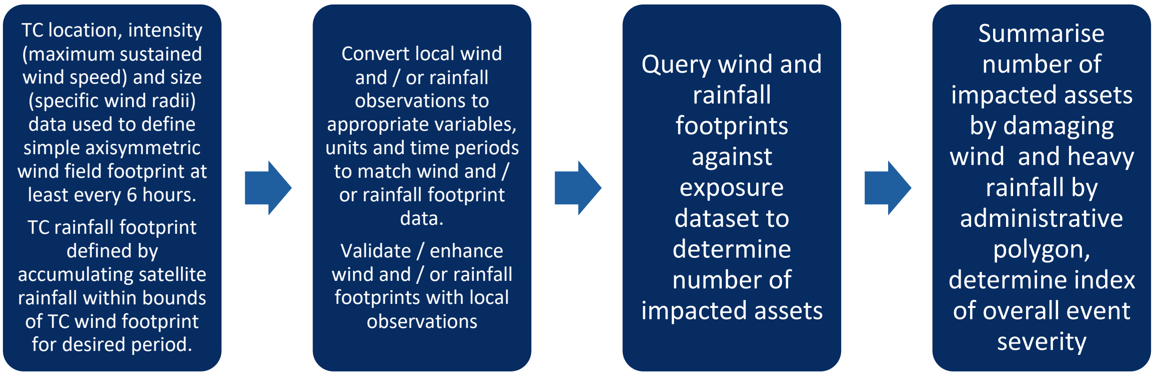
- All TC location, intensity and size data, along with satellite rainfall and wind and rainfall observations from MetDB are available in real time, with a maximum latency for these data sources of 1 day. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.
- Wind and rainfall data requested from NCHMF may take 1 week to become available, adding a delay of less than 2 weeks to the settlement window.
- Rainfall data from MRC Monitoring – Forecast is available with a 1-day latency between June and October, allowing for immediate settlement; however, outside of this period the latency is 1 week, adding a delay of less than 2 weeks to the settlement window.
- Rainfall data from MRC HYCOS is available in real time in graphical format, allowing for immediate settlement. Digital data may be obtainable from MRC directly, although this would likely have a delay of 2-3 weeks, further delaying settlement by approximately 1 month.
- Wind and rainfall observation data retrieved from MIDAS has a latency of 1 month; if this data source is used, settlement would be delayed by at least 1 month, subject to the standard timelines for actual performance of the calculation.

Sri Lanka

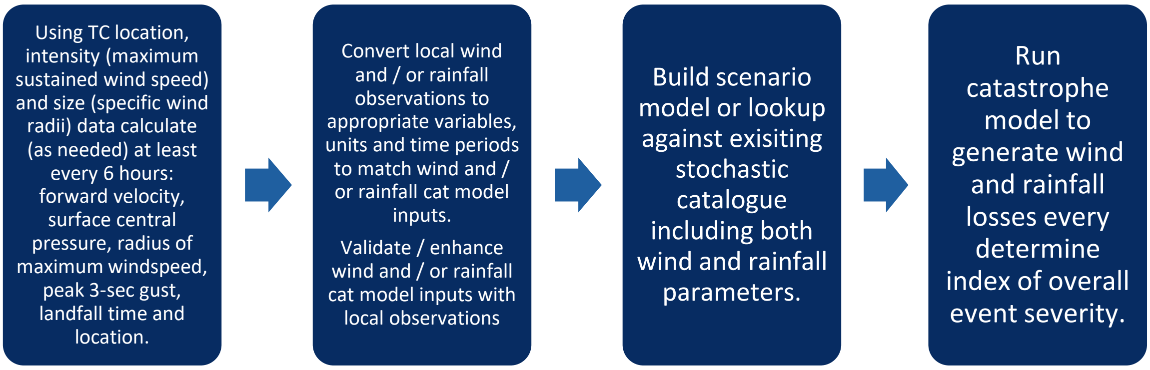
- All TC location, intensity and size data, along with satellite rainfall and wind and rainfall observations from local sources and MetDB are available in real time, with a maximum latency for these data sources of 1 day. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.
- Rainfall data may be obtained from the Irrigation Department; the latency of this data is unknown but speculated to be available in real time or with a delay of less than 1 week. This could add a delay of less than 2 weeks to the settlement window.
- Local data retrieved from MIDAS has a latency of 1 month; if this data source is used, settlement would be delayed by at least 1 month, subject to the standard timelines for actual performance of the calculation.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

Common features:

- Targeted country guidance.
- Most global datasets are supplied by government supported agencies, providing very reliable product deliveries.
- Resolution of wind footprint may be dependent on formulation of cat model for third generation parametric trigger.
- Provision of TC rainfall induced flood extent and depths, and spatial resolution of these, dependent on selected cat model. Rainfall footprints (rather than flood depths and extents) can be generated if a cat model without flood component is selected.
- Minimum temporal resolution of datasets (at least daily) allows for multi-scale assessment of damage throughout entire event.
- TC location, intensity and size estimates from all sources are based on satellite imagery and can be determined using polar-orbiting or geostationary satellite data; there is no reliance on a single source of imagery. When available, all sources will use "in-situ" data (station, ship, buoy or aircraft) to correct the satellite estimates of TC location and intensity; the same applies for TC size estimates by JTWC, NRL and RMSC Tokyo / JMA.

- Historical TC location and intensity datasets are available from approximately 1945 (JTWC), 1997 (NRL) and 1951 (RMSC Tokyo / JMA) to allow contract to be priced and structured. Additional historical TC track and intensity datasets (including the World Meteorological Organisation (WMO)-sanctioned International Best Track Archive for Climate Stewardship (IBTrACS) dataset) and synthetic TC datasets could be used to estimate damage footprints to further assist in contract pricing and structure.
- Conversion of source data into derived TC parameters for ingestion into cat model uses empirically-derived analytical relationships. Application of these estimates over land within a cat model would need to be used with caution; some post-processing may be required to generate more realistic over-land wind fields.
- Resolution of satellite products is relatively high, city-scale.
- JAXA rainfall archive extends from 2008; NASA GPM archive begins in 2014 although TRMM rainfall is being reprocessed using GPM algorithm to extend archive back to 1997; NOAA / NESDIS STAR rainfall archive begins in 2007. These relatively short record lengths, given frequency of tropical cyclone impacts in the region, may pose challenges to structuring and pricing of contract.
- Potential for failure for satellites missions or components within the satellite (e.g. antenna) could impact all products was in this index.
- Some cat models require additional input data not available from the listed sources which may limit the use of some cat models within this index formulation.
- MetDB and MIDAS are global repositories of local weather observations, hence there is less scope for local conflict of interest due to the quality control the observations undergo, and the importance of the observations for use in global numerical weather prediction.
- MetDB data undergo basic quality control with a latency of 1 day.
- MIDAS data undergo more rigorous quality control resulting in a longer latency (1 month).
- All sources of local data, including those included in local repositories may be subject to instrumentation and / or communication outages either dependent on or independent of the hazard.

Bangladesh:

- Spatial coverage of BWD AWS weather stations providing wind data is moderately good, except for gaps in coverage near capital city and near coastline. These gaps could be filled with additional data from the MetDB dataset. The temporal resolution of wind observations from both sources is at least daily, with sub-hourly observations from BWD AWS and a high likelihood of sub-daily observations from MetDB. Both datasets are available in near real time with a maximum latency of 1 day.
- Spatial coverage of rainfall gauges from combined local sources (BWDB and BMD AWS) is reasonably good, with a maximum latency of 1 day. Additional supplementation with rainfall observations from the MetDB dataset could improve coverage further without an increase in latency.

Viet Nam:

- Spatial coverage of wind and rainfall observations from NCHMF is excellent and long records exist, however the requirement for manual data requests may slow contract settlement.
- Spatial coverage of wind and rainfall observations from the MetDB or MIDAS datasets is relatively poor, but may add additional coverage to that of NCHMF in the extreme southern tip of Viet Nam. While the latency of MetDB would not add additional delays to that of NCHMF, the MIDAS dataset would add a few additional weeks to contract settlement.
- The spatial coverage of rainfall gauges from MRC HYCOS is limited; while the data has short latency for the graphical products, direct contact may be needed to secure digital records. These data could not be used in isolation. If used to supplement NCHMF observations, MRC HYCOS would not provide additional spatial coverage, but would add to the density of observations in areas of existing coverage. The latency of MRC HYCOS digital records may not delay settlement when used in combination with NCHMF rainfall data.
- MRC Monitoring – Forecast only provides rainfall for 2 sites, which are also included in the MRC HYCOS dataset. These data could not be used in isolation, and would duplicate existing data is combined with MRC HYCOS. If used to supplement NCHMF observations, MRC Monitoring – Forecast data would not provide additional spatial coverage, but would add to the density of observations in areas of existing coverage. The latency of Monitoring – Forecast data would not delay settlement when used in combination with NCHMF rainfall data.

Sri Lanka:

- No in-country source of wind data is available currently. The data may be obtainable from the Department of Meteorology, Sri Lanka directly, or from global repository centres (MetDB and MIDAS), with approval from the Department of Meteorology, Sri Lanka. Spatial coverage by MetDB / MIDAS stations is sparse but with a relatively evenly space network around the coast and inland near population centres. If wind data could be obtained from the Department of Meteorology, this may improve coverage over that of MetDB / MIDAS but would likely increase the settlement window over that of MIDAS to 2-3 weeks.

- Spatial coverage of Irrigation Department rainfall gauges is relatively good, except on the south east portion of the island. Supplementation by MetDB / MIDAS would improve coverage very slightly in the south eastern portion of the island, but not elsewhere and stations appear approximately collocated with Irrigation Department gauges. Latency of Irrigation Department rainfall data may delay contract settlement by less than 1 week; combining with MetDB observations would not extend this delay, while MIDAS observations would add an additional 3-4 weeks.

SCOPE OF LIVE DATA:

Key attributes:

- Targeted country coverage.
- Option for at least daily updates to wind and rainfall footprints, with a maximum 1-day latency, for all countries.
- Spatial resolution of wind footprint dependent solely on selected cat model.

JTWC and NRL TC locations, intensity and size

- TC locations at least every 6 hours along with intensity estimates as 1-minute maximum sustained surface wind speed in knots and the radii of specific surface wind speed values in each quadrant around the TC, based on satellite imagery and, when available, in situ observations.

RSMC Tokyo / JMA TC locations, intensity and size

- TC locations at least every 6 hours along with intensity estimates as 10-minute maximum sustained surface wind speed in knots and the radii of specific surface wind speed values in each quadrant around the TC, based on satellite imagery and, when available, in situ observations.

NOAA / NESDIS / CIRA / RAMMB TC size

- Radii of specific surface wind speed values in each quadrant around the TC every 6 hours, based on satellite imagery.

JAXA and NASA rainfall

- Spatial resolution of 0.1° (approximately 10 km).

NOAA / NESDIS STAR and Operational Hydro-Estimator rainfall

- Spatial resolution of 0.05° (approximately 5 km).

MetDB wind and rainfall observations (global repository)

- Global coverage with sub-daily observations of wind and rainfall.
- Basic quality control allows 1-day latency

MIDAS wind and rainfall observations (global repository)

- Global coverage with sub-daily observations of wind and rainfall.
- Enhanced quality control leads to 1-month latency

Bangladesh (local sources)

- BMD AWS: Up to 74 stations across the country providing wind and rainfall observations, with notable gaps near the coast and around the capital. Sub-hourly data with latency of less than 1 hour.
- BWDB: 58 rainfall gauges across the country, including near the coast and the capital. Daily rainfall with a latency of 1 day.

Viet Nam (local sources)

- NCHMF: Up to 234 stations across the country providing wind and rainfall observations, with a notable gap in the extreme southern tip of the country. Sub-daily data with latency of up to 2 weeks due to requirement for direct request of data.
- MRC Monitoring - Forecast: 2 rainfall gauges in the south of the country. Daily rainfall with a latency of 1 day (Jun. to Oct.) or 1 week (Nov. to May).
- MRC HYCOS: 12 gauges in the Mekong basin. Sub-hourly rainfall data with a latency of 2 hours.

Sir Lanka (local sources)

- Irrigation Department: Up to 1882 rainfall gauges across the country, with sparser coverage in the less-densely populated south eastern portion of the island. Temporal resolution and latency are unknown.

TC Index 3: Global source TC locations with modelled wind field, satellite rain and local observations

DATA SOURCES:

- TC locations: US Joint Typhoon Warning Center (JTWC) Tropical Cyclone Warning Text [1]
- OR US Naval Research Laboratory (NRL) Tropical Cyclone Warning [2]
- OR Unisys Weather Hurricane / Tropical Data [3]
- OR RMSC Tokyo / JMA Tropical Cyclone Information [14]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Modelled wind field: US National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) [5] OR European Centre for Medium-range Weather Forecasts (ECMWF) Single level analysis [6] OR UK Met Office (UKMO) Global Atmospheric Hi-Res Model [7]
- Satellite rain: Japan Aerospace Exploration Agency (JAXA) Global Rainfall Watch [8] OR National Aeronautics and Space Administration (NASA) Real-time 30 Minute, 3 Hourly and 1 Day Rainfall Data [9] OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS), Center for Satellite Applications Research STAR Satellite Rainfall Estimates - Hydro-Estimator [10] OR National Oceanographic and Atmospheric Administration (NOAA) / National Environmental Satellite, Data, and Information Service (NESDIS), Office of Satellite and Product Operations Operational Hydro-Estimator Satellite Rainfall Estimates [11]
- National weather station wind and rainfall observations (global repositories – all countries): UK Met Office MetDB dataset of global weather observations [12] OR UK Met Office MIDAS Global Weather Observations dataset [13]
- National weather station wind observations (local sources):
  - Bangladesh - Bangladesh Meteorological Department (BMD) Automatic Weather Station (AWS) data [32, 33]
  - Viet Nam - National Centre for Hydro-Meteorological Forecasting Weather station data [31]
- National rain gauge observations (local sources):
  - Bangladesh - Bangladesh Water Development Board (BWDB) Flood Forecasting and Warning Centre – Rainfall [20] and Bangladesh Meteorological Department (BMD) Automatic Weather Station (AWS) data [33]
  - Viet Nam - National Centre for Hydro-Meteorological Forecasting (NCHMF) Weather station data [31], Mekong River Commission (MRC) Mekong river monitoring system – Forecast rainfall observations [23] and Mekong River Commission (MRC) Mekong River Real Time Water Level Monitoring (HYCOS) [24]
  - Sri Lanka - Irrigation Department (Sri Lanka) Hydro-meteorological Observation Network [21]

OVERVIEW:

This index uses the TC locations, along with modelled TC wind field, satellite rain and in-country observations of wind and rain to determine the impact associated with exposure to strong winds and heavy rain.

COUNTRY COVERAGE:

Other countries may have coverage but the following countries were examined: Bangladesh, Viet Nam and Sri Lanka.

POTENTIAL PERIL COVERAGE:

- Tropical cyclone occurring in Bangladesh, Viet Nam and Sri Lanka.
- Tropical cyclone impact for a second generation parametric trigger if supplemented with exposure at risk to strong winds and heavy rain, along with model TC wind field and satellite rainfall.
- Tropical cyclone impact for a third generation parametric trigger if supplemented with a model tropical cyclone (based on model wind field) combined with in-country wind observations (Bangladesh and Viet Nam only), and satellite rain combined with in-country rain observations (all named countries) as input to a catastrophe model.

POTENTIAL IMPACT COVERAGE:

- Damage from wind and rain is covered.
- Tropical cyclone location is supplied in source data every 6 hours, at a minimum. Supplementing with model surface wind analyses either 6-hourly (NCEP, ECMWF) or 12-hourly (UKMO) provides relatively high spatial resolution asymmetrical wind field to allow an estimate of the overall extent of possible damage based on TC impact location and extent of the damaging wind field.
- Supplementing with satellite rainfall estimates, as an event total or defined period rain depth from summation of appropriate 30-minute, 1-hourly, 3-hourly or 1-day rainfall totals (converted from rainfall rates, if necessary), provides additional information on the distribution of heavy rainfall. All suggested rainfall products have a spatial resolution of at least 0.1° (approximately 10 km) except those products derived using the NASA 3B42 algorithm from TRMM or GPM data.
- In modelled loss trigger form, the TC location and modelled surface wind field, along with the satellite rain depths, can be used as an input to a cat model, to capture impacts of strong winds and heavy rain on population and physical assets.
- The resolution of the captured impact is dependent on the output resolution of the selected cat model.
- The provision of flood extents will be dependent on the selected cat model; however, a TC rainfall footprint can be derived from satellite data for cat models without a flood model component.

Bangladesh (local sources)

- In-country observations of wind (at sub-hourly timescales) and rainfall (at daily and sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind data is moderately good. Stations are primarily located near the population centres of Rajshahi and Sirajganj, and in the coastal Noakhali district. Isolated stations are dotted around the rest of the country; notable gaps in coverage are present around the capital, Dhaka, and near the coast.
- The gaps in station wind observation coverage near the coast are particularly problematic for validating and / or enhancing wind footprints which may impact population and assets in Barisal, southern Chittagong divisions.
- Coverage by rainfall gauges, for combined data sources, is reasonably good, with most of the major population centres in relatively close proximity to at least 1 rainfall gauge. A few gauges are present near the coast, generally near population centres.
- Validation and / or enhancement of rainfall footprints should be achievable with the available gauge network.

Bangladesh (global repositories)

- In-country observations of wind (at daily / sub-daily timescales) and rainfall (at daily / sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind and rainfall data is good with fairly even coverage across the country, including a number of stations along the coast and in close proximity to Dhaka.
- Validation and / or enhancement of wind and rainfall footprints should be achievable with the available station network.

Viet Nam (local sources)

- In-country observations of wind (at hourly to sub-daily timescales) and rainfall (at daily and sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind data is excellent. The coast line, except for the extreme southern tip of Viet Nam has excellent coverage, as do the large population centres.
- Validation and / or enhancement of wind footprints should be achievable with the available station network.
- Coverage by rainfall gauges, for combined data sources, is excellent. The extreme southern tip of Viet Nam has no coverage by rainfall gauges; there are no large population centres here.
- Validation and / or enhancement of rainfall footprints should be achievable with the available gauge network.

Viet Nam (global repositories)

- In-country observations of wind (at sub-daily timescales) and rainfall (at sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind and rainfall data is sparse but reasonable. Stations are relatively evenly, but widely, spaced along the coastline, including the extreme southern tip of Viet Nam, and also located at the major population centres.
- Validation and / or enhancement of wind footprints may be possible, but limited, with the available station network.

Sri Lanka (local sources)

- In-country observations of rainfall (at daily and sub-daily timescales) may allow validation and / or enhancement of rainfall footprints.
- Coverage by hydro-meteorological stations collecting rainfall data is relatively good. Stations are concentrated near population centres, mostly on the eastern half of the island; relatively few stations are located on the south eastern portion of the island; however, population density is very low here.
- Validation and / or enhancement of wind footprints should be achievable, with limitations, with the available station network.

Sri Lanka (global repositories)

- In-country observations of wind (at sub-daily timescales) and rainfall (at sub-daily timescales) may allow validation and / or enhancement of wind and rainfall footprints.
- Coverage by meteorological stations collecting wind and rainfall data is sparse but reasonable. Stations are relatively evenly, but widely, spaced along the coastline, with several stations near the middle of the island and near the major centre, Colombo.
- Validation and / or enhancement of wind footprints would be limited but achievable, with the available station network.

SUPPLEMENTARY DATA SOURCE OPTIONS:

Modelled wind field

- NCEP GDAS provides global (90°N-90°S) 6-hourly surface (10 m) wind speed analyses at a spatial resolution of 0.25° (approximately 25 km) with a latency of approximately 6 hours. These data are archived by the US National Climatic Data Center (NCDC) through the NOAA National Operational Model Archive and Distribution System (NOMADS) project. The archive for the 0.25° dataset extends from 13 Feb. 2012. This dataset is free-of cost.
- ECMWF Single level analysis from the High Resolution (HRES) Model provides global (90°N-90°S) 6-hourly surface (10 m) wind speed analyses at a spatial resolution of 0.1° (approximately 10 km) with a latency of approximately 6 hours. The archive of this dataset at 0.1° resolution extends from 2016; older, lower resolution versions are available. This dataset has costs associated with it; archive items are available at additional cost.
- UKMO Global Atmospheric Hi-Res Model provides global (90°N-90°S) 12-hourly surface (10 m) wind speed analyses at a spatial resolution of 0.153° (approximately 15 km) with a latency of 6-12 hours. The archive length of this dataset at 0.153° resolution is unknown, but older, lower resolution versions are available from at least 2000. This dataset has costs associated with it; archive items may have additional costs associated with them.

Satellite rain

- JAXA provides global (60°N-60°S) 1-hourly rainfall estimates at a spatial resolution of 0.1° (approximately 10 km) with a latency of zero (since Nov. 2015) or 4 hours (since Oct. 2008). This dataset is free-of cost.
- NASA provides global (90°N-90°S) 30-minute (6-hour latency for early run since Mar. 2015; 18-hour latency for late run since Mar. 2015; 4-month latency for final run since Mar. 2014), 3-hourly (6-hour latency for early run since Apr. 2015; 18-hour latency for late run since Apr. 2015), 1-day (6-hour latency for early run since Apr. 2015; 18-hour latency for late run since Apr. 2015; 4-month latency for final run since Apr. 2015) rainfall estimates at a spatial resolution of 0.1° (approximately 10 km) through the GPM (IMERG) product. The GPM algorithm is being retrospectively applied to the TRMM (TMPA) dataset (global 60°N-60°S at 0.25°, approximately 25 km) to provide a consistent dataset extending back to 1997. This dataset is free-of cost.
- NOAA / NESDIS STAR Hydro-Estimator provides global (60°N-60°S) 1-hourly rainfall estimates at a spatial resolution of 0.057°x0.047° (approximately 5 km) with a latency of 2-hours since Jan. 2007. This dataset is free-of cost.
- NOAA / NESDIS Operational Hydro-Estimator provides global (60°N-60°S) instantaneous and 1-hourly rainfall estimates at a spatial resolution of 0.057°x0.047° (approximately 5 km) with a latency of 2-hours. This dataset is free-of cost.

National weather station wind and rain observations (global repositories)

- UKMO MetDB provides nominally 6-hourly rainfall accumulation, mean wind speed and direction and maximum gust wind speed with latencies between 20 minutes and 1 day, depending on the station. Some stations may report more or less frequently. Data undergo basic quality control before entering the repository. Length of historical archive varies by station. Approval for use must be sought from each respective country to use that country's data; these data may have costs associated with, dependent on the country.
- UKMO MIDAS provides nominally 3-hourly rainfall accumulation, mean wind speed and direction and maximum gust wind speed with a latency of up to 1 month. Some stations may report more or less frequently. Data undergo more rigorous quality control before entering the repository. Length of historical archive varies by station. Approval for use must be sought from each respective country to use that country's data; these data may have costs associated with, dependent on the country.

Bangladesh

- BWDB provides daily rainfall for 58 gauges across Bangladesh with a latency of 1 day. This dataset is free of cost. Historical data, with costs associated, are available from 2012 or 2014 onwards, depending on the gauge.
- BMD provides AWS 1-minute rainfall, 1-minute average and maximum wind speed and 1-minute average, maximum and minimum wind direction for up to 73 climate stations across Bangladesh, and 1-minute and 10-minute average, minimum and maximum wind speed and direction for 1 airport station (Jessore). This data is provided with a latency of up to 30 minutes. Costs associate with using this data are unknown. Historical data is available from at least 2014 onwards.
- MetDB and MIDAS provide wind and rainfall for up to 54 stations.

Viet Nam

- NCHMF provides 1-, 3- or 6-hourly wind and rainfall for up to 234 stations around Viet Nam. The majority of these stations are manual and hence data must be obtained directly from NCHMF. These data have costs associated with them. Historical records are also available at additional costs; most station records extend from 1976 onwards, however 50-80- year records exist for some stations.
- MRC Monitoring – Forecast provides daily rainfall for 2 stations in southern Viet Nam with a latency of 1 day between June and October and 1 week outside of that period. These data are free of cost; historical data, available from 2008 onwards have costs associated with them.
- MRC HYCOS provides 15-minute rainfall for 12 stations with a latency of 2 hours. These data are free of cost; however, they are only provided in graphical form; digital data is recorded and may be available by contacting the agency. Historical record lengths are unknown at present. lengths are unknown at present.
- MetDB and MIDAS provide wind and rainfall for up to 19 stations.

Sri Lanka

- The Irrigation Department collects rainfall information for at least 1882 sites in Sri Lanka, with the first gauges installed in the 1970s. Obtaining the data requires a login, presumably this can be provided through contact with the data source, although they have not responded to requests for information.
- MetDB and MIDAS provide wind and rainfall for up to 22 stations.

Additional data sources

- Property / exposure information to determine the number of assets at risk to damaging winds or heavy rainfall within the extent.
- Additional historical TC track datasets (including the World Meteorological Organisation (WMO)-sanctioned International Best Track Archive for Climate Stewardship (IBTrACS) dataset) and synthetic TC datasets could be needed to estimate historical damage footprints to further assist in contract pricing and structure.
- Background mean environmental surface pressure in the region of interest as an input parameter for certain cat models. These data could be obtained from freely available mean sea level pressure analyses from global (e.g. NCEP or UKMO) or local / regional reporting agencies (e.g. in-country national meteorological services).
- Maximum water depth (surge) as an input for certain cat models. These data could be obtained from local tide gauges (if available) or from ocean model forecasts (e.g. NCEP Real Time Ocean Forecasting System (RTOFS) and NOAA WAVEWATCH III).

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the flood peril, full catastrophe models are available for the following countries:
- Bangladesh (AIR, ARA), Cambodia (ARA), India (AGR, AIR, ARA, CL, IF), Indonesia (KR), Malaysia (ARA, CL, IF), Myanmar (ARA), Pakistan (ARA, CL), Philippines (ARA, CL), Sri Lanka (ARA), Thailand (ARA, IF, CL) and Viet Nam (AIR, ARA, IF, IMP, KR).
- Afghanistan, Lao PDR and Nepal do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Bangladesh, Viet Nam, and Sri Lanka.

Bangladesh

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution.
- The AIR Bangladesh Tropical Cyclone model requires 1-min sustained wind speed, track points and central pressure, environmental pressure, radius of maximum winds, maximum precipitation rate, precipitation radius, landfall time and location as input parameters. An insurance industry exposure database (residential, non-residential) is available. This model captures the impacts due to TC winds and rainfall at a spatial resolution of 5 km.

Viet Nam

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution.
- The KatRisk Indonesia and Viet Nam model requires 3-sec peak gust wind speed, cyclone track (location of landfall, direction at landfall, central pressure, radius to maximum wind, forward speed) as input parameters. Exposure including gridded economic and population datasets are available. This model captures the impacts due to TC winds rainfall at a spatial resolution of 1-5 km.
- The forthcoming Impact Forecasting Viet Nam Typhoon model requires 3 second peak gust wind speed; daily rainfall during storm (flooding), max water depth (surge), with track with central pressure at 6 hourly points as input parameters. Economic and insurance industry exposure databases are available. This model captures the impacts due to TC winds rainfall at a spatial resolution of 240 m.
- The AIR Viet Nam Tropical Cyclone model requires 1-min sustained wind speed, track points and central pressure, environmental pressure, radius of maximum winds, maximum precipitation rate, precipitation radius, landfall time and location as input parameters. An insurance industry exposure database (residential, non-residential) is available. An insurance industry residential buildings exposure database is available. This model captures the impacts due to TC winds and rainfall at a spatial resolution of 1 km.

Sri Lanka

- The ARA Asia Tropical Cyclone model requires 3-sec peak gust wind speed and surface pressure as input parameters. Exposure components are not available. This model captures the impacts due to TC winds at a desired spatial resolution. This model captures the impacts due to TC winds at a desired spatial resolution.

POTENTIAL SETTLEMENT WINDOW:

Bangladesh

- All TC location and modelled TC wind field sources, along with satellite rainfall and wind and rainfall observations from local sources and MetDB are available in real time, with a maximum latency for these data sources of 1 day. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.
- Wind and rainfall observation data retrieved from MIDAS has a latency of 1 month; if this data source is used, settlement would be delayed by at least 1 month, subject to the standard timelines for actual performance of the calculation.

Viet Nam

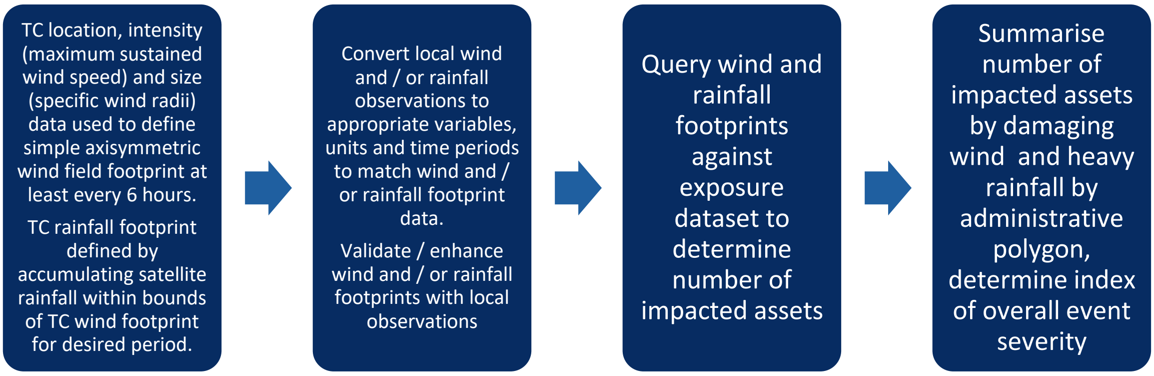
- All TC location and modelled TC wind field sources, along with satellite rainfall and wind and rainfall observations from MetDB are available in real time, with a maximum latency for these data sources of 1 day. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.
- Wind and rainfall data requested from NCHMF may take 1 week to become available, adding a delay of less than 2 weeks to the settlement window.
- Rainfall data from MRC Monitoring – Forecast is available with a 1-day latency between June and October, allowing for immediate settlement; however, outside of this period the latency is 1 week, adding a delay of less than 2 weeks to the settlement window.
- Rainfall data from MRC HYCOS is available in real time in graphical format, allowing for immediate settlement. Digital data may be obtainable from MRC directly, although this would likely have a delay of 2-3 weeks, further delaying settlement by approximately 1 month.
- Wind and rainfall observation data retrieved from MIDAS has a latency of 1 month; if this data source is used, settlement would be delayed by at least 1 month, subject to the standard timelines for actual performance of the calculation.

Sri Lanka

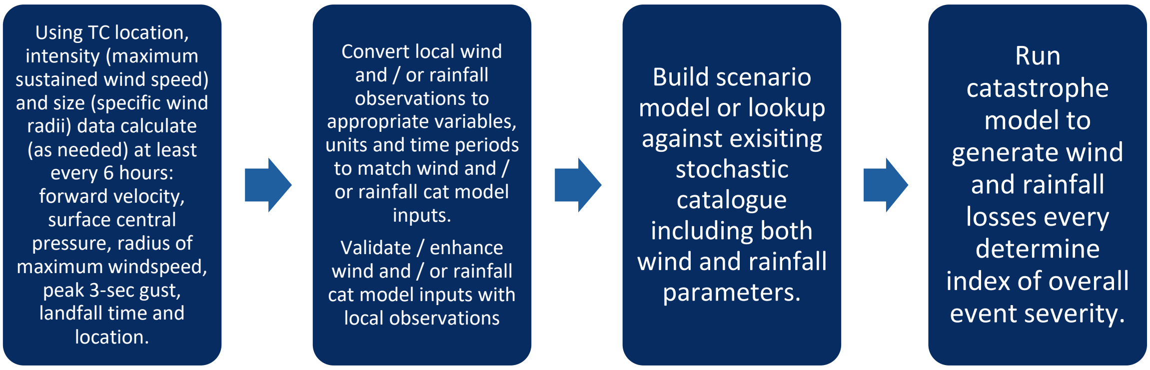
- All TC location and modelled TC wind field sources, along with satellite rainfall and wind and rainfall observations from local sources and MetDB are available in real time, with a maximum latency for these data sources of 1 day. This allows for immediate settlement following event, subject to the standard timelines for actual performance of the calculation.
- Rainfall data may be obtained from the Irrigation Department; the latency of this data is unknown but speculated to be available in real time or with a delay of less than 1 week. This could add a delay of less than 2 weeks to the settlement window.
- Local data retrieved from MIDAS has a latency of 1 month; if this data source is used, settlement would be delayed by at least 1 month, subject to the standard timelines for actual performance of the calculation.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

Common features:

- Targeted country guidance.
- Most global datasets are supplied by government supported agencies, providing very reliable product deliveries.
- Minimum temporal resolution of datasets (at least daily) allows for multi-scale assessment of damage throughout entire event.
- Historical TC location datasets are available from approximately 1945 (JTWC), 1997 (NRL), 1845 (but depends on basin; Unisys) and 1951 (RMSC Tokyo / JMA) to allow contract to be priced and structured. Additional historical TC track and intensity datasets (including the World Meteorological Organisation (WMO)-sanctioned International Best Track Archive for Climate Stewardship (IBTrACS) dataset) and synthetic TC datasets could be used to estimate damage footprints to further assist in contract pricing and structure.

- TC locations from all sources are usually based on satellite imagery and can be determined using polar-orbiting or geostationary satellite data; there is no reliance on a single source of imagery. When available, all sources will use "in-situ" data (station, ship, buoy or aircraft) to correct the satellite estimates.
- Some cat models may not accept modelled wind fields as a direct input; however, desired inputs could be defined based on modelled wind fields.
- Archive lengths for model wind field products is short (maximum is a decade for NCEP); however, substitutions can be made with older, lower resolution versions, or by using appropriate reanalysis datasets.
- Resolution of satellite products is relatively high, city-scale.
- JAXA rainfall archive extends from 2008; NASA GPM archive begins in 2014 although TRMM rainfall is being reprocessed using GPM algorithm to extend archive back to 1997; NOAA / NESDIS STAR rainfall archive begins in 2007. These relatively short record lengths, given frequency of tropical cyclone impacts in the region, may pose challenges to structuring and pricing of contract.
- Potential for failure for satellites missions or components within the satellite (e.g. antenna) could impact all products was in this index.
- Some cat models require additional input data not available from the listed sources which may limit the use of some cat models within this index formulation.
- MetDB and MIDAS are global repositories of local weather observations, hence there is less scope for local conflict of interest due to the quality control the observations undergo, and the importance of the observations for use in global numerical weather prediction.
- MetDB data undergo basic quality control with a latency of 1 day.
- MIDAS data undergo more rigorous quality control resulting in a longer latency (1 month).
- All sources of local data, including those included in local repositories may be subject to instrumentation and / or communication outages either dependent on or independent of the hazard.

Bangladesh:

- Spatial coverage of BWD AWS weather stations providing wind data is moderately good, except for gaps in coverage near capital city and near coastline. These gaps could be filled with additional data from the MetDB dataset. The temporal resolution of wind observations from both sources is at least daily, with sub-hourly observations from BWD AWS and a high likelihood of sub-daily observations from MetDB. Both datasets are available in near real time with a maximum latency of 1 day.
- Spatial coverage of rainfall gauges from combined local sources (BWDB and BMD AWS) is reasonably good, with a maximum latency of 1 day. Additional supplementation with rainfall observations from the MetDB dataset could improve coverage further without an increase in latency.

Viet Nam:

- Spatial coverage of wind and rainfall observations from NCHMF is excellent and long records exist, however the requirement for manual data requests may slow contract settlement.
- Spatial coverage of wind and rainfall observations from the MetDB or MIDAS datasets is relatively poor, but may add additional coverage to that of NCHMF in the extreme southern tip of Viet Nam. While the latency of MetDB would not add additional delays to that of NCHMF, the MIDAS dataset would add a few additional weeks to contract settlement.
- The spatial coverage of rainfall gauges from MRC HYCOS is limited; while the data has short latency for the graphical products, direct contact may be needed to secure digital records. These data could not be used in isolation. If used to supplement NCHMF observations, MRC HYCOS would not provide additional spatial coverage, but would add to the density of observations in areas of existing coverage. The latency of MRC HYCOS digital records may not delay settlement when used in combination with NCHMF rainfall data.
- MRC Monitoring – Forecast only provides rainfall for 2 sites, which are also included in the MRC HYCOS dataset. These data could not be used in isolation, and would duplicate existing data is combined with MRC HYCOS. If used to supplement NCHMF observations, MRC Monitoring – Forecast data would not provide additional spatial coverage, but would add to the density of observations in areas of existing coverage. The latency of Monitoring – Forecast data would not delay settlement when used in combination with NCHMF rainfall data.

Sri Lanka:

- No in-country source of wind data is available currently. The data may be obtainable from the Department of Meteorology, Sri Lanka directly, or from global repository centres (MetDB and MIDAS), with approval from the Department of Meteorology, Sri Lanka. Spatial coverage by MetDB / MIDAS stations is sparse but with a relatively evenly space network around the coast and inland near population centres. If wind data could be obtained from the Department of Meteorology, this may improve coverage over that of MetDB / MIDAS but would likely increase the settlement window over that of MIDAS to 2-3 weeks.

- Spatial coverage of Irrigation Department rainfall gauges is relatively good, except on the south east portion of the island. Supplementation by MetDB / MIDAS would improve coverage very slightly in the south eastern portion of the island, but not elsewhere and stations appear approximately collocated with Irrigation Department gauges. Latency of Irrigation Department rainfall data may delay contract settlement by less than 1 week; combining with MetDB observations would not extend this delay, while MIDAS observations would add an additional 3-4 weeks.

SCOPE OF LIVE DATA:

Key attributes:

- Targeted country coverage.
- Option for at least daily updates to wind and rainfall footprints, with a maximum 1-day latency, for all countries.
- Spatial resolution of wind footprint dependent solely on selected cat model.

JTWC, NRL, Unisys and RSMC Tokyo / JMA TC locations

- TC locations at least every 6 hours, based on satellite imagery and, when available, in situ observations.

NCEP GDAS modelled wind field

- Spatial resolution of 0.25° (approximately 25 km).
- Analyses available at 6-hourly intervals.
- Free-of-cost for real time and archive data.

UKMO modelled wind field

- Spatial resolution of 0.1° (approximately 10 km).
- Analyses available at 12-hourly intervals.
- Costs associated with both real time and archive data.

ECMWF modelled wind field

- Spatial resolution of 0.1° (approximately 10 km).
- Analyses available at 6-hourly intervals.
- Costs associated with both real time and archive data.

JAXA and NASA rainfall

- Spatial resolution of 0.1° (approximately 10 km).

NOAA / NESDIS STAR and Operational Hydro-Estimator rainfall

- Spatial resolution of 0.05° (approximately 5 km).

MetDB wind and rainfall observations (global repository)

- Global coverage with sub-daily observations of wind and rainfall.
- Basic quality control allows 1-day latency

MIDAS wind and rainfall observations (global repository)

- Global coverage with sub-daily observations of wind and rainfall.
- Enhanced quality control leads to 1-month latency

Bangladesh (local sources)

- BMD AWS: Up to 74 stations across the country providing wind and rainfall observations, with notable gaps near the coast and around the capital. Sub-hourly data with latency of less than 1 hour.
- BWDB: 58 rainfall gauges across the country, including near the coast and the capital. Daily rainfall with a latency of 1 day.

Viet Nam (local sources)

- NCHMF: Up to 234 stations across the country providing wind and rainfall observations, with a notable gap in the extreme southern tip of the country. Sub-daily data with latency of up to 2 weeks due to requirement for direct request of data.
- MRC Monitoring - Forecast: 2 rainfall gauges in the south of the country. Daily rainfall with a latency of 1 day (Jun. to Oct.) or 1 week (Nov. to May).
- MRC HYCOS: 12 gauges in the Mekong basin. Sub-hourly rainfall data with a latency of 2 hours.

Sir Lanka (local sources)

- Irrigation Department: Up to 1882 rainfall gauges across the country, with sparser coverage in the less-densely populated south eastern portion of the island. Temporal resolution and latency are unknown.

Drought (DR)

DR Index 1: Agricultural drought index for vegetation

DATA SOURCE:

- Drought Index - National Oceanic and Atmospheric Administration (NOAA) Center for Satellite Applications and Research [1]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- National rainfall and river gauge data
- Crop type, statistics, and calendar (e.g. crop production analysis or national agencies crop and yield reports)
- Alternative global satellite-derived precipitation, soil moisture, and vegetation health products (e.g. Global Food Supply monitoring- Crop Explorer)

OVERVIEW:

A 7-day composite global drought index based on several vegetation health indexes. The Drought Index (D) assessment is based on Vegetation Health Index (VHI), Vegetation Condition Index (VCI) and Temperate Condition Index (TCI) if their values are below 40. D is 'Exceptional' if the indices are between 0 and 5 (level 3); 'Extreme' if they are 6-15 (level 2); 'Severe' 16-25 (level 1); 'Moderate' 26-35 (level 0); 'Abnormally dry condition' 35-40.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

POTENTIAL PERIL COVERAGE:

- Agricultural drought composite index based on thresholds for vegetation health (Vegetation Health Index), soil moisture (Vegetation Condition Index), and temperature (Temperate Condition Index). Drought extent, severity, and duration for a second generation parametric trigger if supplemented with 'exposure at risk to drought' information.

POTENTIAL IMPACT COVERAGE:

- Medium resolution drought extent is provided based on Global and Regional Vegetation Health (VH) products by estimating vegetation health, moisture condition, and thermal condition from the Advanced Very High Resolution Radiometer (AVHRR).
- In this context, drought is defined as “sustained and regional extensive occurrence of below average natural water availability”, and therefore the impacted area is typically larger than for other perils, even though the impacts will vary on the assets present in each region. This data scope and resolution has the potential to capture the extent and severity of drought on vegetation health (including crops) at administrative level 1. A deficit on crops can have direct impacts on livestock and population, however additional information on exposure and vulnerability of those might be required for this assessment.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- National rain gauge data can be used to validate the anomalies of precipitation which is the primary driver for the onset of the drought.
- National river gauge data can be used validate the anomalies of river flow as it is one of the last parameters to be affected during droughts. The lag between a meteorological and a streamflow/hydrological drought varies from days in a flashy catchment to months in a groundwater-fed catchment.
- This drought index could be complemented by additional precipitation products for early monitoring of the drought and by alternative soil moisture and vegetation health products as later indicators of droughts. An example is from the Global Food Supply monitoring - Crop Explorer of the United States Department of Agriculture - Foreign Agricultural Service (http://www.pecad.fas.usda.gov/cropexplorer/Default.aspx). 10-day precipitation totals, number of dry days in the past 10 days, maximum consecutive dry days in the past 30 days, number of dry days since last rainy day, soil moisture anomalies from the European Space Agency’s Soil Moisture Ocean Salinity (SMOS), and a vegetation index anomaly (Normalized Difference Vegetation Index (NDVI) product). Note that NVDI is not so suitable for crop rotation fields or where land use change has happened recently.
- Crops / Livestock to determine the numbers affected at risk of droughts within the extent.
- Crop type, statistics, and calendar information can be used to determine the amount of production at risk of drought damage within the area of interest. The information can also be provided in yield reports and/or the national agencies that report on crops.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

From our findings, there are no probabilistic drought catastrophe models for the shortlisted countries for in-depth examination: Bangladesh, Viet Nam, Sri Lanka, Indonesia, and Pakistan.

Exposure data on crop, livestock, and population data will be needed for an assessment of the agricultural drought impacts and is expected to be available through national census and statistical agencies.

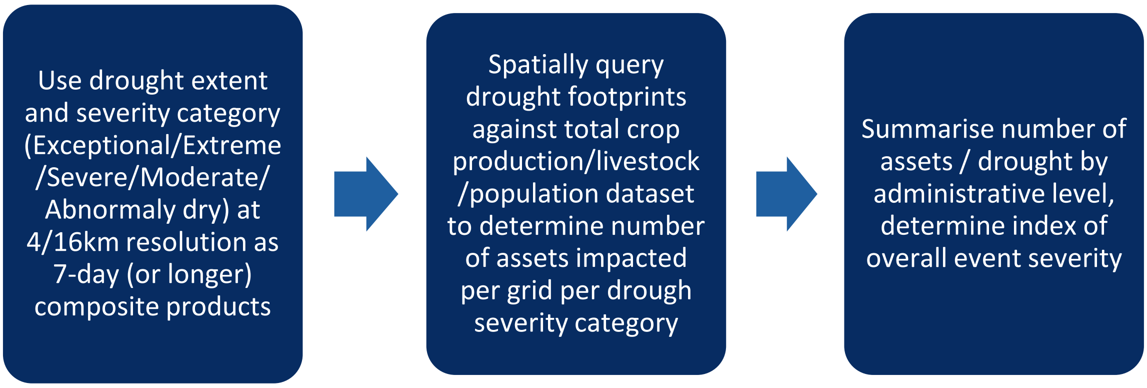
Other models from the regional coverage: AgRisk models available for India. They are crop models that include the perils of tropical cyclone and drought. They are not peril specific models in the traditional sense.

POTENTIAL SETTLEMENT WINDOW:

- The dataset is updated every 7 days with the new satellite information, therefore all products are multi-day composites. A 'week' is defined here based on 'day of the year', i.e. week 1 covers day-of-the-year 1 to 7.
- The dataset can be accessed from the online NOAA platform.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Global coverage.
- Full spatial coverage of the event.
- Free and open licence.
- 7-day composite global drought index based on several vegetation health indexes derived from remote sensing: Vegetation Health Index (VHI), Vegetation Condition Index (VCI), soil moisture), and the Temperature Condition Index (TCI, temperature).
- The drought index (D) assessment is based on VHI, VCI, and TCI if their values are below 40. D is 'Exceptional' if the indices are between 0 and 5 (level 3), 'Extreme' if they are 6-15 (level 2), 'Severe' for 16-25 (level 1), 'Moderate' for 26-35 (level 0), and 'Abnormally dry' for 35-40.
- Several resolutions are available: 4 and 16 km (since 1981), and 1km (since 2015). The lower resolution products have a longer historical dataset available and are therefore preferable, although the 1km dataset can be used to complement the lower resolution datasets, but currently not available to download. On the website, 16km products are available from 2005, 4km products are available from 2011, 1km product are available from 2015.
- Duration and severity could be derived and used to calculate the total crop production and the population affected by drought, but detailed and accurate exposure information may be difficult to obtain in some regions.
- 36 years' historic data is recorded since the Vegetation Health products from AVHRR were produced from the NOAA/NESDIS Global Area Coverage (GAC).
- There is potential for satellite mission failure or satellite component failure (e.g. antenna).

SCOPE OF LIVE DATA:

Key attributes:

- Automated drought area delineation and severity from AVHRR.
- Global and Regional Vegetation Health (VH) is a NOAA/NESDIS system estimating vegetation health, moisture condition, thermal condition and their products at 1, 4, and 16 km resolution.
- Automated global mapping started in November 1981 for the earliest products.

DR Index 2: Agricultural drought index for crops

DATA SOURCE:

- Agricultural Stress Index (ASI) - Global Information and early Warning Systems on food and agriculture (GIEWS) from the Food and Agriculture Organization of the United Nations (FAO). [2]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- National rainfall and river gauge data
- Crop type, statistics, and calendar (e.g. Global Crop Production Analysis or national agencies crop and yield reports)
- Alternative global satellite-derived precipitation, soil moisture, and vegetation health products (e.g. Global Food Supply monitoring - Crop Explorer)

OVERVIEW:

The Agricultural Stress Index (ASI) is a quick-look indicator for early identification of agricultural areas probably affected by dry spells, or, in extreme cases, drought. The index is based on the integration of the Vegetation Health Index (VHI) in both spatial and temporal dimensions, critical in the assessment of a drought event in agriculture at 1km resolution.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

POTENTIAL PERIL COVERAGE:

- Agricultural drought index based on a spatio-temporal analysis of the Vegetation Health Index (VHI).
- Drought extent, severity, and duration for a second generation parametric trigger if supplemented with ‘exposure at risk to drought’ information.

POTENTIAL IMPACT COVERAGE:

- Medium resolution drought extent is provided based on Global and Regional Vegetation Health (VH) products by estimating vegetation health, moisture condition, and thermal condition from the Advanced Very High Resolution Radiometer (AVHRR).
- In this context, drought is defined as “sustained and regional extensive occurrence of below average natural water availability”, and therefore the impacted area is typically larger than for other perils, even though the impacts will vary on the assets present in each region. This data scope and resolution has the potential to capture the extent and severity of drought affecting crops at administrative level 1, 2 and 3.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- National rain gauge data can be used to validate the anomalies of precipitation which are the primary drivers for the onset of the drought.
- National river gauge data can be used validate the anomalies of river flow as it is the last parameter to be affected during droughts.
- Crop type, statistics, and calendar information can be used to determine the total production at risk of drought within the area of interest. The information can also be provided in yield reports and/or the national agencies that report on crops.
- The ASI could be complemented by additional precipitation products for early monitoring of the drought and by soil moisture and vegetation health products as later indicators of droughts. An example is from those provided within the Global Information and Early Warning System on Food and Agriculture (GIEWS) platform (http://www.fao.org/giews/earthobservation/) or within the Global Food Supply monitoring - Crop Explorer of the United States Department of Agriculture - Foreign Agricultural Service (http://www.pecad.fas.usda.gov/cropexplorer/Default.aspx). 10-day precipitation totals, number of dry days in the past 10 days, maximum consecutive dry days in the past 30 days, number of dry days since last rainy day, soil moisture anomalies from the European Space Agency's Soil Moisture Ocean Salinity (SMOS), and a vegetation index anomaly (Normalized Difference Vegetation Index (NDVI) product). Note that NVDI is not so suitable for crop rotation fields or where land use change has happened recently.
- Crop type, statistics, and calendar information can be used to determine the total production at risk of drought within the area of interest. The information can also be provided in yield reports and/or the national agencies that report on crops.
- Livestock to determine the numbers affected at risk of droughts within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

From our findings, there are no probabilistic drought catastrophe models for the shortlisted countries for in-depth examination: Bangladesh, Viet Nam, Sri Lanka, Indonesia, and Pakistan.

Exposure data on crop, livestock, and population data will be needed for an assessment of the agricultural drought impacts and is expected to be available through national census and statistical agencies.

Other models from the regional coverage: AgRisk models available for India. They are crop models that include the perils of tropical cyclone and drought. They are not peril specific models in the traditional sense.

POTENTIAL SETTLEMENT WINDOW:

- The dataset is updated every 10 days with the new satellite information, therefore all products are multi-day composites. The third 10-day composite within each month might contain information between 8 and 11 days depending on the calendar month. Months with 30 days, will contain 10-day information, months with 31 days will contain 11 days' information, and February will contain 8 or 9 days' information depending of the year.
- The dataset can be accessed from the FAO platform (http://www.fao.org/giews/earthobservation/). Currently, no FTP site or system to download the data is available.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:

Use drought extent by cropland areas and severity range (% of pixels with VHI < 35%) per cropping season at 1km resolution as 10-day (or longer) composite products

→

Spatially query* drought footprints above a defined severity % against total crop production/livestock /population dataset to determine number of assets impacted on cropland grids

→

Summarise number of assets / drought by administrative level, determine index of overall event severity

*Note that the ASI maps are not currently available for download to do spatial analysis, only for visualisation at global and country based maps. The data provider will need to be contacted.

STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Global coverage.
- Full coverage of the event.
- Free and open licence.
- 10-day composite global drought index based on a spatio-temporal analysis of the Vegetation Health Index (VHI). Some products are also aggregate by month, season, and year.
- Data products used:
    - METOP (Meteorological Operational satellite programme)-AVHRR sensor at 1km resolution (from 2007 onwards).
    - Data at 1km resolution for the period 1984-2006 was derived from the NOAA-AVHRR dataset at 16km resolution.
    - The crop mask is a modified version of an EC-JRC data set that compiles several different sources of land cover data, including GlobCover V2.2, Corine-2000, AfriCover, SADC (Southern African Development Community) data set, and USGS Cropland Use Intensity Data Set.
- Duration and severity could be derived and used to calculate the total crop production and the population size affected by drought, but detailed and accurate exposure information may be difficult to obtain in some regions.
- 33 years' historic data record used here since the Vegetation Health products from AVHRR were produced from the NOAA/NESDIS combined with the METOP Global Area Coverage (GAC) is adequate.
- There is potential for satellite mission failure or satellite component failure (e.g. antenna).
- The main difference with the Drought Index - Global Vegetation Health (GVH) Products (data source 1), is that the Agricultural Stress Index (ASI) focuses its analysis on croplands, excluding non-croplands areas.
- The first step of the ASI calculation is a temporal averaging of the VHI, assessing the intensity and duration of dry periods occurring during the crop cycle at pixel level.
- The second step determines the spatial extent of drought events by calculating the percentage of pixels in arable areas with a VHI value below 35 percent (this value was

identified as a critical threshold in assessing the extent of drought in previous research by Kogan, 1995). Finally, each administrative area is classified according to its percentage of affected area to facilitate the quick interpretation of results by analysts.

- NVDI vegetation index, estimated and accumulated precipitation values are also classified by administrative level 1 of the Global Administrative Unit Layers (GAUL).

SCOPE OF LIVE DATA:

Key attributes:

- Automated drought delineation and severity from the AVHRR from NOAA and METOP.
- The Agricultural Stress Index (ASI) is a 'quick-look' indicator for early identification of agricultural areas that may be affected by dry spells, or drought in extreme cases at 1 km resolution. Non-crop areas are excluded from the maps.
- Automated global mapping started in 1984 for the earliest products

DR Index 3: Meteorological drought index

DATA SOURCE:

- Standardized Precipitation-Evapotranspiration Index (SPEI) Global Drought Monitor - Spanish National Research Council (CSIC) [4]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- National rainfall and river gauge data
- Crop type, statistics, and calendar (e.g. Global Crop Production Analysis or national agencies crop and yield reports)
- Soil moisture and vegetation health products (e.g. Global Food Supply monitoring- Crop Explorer)

OVERVIEW:

A global drought monitoring system based on the SPEI operative, based on precipitation and temperature. It provides monthly global SPEI maps and data at a spatial resolution of 0.5°.

COUNTRY COVERAGE:

Global including: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

POTENTIAL PERIL COVERAGE:

- Meteorological drought indicator- based on precipitation (GSMaP) and temperature data.
- Drought extent, severity, and duration for a second generation parametric trigger if supplemented with ‘exposure at risk to drought’ information.

POTENTIAL IMPACT COVERAGE:

- Low resolution meteorological drought extent is provided based on NOAA satellite-derived mean temperature and the Global Precipitation Climatology Centre (GPCC) monthly total precipitation amounts.
- In this context, drought is defined as “sustained and regional extensive occurrence of below average natural water availability”, and therefore the impacted area is typically larger than for other perils, even though the impacts will vary on the assets present in each region. This data scope and resolution has the potential to capture the extent and severity of meteorological drought at administrative level 1, prolonged meteorological drought conditions can have impacts on crops, and therefore on livestock and population. However, this index does not include information on vegetation health and production.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- National rain gauge data can be used to validate the anomalies of precipitation which are the primary drivers for the onset of the drought.
- National river gauge data can be used validate the anomalies of river flow as it is the last parameter to be affected during droughts.
- The SPEI index is based on precipitation and temperature, therefore it will be beneficial to complement the analysis with additional products on soil moisture and vegetation health as later indicators of droughts and at higher resolution. An example is those from the Global Food Supply monitoring - Crop Explorer of the United States Department of Agriculture - Foreign Agricultural Service (http://www.pecad.fas.usda.gov/cropexplorer/Default.aspx), mainly the soil moisture anomaly from the European Space Agency's Soil Moisture Ocean Salinity (SMOS) and vegetation index anomaly as a NDVI product. Other datasets available from Crop Explorer at higher resolution than the SPEI index which might complete this index are the precipitation, number of dry days in the past 10 days, maximum consecutive dry days in past 30 days, and the number of dry days since last rainy day.
- Crop type, statistics, and calendar information can be used to determine the total production at risk of drought within the area of interest. The information can also be provided in yield reports and/or the national agencies that report on crops.
- Livestock to determine the numbers affected at risk of droughts within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

From our findings, there are no probabilistic drought catastrophe models for the shortlisted countries for in-depth examination: Bangladesh, Viet Nam, Sri Lanka, Indonesia, and Pakistan.

Exposure data on crop, livestock, and population data will be needed for an assessment of the agricultural drought impacts and is expected to be available through national census and statistical agencies.

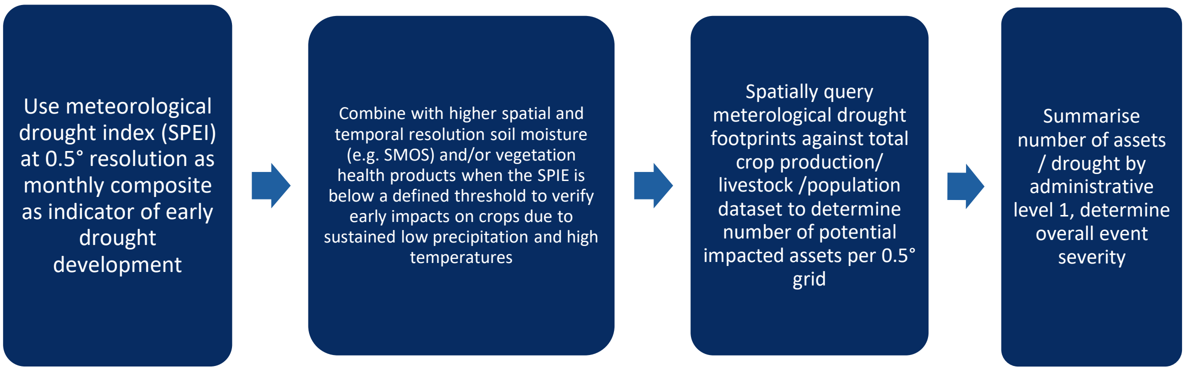
Other models from the regional coverage: AgRisk models available for India. They are crop models that include the perils of tropical cyclone and drought. They are not peril specific models in the traditional sense.

POTENTIAL SETTLEMENT WINDOW:

- The dataset can be accessed from the CSIC platform (http://sac.csic.es/spei/map/maps.html).
- The dataset is updated during the first days of the following month based on the most reliable and updated sources of climatic data.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Global coverage.
- Full coverage of the event.
- Free and open licence.
- Drought monitoring system based on the Standardized Precipitation-Evapotranspiration Index (SPEI), based on precipitation and temperature at a spatial resolution of 0.5°
- Monthly composite available since 1955.
- Mean temperature data are obtained from the NOAA NCEP CPC GHCN_CAMS gridded dataset. Monthly precipitation sum data are obtained from the Global Precipitation Climatology Centre (GPCC). Data from the 'first guess' GPCC product, with an original resolution of 1°, are interpolated to the resolution of 0.5°.
- An advantage of the SPEI over other widely used drought indices such as the Standardized Precipitation Index (SPI) is that it considers the effect of potential evapotranspiration (PET) on drought severity.
- Nor the SPI or SPIE contain information on the vegetation health or soil moisture useful to have an understanding on the affected crop production.
- Easy to download netCDF and csv (at single locations)
- Duration and severity could be derived to have an indication of the meteorological drought extent on a regional level. However, it will not be suitable for calculating the total crop production and population size affected by drought for specific areas.
- 62 years' historic data record is used here since availability of NOAA NCEP CPC GHCN_CAMS and GPCC precipitation datasets is adequate.
- There is potential for satellite mission failure or satellite component failure (e.g. antenna).
- The SPEI (an SPI) are meteorological drought indicators, where its key strength is on detecting regions with rainfall deficits that can be affected by droughts. However, nor SPI or SPIE contain information on the vegetation health or soil moisture useful to have an understanding on the affected crop production, as the Drought Index - Global Vegetation Health (GVH) Products (data source 1), and the Agricultural Stress Index (ASI) (data source 2). In addition, the resolution of this product limits the spatial identification of drought impacts. SPE is available at 0.5° resolution, whereas the GVH and ASI are available up to 1 km resolution (~0.01°).

- The SPEI index was suggested as an alternative to the common SPI drought index by the World Meteorological Organisation (WMO) (2009).

SCOPE OF LIVE DATA:

Key attributes:

- Automated drought monitoring from the NOAA NCEP CPC GHCN_CAMS mean temperature gridded dataset and the Global Precipitation Climatology Centre (GPCC) monthly precipitation total data.
- The SPEI Global Drought Monitor offers near real-time information about drought conditions at the global scale at 0.5° resolution
- Automated global mapping provides data starting in 1955.

Earthquake (EQ)

EQ Index 1: Ground Motion Maps

DATA SOURCES:

- United States Geological Survey (USGS) ShakeMaps [1]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Shaking instrumentation data from local networks
- High-resolution local geologic maps
- Regional empirical ground motion models

OVERVIEW:

ShakeMap is a product of the U.S. Geological Survey Earthquake Hazards Program in conjunction with regional seismic network operators. ShakeMap sites provide near-real-time maps of ground motion and shaking intensity following significant earthquakes. In the U.S., these maps are used by federal, state, and local organizations, both public and private, for post-earthquake response and recovery, public and scientific information, as well as for preparedness exercises and disaster planning. Worldwide, these maps are viewed as one of the best sources of ground motions following a significant earthquake.

COUNTRY COVERAGE:

Global, including Afghanistan, Cambodia, India, Lao PDR, Malaysia, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, Vietnam, Indonesia, Pakistan and Bangladesh

POTENTIAL PERIL COVERAGE:

- Global coverage of earthquake ground shaking impact for a second generation parametric trigger if supplemented with exposure at risk, local geological mapping and determination of fault rupture surfaces (such as using information from aftershocks) and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings. USGS needs near real-time data from local ground motion recordings captured through the network of seismic recording stations for improving ShakeMaps.
- Earthquake ground shaking impact for a third generation parametric trigger if supplemented with denser ground motion instrumentation from locally managed network, high-resolution geologic information, and regionally developed ground motion model to produce more reliable shaking intensity maps as input to catastrophe loss model. Presently, ShakeMap is fully maintained and operated by USGS. Supplementing with local networks needs collaboration with USGS.
- Tsunami footprints developed from offshore earthquake rupture source parameters using near real-time tsunami modeling capability and probabilistic tsunami models and therefore tsunami loss using the PCRAFI earthquake and tsunami loss calculation package developed for the World Bank.

POTENTIAL IMPACT COVERAGE:

- Near real-time post-event ground shaking footprints (Modified Mercalli Intensity or MMI, Peak Ground Acceleration or PGA, Peak Ground Velocity or PGV maps at 1-km gridded seismicity) from USGS, captured by ground motion recording stations as part of the Global Seismic Network (GSN). A resolution of 1-km gridded seismicity is a good choice for ground motion footprints, given the level of uncertainty in capturing the ground motions. Most catastrophe models could either input the footprint directly or translate it into its own geographic coordinate system for analysis.
- In modelled loss trigger form, the ground shaking intensity maps can be input to a catastrophe loss model, capturing impacts to physical assets.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- An enhanced set of ShakeMaps from USGS would be supplemented by more ground motion recordings, enhanced geological maps, and regionally developed ground motion prediction equations (GMPEs).
    - Local geological maps including micro-zonation maps to create site condition maps. The effort of creating a local site classification map in Indonesia is being undertaken by local researchers in collaborating with the USGS. However, the timeline of completion and details of final outcome is unknown.
    - Ground motion recordings captured through the network of seismic recording stations and analysed by seismologists from local networks. USGS is working with Indonesia researchers to integrate the recordings from local seismic networks into ShakeMap. However, the timeline of completion is unknown.
    - Aftershock maps and local known faulting maps to determine the potential rupture plane.
    - Possibility of supplementing with GEM data and geologic information available from World Bank- EMI study on Dhaka: http://emi-megacities.org/wp-content/uploads/2015/01/HVRA-Guidebook_FINAL.pdf
- Property/exposure information to determine the number of assets at risk to ground shaking within the extent.

No additional work is being done by USGS in Bangladesh or Pakistan. Other countries exposed to earthquake in the region were not examined.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the earthquake peril, full catastrophe models are available for the following countries:
- India (AIR, CL, RMS), Indonesia (AIR, CAT, CL, RMS), Malaysia (AIR, CAT, CL, RMS), Pakistan (CL), Philippines (AIR, CAT, CL, RMS), Thailand (AIR, CAT, CL, RMS) and Viet Nam (AIR, CAT, RMS).
- Afghanistan, Bangladesh, Cambodia, Lao PDR, Myanmar, Nepal and Sri Lanka do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Indonesia, Pakistan, and Bangladesh.

Indonesia

- The AIR Earthquake Model for Southeast Asia is available and can model an earthquake based on moment magnitude, location, and rupture plane information. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can translate the footprint into an equivalent footprint that is compatible with the model's analysis module. Insurance industry exposure data (i.e, property covered by earthquake insurance) is available.
- The Catalytics Earthquake model is available. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can likely translate the footprint into an equivalent footprint that is compatible with the model's analysis model. Economic and infrastructure data is available.
- CoreLogic Indonesia Earthquake is available and the company is working on allowing a peak ground acceleration (PGA) footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.
- The RMS Indonesia Earthquake (Version 16) model is available and can take peak ground acceleration (PGA) or Modified Mercalli Intensity (MMI) ShakeMap footprints as input into model. Exposure databases are not available.
- The RMS Indonesia Earthquake (Version 17) model will be available (2017) and can take Peak Ground Acceleration (PGA), Modified Mercalli Intensity (MMI), or Spectral Acceleration (SA) ShakeMap footprints as input into model. A high-resolution economic exposure database will be available.

Pakistan

- The CoreLogic Pakistan Earthquake model is available and the company is working on allowing a SA footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

Bangladesh

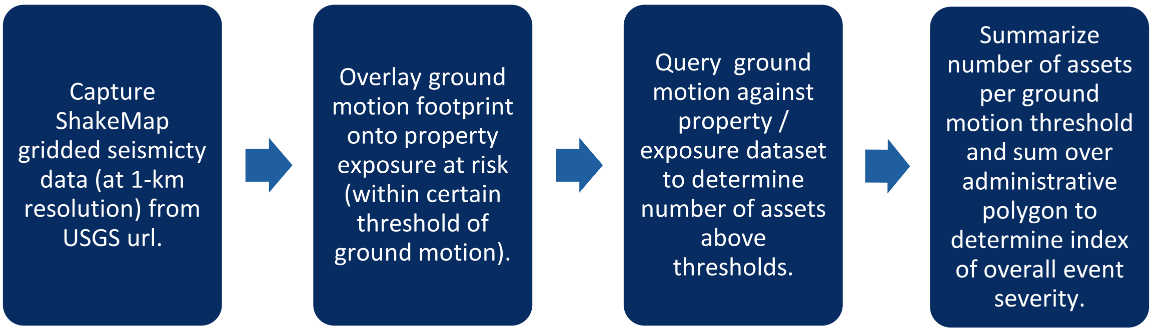
- A probabilistic earthquake catastrophe model is not available.

POTENTIAL SETTLEMENT WINDOW:

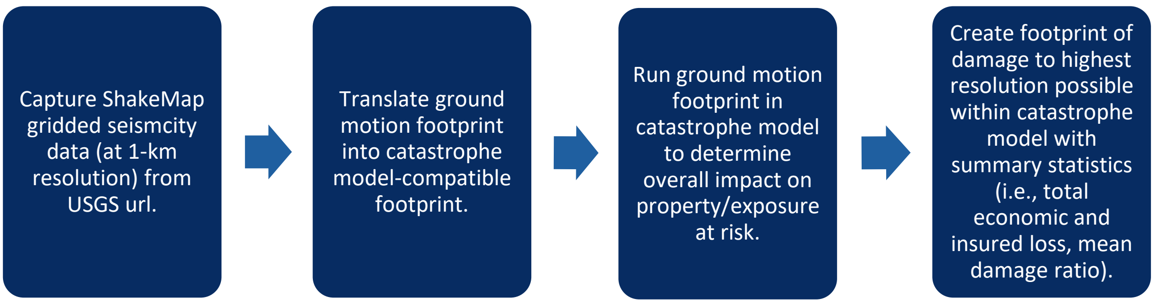
- Near-real time earthquake ground motion (MMI, PGA, PGV, SA at 0.3-, 1.0-, and 3.0-seconds) maps are produced within minutes after an event has occurred but are associated with high degree of uncertainty.
- The time frame of the availability of local instrumental recordings is unknown but often weeks or months later.
- A supplemented modelled loss trigger would produce a longer duration settlement that could take days or weeks depending on availability of refined earthquake ground motion maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



USGS has developed the analytical framework and automated system to include recording data in creating near real time shaking intensity footprint - ShakeMap. No additional processing work is necessary if the seismic network is linked to the USGS ShakeMap system.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available near real-time. If rupture information is provided for an offshore (tsunami-generating) source, potential tsunami run up data can be developed.
- Recorded waveforms are processed and used in creating shaking intensity footprint automatically if the network of ground motion sensors are connected to the USGS ShakeMap system.
- Local ground motion instrumentation networks are lacking or limited, and may not be linked to the USGS ShakeMaps- only Indonesia has relatively dense network and capability to be linked up to USGS Shakemaps:
- Lack of high-resolution local geological maps for site classification.
- Detailed and accurate exposure information may be difficult to obtain in some countries or regions.
- Potential for inadequately representing the actual shaking intensity field
- Potential of systemically mischaracterizing of the seismic performance of local constructions.

Indonesia Station Network

Network	Hazard Parameter(s)	Details
Earthquake parameters and Tsunami simulation results from International Seismic Network of NIED	Location, Magnitude, Depth, Dip, Strike, Rake, estimates of Tsunami heights	148 broadband stations in Indonesia and surrounding region
Indonesian Tsunami Early Warning System from BKMG	Location, depth, magnitude, areas at risk of tsunami inundation and time of arrival	257 stations across Indonesia and the surrounding region

Bangladesh and neighbouring station network in India

Name	Hazard Parameter(s)	Notes
Bangladesh strong motion network from Bangladesh University of Engineering & Technology	Location, magnitude, depth and PGA	60 potential accelerographs, 38 confirmed as currently active
Digital Seismic Real Time Monitoring Network from the Bangladesh Meteorological Dept	Location, distance to epicentre (from station), and magnitude	BMD's seismic monitoring system nation-wide consists of four digital broadband seismometers, two boreholes, two digital short-period seismometers and six accelerometers with GPS synchronization
National seismic network of India from the India Meteorological Dept	Location, magnitude, depth, intensity	55 seismological stations (30 digital, 25 analog)

Pakistan network

Name	Hazard Parameter(s)	Notes
National Seismic Monitoring Centre from Pakistan Meteorological Dept	Location, magnitude, depth	Circa 30 stations

Source. Catastrophe modelling and live data scoping in Asia: Summary report and priorities for investment

SCOPE OF LIVE DATA:

Key attributes:

- Near real-time maps of ground motion and shaking intensity following significant earthquakes.

EQ Index 2: Estimated economic damage and fatalities derived from estimates

DATA SOURCES:

- USGS: Prompt Assessment of Global Earthquakes for Response (PAGER) [2]
- ICES/WAPMERR: Quake Loss Assessment for Response and Mitigation (QLARM) [7]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Relevant supplementary data sources:
- USGS ShakeMaps
- High-resolution exposure data (local data)

OVERVIEW:

PAGER is an automated system that produces content concerning the impact of significant earthquakes around the world - primarily used for rapid assessment (with acknowledgment of uncertainties).

QLARM (Quake Loss Assessment for Response and Mitigation) is a computer code with world data sets of population and building stock that calculates losses (building damage, injured, and fatalities) due to strong shaking in earthquakes.

COUNTRY COVERAGE:

PAGER: Global data - historic events in targeted countries have been reported, including Bangladesh, Indonesia and Pakistan. Events also reported in Afghanistan, India, Laos, Malaysia, Myanmar, Nepal, Philippines and Thailand. No reports to date in Cambodia, Sri Lanka or Vietnam.

QLARM: Global data - historic events in targeted countries have been reported, including Bangladesh, Indonesia and Pakistan. Events also reported in Afghanistan, India, Myanmar, Nepal, Myanmar, Philippines and Thailand.

Note: Both products use global datasets and have global coverage. The countries identified have experienced earthquake events since the inception of these products.

POTENTIAL PERIL COVERAGE:

- Earthquake ground shaking impact – both provide loss estimates following significant earthquakes anywhere in the world:
    - PAGER provides earthquake impact scales showing distributions of human and economic losses (range of likely losses and uncertainties are shown in these histograms)
    - QLARM provides estimates of human fatalities and injuries (min/max values)
- PAGER provides shaking intensity values with population exposure estimates for each MMI intensity class. QLARM provides mean damage information by location (lists of the urban areas affected are available on request to ICES/WAPMERR).
- Both provide basic earthquake parameters – origin time, local time, magnitude, hypocentre location and the name of the region where the earthquake took place.

- Both products provide a list of major cities impacted and the intensity felt at those locations (PAGER uses MMI, QLARM uses mean damage).
- Both products can be accessed by registering on email distribution lists[1]. Alerts are sent via email for earthquakes greater than 6.0 (PAGER) and alerts can be customized to only deliver messages for certain areas, at specified times, and to multiple addresses.

POTENTIAL IMPACT COVERAGE:

- Near real-time post-event data (date, location, magnitude and depth) acquired from regional sensors.
- Instrumental intensity (a proxy for MMI) is provided at major cities by PAGER.
- Both products produce estimates of human casualties and fatalities. PAGER includes estimates of aggregated economic impact.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Both products can be used alongside GIS data (shapefiles/KMLs) of USGS ShakeMaps. These data can be downloaded to show instrumental intensity, PGA, PGV or Spectral Acceleration.
- Both datasets would benefit from better exposure information (both property and population) to estimate damage and loss. In addition, local vulnerability functions for typical local construction practices would reduce the uncertainty in the loss estimates.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the earthquake peril, full catastrophe models are available for the following countries:
- India (AIR, CL, RMS), Indonesia (AIR, CAT, CL, RMS), Malaysia (AIR, CAT, CL, RMS), Pakistan (CL), Philippines (AIR, CAT, CL, RMS), Thailand (AIR, CAT, CL, RMS) and Viet Nam (AIR, CAT, RMS).
- Afghanistan, Bangladesh, Cambodia, Lao PDR, Myanmar, Nepal and Sri Lanka do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Indonesia, Pakistan, and Bangladesh.

Indonesia

- The AIR Earthquake Model for Southeast Asia is available and can model an earthquake based on moment magnitude, location, and rupture plane information. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can translate the footprint into an equivalent footprint that

[1] *USGS earthquake notification service: https://sslearthquake.usgs.gov/ens/*

QLARM alerts mailing list: http://www.icesfoundation.org/Pages/CustomPage.aspx?ID=122 is compatible with the model's analysis module. Insurance industry exposure data (i.e, property covered by earthquake insurance) is available.

- The Catalytics Earthquake model is available. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can likely translate the footprint into an equivalent footprint that is compatible with the model's analysis model. Economic and infrastructure data is available.
- CoreLogic Indonesia Earthquake is available and the company is working on allowing a peak ground acceleration (PGA) footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.
- The RMS Indonesia Earthquake (Version 16) model is available and can take peak ground acceleration (PGA) or Modified Mercalli Intensity (MMI) ShakeMap footprints as input into model. Exposure databases are not available.
- The RMS Indonesia Earthquake (Version 17) model will be available (2017) and can take Peak Ground Acceleration (PGA), Modified Mercalli Intensity (MMI), or Spectral Acceleration (SA) ShakeMap footprints as input into model. A high-resolution economic exposure database will be available.

Pakistan

- The CoreLogic Pakistan Earthquake model is available and the company is working on allowing a SA footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

Bangladesh

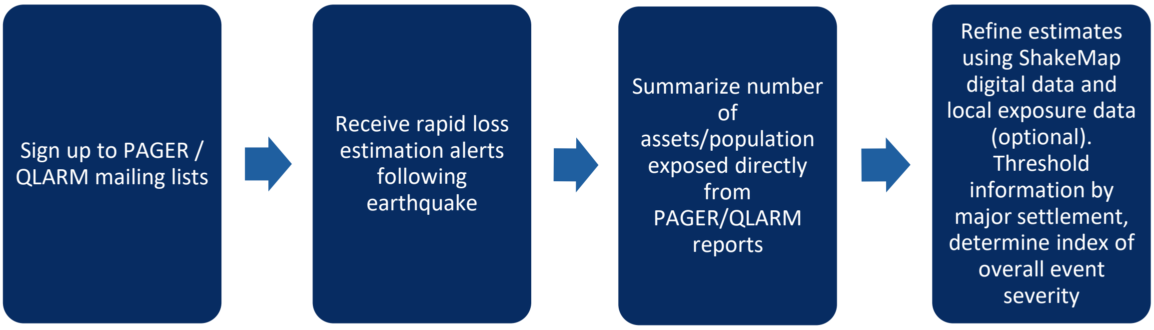
- A probabilistic earthquake catastrophe model is not available.

POTENTIAL SETTLEMENT WINDOW:

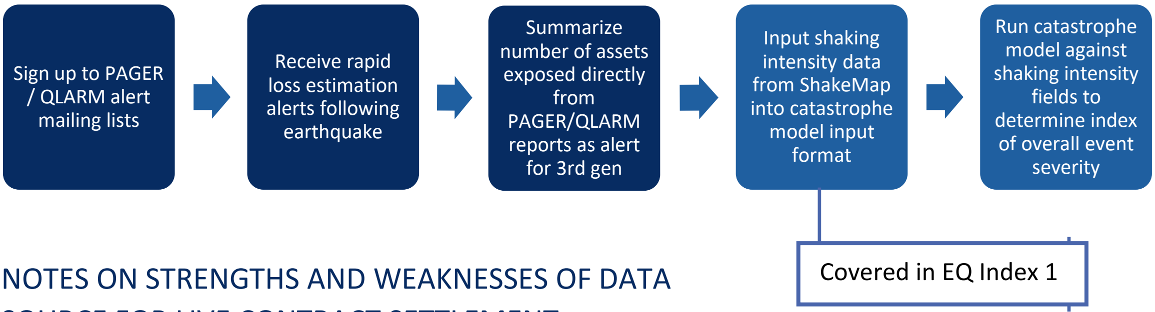
- For both sources, loss estimates are produced in less than 1 hour after the earthquake and are frequently updated in the first day as new information becomes available.
- Suitable for developing a product with a rapid settlement.
- A modelled loss trigger would produce a longer duration for settlement and could take days or weeks depending on availability of refined intensity maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger (alert only):



NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available in near real-time.
- Does not rely on local exposure information as structure classification is currently poor. However, both products could be improved if local exposure data is provided. Currently, the open Geonames geographic database of settlements is used by both products.
- PAGER provides estimates of human and economic losses, with estimated uncertainty
- Useful for a rapid assessment of impact in the absence of a catastrophe risk model with detailed exposure data. May not be suitable for market-based risk transfer.
- Acts as alert for a 3rd generation parametric trigger, but ShakeMaps would be required to create a 3rd generation parametric trigger that captures uncertainties in estimates more accurately than a 2nd generation trigger

A detailed comparison of both of these products and their relative strengths and weaknesses can be found in Wyss (2014)[2].

[2] *Wyss, M. (2014) Ten Years of Real-time Earthquake Loss Alerts. In Wyss, M. (ed.) (2014) Earthquake Hazard, Risk and Disasters. Elsevier, Oxford. Pp. 143-165.*

SCOPE OF LIVE DATA:

Key attributes:

PAGER

- Near real-time acquisition of the date, location, magnitude, and depth of hypocenter.
- Population exposed by Instrumental Intensity Includes estimates of possible damage at different intensity levels for resistant and vulnerable structures (as defined by USGS).
- Instrumental Intensity contours mapped with Landscan data.
- Generic region structure classification with large uncertainties.
- Instrumental Intensity estimates for selected settlements.

QLARM

- Estimates include location and EMS-98 intensity, depth and time of quake (with source), human casualties, alert level (green-red), map of mean building damage by settlement, and estimated population exposure by Instrumental Intensity.

EQ Index 3: Event source parameters

DATA SOURCES:

- European - Mediterranean Seismological Centre (EMSC) Earthquake Notification Service [9]
- Geoscience Australia: Recent Earthquakes [10]
- GEOFON – Seismological Infrastructures, Global Seismic Warning and Tsunami Warning: Recent Earthquakes [11]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- ShakeMaps
- High-resolution Local Geological Maps
- Regional empirical ground motion models

OVERVIEW:

EMSC collects real-time parametric data (source parameters and phase pickings) provided by 70 seismological networks of the Euro-Med region.

Geoscience Australia monitors, analyses and reports on significant earthquakes to alert the Australian Government, State and Territory Governments and the public about earthquakes in Australia and overseas.

GEOFON is a global seismological broad-band network operated by the German GeoForschungsZentrum (GFZ). The program and its seismic network were created to provide high-quality broadband data for scientific use and foster common standards in the seismological community. The network has evolved towards real-time data acquisition and distribution while keeping the high quality broad-band data in focus.

COUNTRY COVERAGE:

Global including Afghanistan, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam

POTENTIAL PERIL COVERAGE:

- Earthquake size (magnitude) and location (latitude, longitude, depth)
- Earthquake ground shaking impact for a second and third generation parametric trigger could be highly unreliable, given the density of the global strong motion network (GSN). To improve on estimate of earthquake impacts, supplemental information will be required for exposure mapping, local geologic mapping and determination of finite fault rupture and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings.

POTENTIAL IMPACT COVERAGE:

- Near real-time post-event data (date, location, magnitude, and depth) acquired from standard approaches (to determine earthquake origination and magnitude). Data is limited to point estimates of latitude/longitude and magnitude estimates. From this information, a footprint of ground motion and shaking damage could be developed.
- Waveform data (time series data) is available from GEOFON stations in Indonesia and a single station in Pakistan.

SUPPLEMENTARY DATA SOURCE OPTIONS:

Indonesia

- Development of shaking intensity maps.
    - Local geological maps to create site classification maps (i.e., amplification for soft soils, etc.). The efforts of compiling a local site classification map in Indonesia is being undertaken by local researchers in collaborating with the USGS. However, the timeline of completion is unknown.
    - It may be possible to determine the potential finite-fault rupture plane in Indonesia from aftershock maps and local fault maps.
    - Ground motion recordings captured through the local network of seismic recording stations and analysed by seismologists may be possible. However, network density for the countries of interest is quite sparse or non-existent for the sources under consideration:
        - In Indonesia there are 22 seismic stations within the GEOFON seismic network and a single seismic station near Indonesia (Christmas Island) from Geoscience Australia network
        - In Pakistan 1 seismic station is located along Afghanistan border within the GEOFON seismic network
        - For Bangladesh, 4 seismic stations are located around the Bangladesh border (not in the country) from EMSC network via the India Meteorological Department.

- Property and exposure data can be used to estimate the number of assets at risk to ground shaking for a given extent. This would most likely come from proprietary catastrophe models.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the earthquake peril, full catastrophe models are available for the following countries:
- India (AIR, CL, RMS), Indonesia (AIR, CAT, CL, RMS), Malaysia (AIR, CAT, CL, RMS), Pakistan (CL), Philippines (AIR, CAT, CL, RMS), Thailand (AIR, CAT, CL, RMS) and Viet Nam (AIR, CAT, RMS).
- Afghanistan, Bangladesh, Cambodia, Lao PDR, Myanmar, Nepal and Sri Lanka do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Indonesia, Pakistan, and Bangladesh.

Indonesia

- The AIR Earthquake Model for Southeast Asia is available and can model an earthquake based on moment magnitude, location, and rupture plane information. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can translate the footprint into an equivalent footprint that is compatible with the model's analysis module. Insurance industry exposure data (i.e, property covered by earthquake insurance) is available.
- The Catalytics Earthquake model is available. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can likely translate the footprint into an equivalent footprint that is compatible with the model's analysis model. Economic and infrastructure data is available.
- CoreLogic Indonesia Earthquake is available and the company is working on allowing a peak ground acceleration (PGA) footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.
- The RMS Indonesia Earthquake (Version 16) model is available and can take peak ground acceleration (PGA) or Modified Mercalli Intensity (MMI) ShakeMap footprints as input into model. Exposure databases are not available.
- The RMS Indonesia Earthquake (Version 17) model will be available (2017) and can take Peak Ground Acceleration (PGA), Modified Mercalli Intensity (MMI), or Spectral Acceleration (SA) ShakeMap footprints as input into model. A high-resolution economic exposure database will be available.

Pakistan

- The CoreLogic Pakistan Earthquake model is available and the company is working on allowing a SA footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

Bangladesh

- A probabilistic earthquake catastrophe model is not available.

POTENTIAL SETTLEMENT WINDOW:

- Near real-time post-event data (date, location, magnitude and depth) are acquired immediately after an event and available for settlement procedure; supplementary ground motion maps are acquired from USGS.
- The time frame of the availability of local instrumental recordings is unknown.
- A supplemented modelled loss trigger would produce a longer settlement window and could take days or weeks depending on availability of refined intensity maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:

Use intensity map product providing gridded seismicity data (similar to the USGS ShakeMaps) → Overlay ground motion footprint onto property exposure at risk (within certain threshold of ground motion). → Query ground motion against property / exposure dataset to determine number of assets above thresholds. → Summarize number of assets per ground motion threshold and sum over administrative polygon to determine index of overall event severity.

Third generation parametric trigger:

Use intensity map product providing gridded seismicity data (similar to the USGS ShakeMaps) → Translate ground motion footprint into catastrophe model-compatible footprint. → Run ground motion footprint in catastrophe model to determine overall impact on property/exposure at risk. → Create footprint of damage to highest resolution possible within catastrophe model with summary statistics (i.e., total economic and insured loss, mean damage ratio).

The capacity of creating the intensity maps in near real-time using the recordings from the local ground motion networks, combined with finite fault rupture plane, regional GMPEs and site classification maps is unclear.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available near real-time.
- Current ground motion instrumentation networks may be lacking or limited (e.g. one station from Geoscience Australia).
  - Location of instrumentation from European-Mediterranean Seismological Centre (EMSC) unknown.
  - The ability of near real-time processing the recorded ground motions and improving the accuracy of intensity footprints after the event are generally lacking.
- EQ index 11 provides raw wave form data as well as event source parameters.
- Lack of high-resolution local geological maps for site classification.
- Due to the uncertain and slow nature of generating the intensity maps (and general lack of capacity in these areas), the 2nd and 3rd generation triggers may not be practical for the time being from these sources under consideration
- Detailed exposure information may be difficult to obtain in some countries or regions.

SCOPE OF LIVE DATA:

Key attributes:

- Near real-time acquisition of date, location, magnitude and depth of seismic event.

EQ Index 4: Raw waveform

DATA SOURCES:

- National Earthquake Information Center (NEIC) and US Geological Survey – Fast Finite Faults [12]
- US Geological Survey – W-Phase Moment Tensor Solution (Mww) [13]
- US Geological Survey – Body-Wave Moment Tensor Solution (Mwb) [14]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- High resolution local geologic maps
- Regional empirical ground motion models

OVERVIEW:

Fast Finite Faults, W-phase moment tensor solution and Body-wave moment tensor solution provided data describing earthquake rupture plane information.

COUNTRY COVERAGE:

Global, including Afghanistan, Cambodia, India, Lao PDR, Malaysia, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, Vietnam, Indonesia, Pakistan and Bangladesh

POTENTIAL PERIL COVERAGE:

- Earthquake rupture plane information
- To estimate earthquake impacts from the earthquake's slip, supplemental information will be required for exposure mapping, local geologic mapping, and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings. Local data is available, however may not be available rapidly or even consistently to enhance the earthquake rupture/slip information.

POTENTIAL IMPACT COVERAGE:

- Near real time post-event data
    - For the W-Phase Moment Tensor Solution and Body-Wave Moment Tensor Solution, information on the faulting mechanism (strike, dip and rake) and moment magnitude can be viewed and extracted from the webpage.
    - For Fast Finite Faults, information includes at least one definition of the nodal plane (strike, dip, rake – if applicable) from moment tensor solutions, seismic moment and moment magnitude of the event and slip distribution from waveform fitting. If solutions of two nodal planes explain the waveforms equally well, both solutions are presented for a given M7 or greater event.
- In modelled loss trigger form, the rupture plane could be used as an input to a catastrophe loss model and capture impacts to physical assets. If the rupture plane is within an offshore seismic source (i.e., tsunami-generating), it could be used to define extent of tsunami run-up.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Development of shaking intensity maps.
    - Local geological maps to create site classification maps- could be used to better defined fault geometry. Catastrophe models contain proprietary information on site classification.
    - Ground motion recordings captured through the network of seismic recording stations and analysed by seismologists
    - Recordings from local and global seismic networks.
- Property / exposure information to determine the number of assets at risk to ground shaking within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the earthquake peril, full catastrophe models are available for the following countries:
- India (AIR, CL, RMS), Indonesia (AIR, CAT, CL, RMS), Malaysia (AIR, CAT, CL, RMS), Pakistan (CL), Philippines (AIR, CAT, CL, RMS), Thailand (AIR, CAT, CL, RMS) and Viet Nam (AIR, CAT, RMS).
- Afghanistan, Bangladesh, Cambodia, Lao PDR, Myanmar, Nepal and Sri Lanka do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Indonesia, Pakistan, and Bangladesh.

Indonesia

- The AIR Earthquake Model for Southeast Asia is available and can model an earthquake based on moment magnitude, location, and rupture plane information. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can translate the footprint into an equivalent footprint that is compatible with the model's analysis module. Insurance industry exposure data (i.e, property covered by earthquake insurance) is available.
- The Catalytics Earthquake model is available. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can likely translate the footprint into an equivalent footprint that is compatible with the model's analysis model. Economic and infrastructure data is available.
- CoreLogic Indonesia Earthquake is available and the company is working on allowing a peak ground acceleration (PGA) footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

- The RMS Indonesia Earthquake (Version 16) model is available and can take peak ground acceleration (PGA) or Modified Mercalli Intensity (MMI) ShakeMap footprints as input into model. Exposure databases are not available.
- The RMS Indonesia Earthquake (Version 17) model will be available (2017) and can take Peak Ground Acceleration (PGA), Modified Mercalli Intensity (MMI), or Spectral Acceleration (SA) ShakeMap footprints as input into model. A high-resolution economic exposure database will be available.

Pakistan

- The CoreLogic Pakistan Earthquake model is available and the company is working on allowing a SA footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

Bangladesh

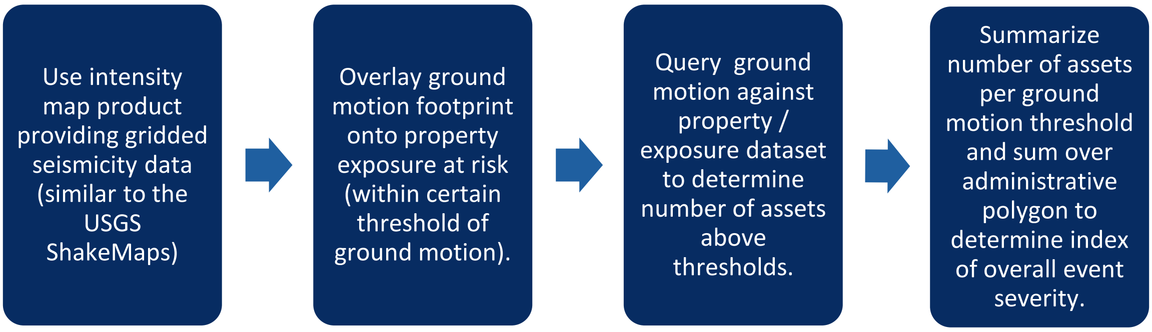
- A probabilistic earthquake catastrophe model is not available.

POTENTIAL SETTLEMENT WINDOW:

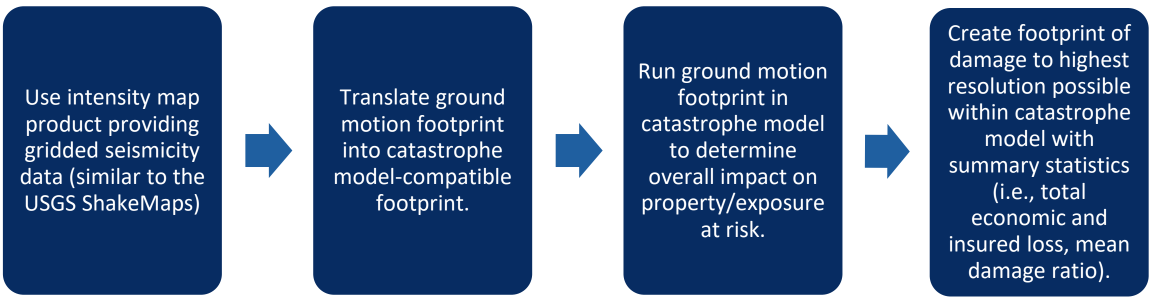
- Near real-time information regarding solutions to faulting mechanisms following significant earthquakes.
- A supplemented modelled loss trigger would produce a longer settlement window and could take days or weeks depending on availability of refined intensity maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important information regarding solutions to faulting mechanisms.
- W-Phase Moment Tensor Solution and Body-Wave Moment Tensor Solution tied to an event page for an earthquake of M5.5 or greater.
- Fast Finite Faults tied to an event page of earthquakes of M7 or greater.
- The event source information has been used in the USGS Global ShakeMap product.
- Local ground motion instrumentation networks are lacking or limited, and may not be linked to the USGS ShakeMaps – as such may not produce the necessary waveform data required for designing prototype triggers.
- Lack of high-resolution local geological maps for site classification.
- Detailed exposure information may be difficult to obtain in some countries or regions.
- Potential for inadequately representing the actual shaking intensity field
- Potential of systemically mischaracterizing of the seismic performance of local constructions.

SCOPE OF LIVE DATA:

Key attributes:

- Near real-time information regarding solutions to faulting mechanisms following significant earthquakes. This information provides how extensive the seismic source has ruptured in a given event, as well as the direction of rupture (two of the key ingredients in creating a ground motion footprint).

EQ Index 5: Damage Proxy Maps

DATA SOURCES:

- NASA Jet Propulsion Laboratory – Damage Proxy Maps (Global) [16]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Copernicus EMS (Global)
- UNOSAT (Global)
- SUPARCO – Rapid Damage Assessment Maps (Pakistan) / national space agencies
- USGS ShakeMaps (Global)
- OpenStreetMap

OVERVIEW:

Global damage proxy maps from NASA Jet Propulsion Laboratory

COUNTRY COVERAGE:

Global. Previous activation following 2015 Nepal earthquake. No information on other earthquake activations.

POTENTIAL PERIL COVERAGE:

- Earthquakes (e.g. 2015 Nepal earthquake), hurricanes (e.g. 2012 Hurricane Sandy)
- Damage Proxy Maps (DPMs) delineate physical changes between two time periods and are produced on a case by case basis. DPMs can be used as rapid proxy maps for damage and could be used in a second generation parametric trigger if supplemented with ground motion data and exposure information.
- International and local data sources can be used to provide more detail on actual damage to structures or damage grading from which a second generation trigger could be built (see prototype on Copernicus EMS).

POTENTIAL IMPACT COVERAGE:

- For earthquake, impacted areas are provided as a map showing areas that have experienced change between two points in time. A 'before' earthquake and 'after' earthquake radar image is captured and the changes between the two are automatically assessed using an algorithm that is <u>currently in prototype</u>, but was effectively used in the 2015 Nepal earthquake. Damage identified over building block size area with a general user resolution of 30m grids
- Damage proxy maps are based on high resolution synthetic aperture radar (SAR) data (e.g. COSMO-SkyMed at 1m-30m spatial resolution, depending on sensor mode used).

SUPPLEMENTARY DATA SOURCE OPTIONS:

To supplement the Damage Proxy Maps:

Global

- USGS ShakeMaps
  - Used to identify and validate that all affected regions are covered
- International damage sources – e.g. Copernicus EMS, UNOSAT
  - Validate and cross-check all affected areas are covered and individual damage assessments are in agreement.

Local

- e.g. SUPARCO Rapid Damage Assessment Maps (Pakistan)
  - National resource for damage mapping using very high resolution EO data
  - Validate and/or extend the spatial coverage of damage grading data.
- Aerial and ground-based reconnaissance
  - Aerial reconnaissance missions can provide a targeted approach for validation of catastrophic or heavy damage. In addition, provision of data at an oblique angle can aid the estimation of levels of moderate damage.
  - Sampled ground-based reconnaissance and damage mapping would be required to gauge the extent of slight and moderate levels of damage.
  - This would be an expensive way to supplement the available damage information, but information from local reconnaissance missions planned anyway for general disaster response purposes could be integrated into a process. This type of information may not be suitable for risk transfer purposes due to the ad-hoc, and locally-managed nature of the information acquisition. However, it could be used for general impact assessment for broad disaster risk financing and management purposes.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The following catastrophe models would be valuable to assess the potential areas of damage. This information could be used to identify areas where EO data are missing, or where priority EO or ground-based mission should target.

- GEM OpenQuake (Hazard model only) - global databases of instrumental catalogue (1900-2009) as well as a historical catalog (1000-1903) have been developed, as well as global database of ground motion prediction equations and an active fault database. So building blocks are there.
- INASAFE (Indonesia) - may provide some basic scenario impact analysis capabilities for response and mitigation planning. This may not be directly used for designing risk transfer tools.
- RiskScape (Vietnam- platform only)
- Probabilistic earthquake model for Indonesia – AIR Worldwide, Catalytics, RMS, CoreLogic
- Probabilistic earthquake model for Pakistan – CoreLogic

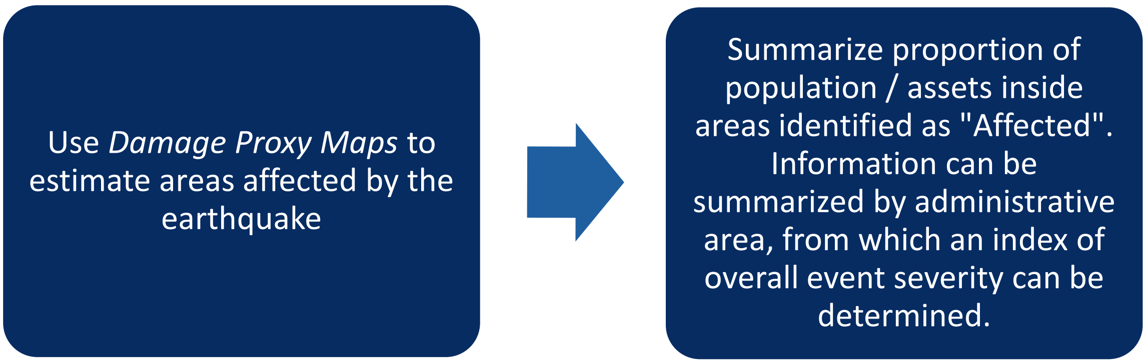
POTENTIAL SETTLEMENT WINDOW:

- Rapid settlement potential – DPMs can be produced within days of the disaster event, depending on data availability.
- Greater certainty can be gained by integrating multiple sources of data – EO, aerial, and ground-based. This would be beneficial, although will increase the amount of time taken for footprint generation (days-weeks).

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:

a.



b.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

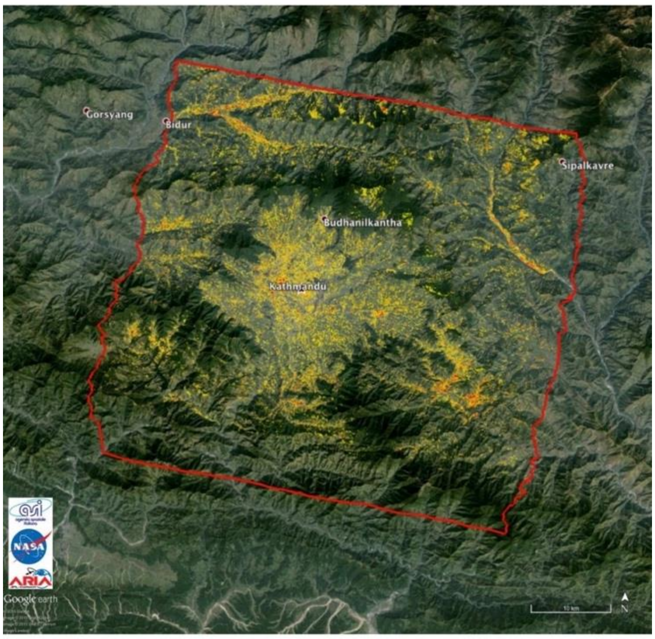
- Global coverage but targeted for major (earthquake) disasters
- Free and open licence
- ARIA has no existing mandate, and has been sporadic in their response to events. In public mode, this is unreliable. However, JPL could be approached to provide a commercial service.
- DPMs are derived from synthetic aperture radar, meaning data can be captured at night and when cloud is present. This is a big advantage over optical sensors.
- DPMs only provide a proxy for damage and might display changes that have not resulted from the earthquake.
- DPMs can be used in a rapid mapping project and be augmented with data from optical or local sources. DPMs could be used as a first-order information source from which to target and prioritise other data collection activities.
- Additional in-situ data will be required to estimate the grading of damage – from not affected to total collapse. Gathering these data can be time consuming and financially expensive and involve collaboration at the local level to gain flight clearance and/or on-the-ground access to affected areas.

SCOPE OF LIVE DATA:

Key attributes:

- Rapid, radar-based post-event data of affected regions
- Rapid delineation of affected areas from which more detailed damage grading can be evaluated

EXAMPLE DATA – DPM FROM 2015 NEPAL EARTHQUAKE:



Source: JPL - https://aria.jpl.nasa.gov/node/43

EQ Index 6: Earth Observation Imagery

DATA SOURCE:

- European Commission - Copernicus Emergency Management Service (EMS) [16]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Jet Propulsion Laboratory – Damage Proxy Maps (Global)
- SUPARCO – Rapid Damage Assessment Maps (Pakistan)
- USGS ShakeMaps (Global)
- OpenStreetMap

OVERVIEW:

Copernicus Emergency Management Service (Copernicus EMS) provides information for emergency response in relation to different types of disasters, including meteorological hazards, geophysical hazards, deliberate and accidental man-made disasters and other humanitarian disasters as well as prevention, preparedness, response and recovery activities.

COUNTRY COVERAGE:

Global. Previous activations in the region have included Afghanistan (EQ), Bangladesh (FLD, TC), Cambodia (FLD), India (FLD, TC), Lao PDR (other), Myanmar (FLD), Nepal (EQ), Philippines (FLD, TC).

POTENTIAL PERIL COVERAGE:

- Floods, earthquakes, landslides, severe storms, fires, technological disasters, volcanic eruptions, humanitarian crises and tsunamis.
- Delineation maps of earthquake impact areas for a second generation parametric trigger if supplemented with ground motion data and exposure information.
- Grading maps, which provide an estimate of varying levels of damage as a more refined second generation, or third generation parametric trigger if a catastrophe risk model is used to convert damage gradings to loss.

POTENTIAL IMPACT COVERAGE:

- For earthquake, impacted areas are provided as a delineation map and are based on satellite missions such as Sentinel 1-A (European Space Agency; 20 m) and Radarsat-2 (Canadian Space Agency; up to 3m resolution). The data scope and resolution has the potential to capture the extent of affected areas at administrative level 1, municipal level and potentially for individual assets.
- The grading maps (generated from very high resolution* data (e.g. DigitalGlobe WorldView-3 at 0.5-0.3m, or Airbus Defence and Space Pleiades at 0.5m resolution) can be used directly to assess the extent and levels of damage throughout the affected region.

**the very high resolution imagery data used here are provided to Copernicus/EC under the Space Component Data Access license agreement with the European Space Agency*

SUPPLEMENTARY DATA SOURCE OPTIONS:

To supplement the Grading Maps:

International

- USGS ShakeMaps
    - Used to identify and validate that all affected regions are covered
- JPL Damage Proxy Maps
    - Validate and cross-check all affected areas are covered and individual damage assessments are in agreement.

Local

- SUPARCO Rapid Damage Assessment Maps (Pakistan)
    - National resource for damage mapping using very high resolution EO data
    - Validate and/or extend the spatial coverage of damage grading data
- Aerial and ground-based reconnaissance
    - Aerial reconnaissance missions can provide a targeted approach for validation of catastrophic or heavy damage. In addition, provision of data at an oblique angle can aid the estimation of levels of moderate damage.
    - Sampled ground-based reconnaissance and damage mapping would be required to gauge the extent of slight and moderate levels of damage.
    - This would be an expensive way to supplement the available damage information, but information from local reconnaissance missions planned anyway for general disaster response purposes could be integrated into a process. This type of information may not be suitable for risk transfer purposes due to the ad-hoc, and locally-managed nature of the information acquisition. However, it could be used for general impact assessment for broad disaster risk financing and management purposes.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The following catastrophe models would be valuable to assess the potential areas of damage. This information could be used to identify areas where EO data are missing, or where priority EO or ground-based mission should target.

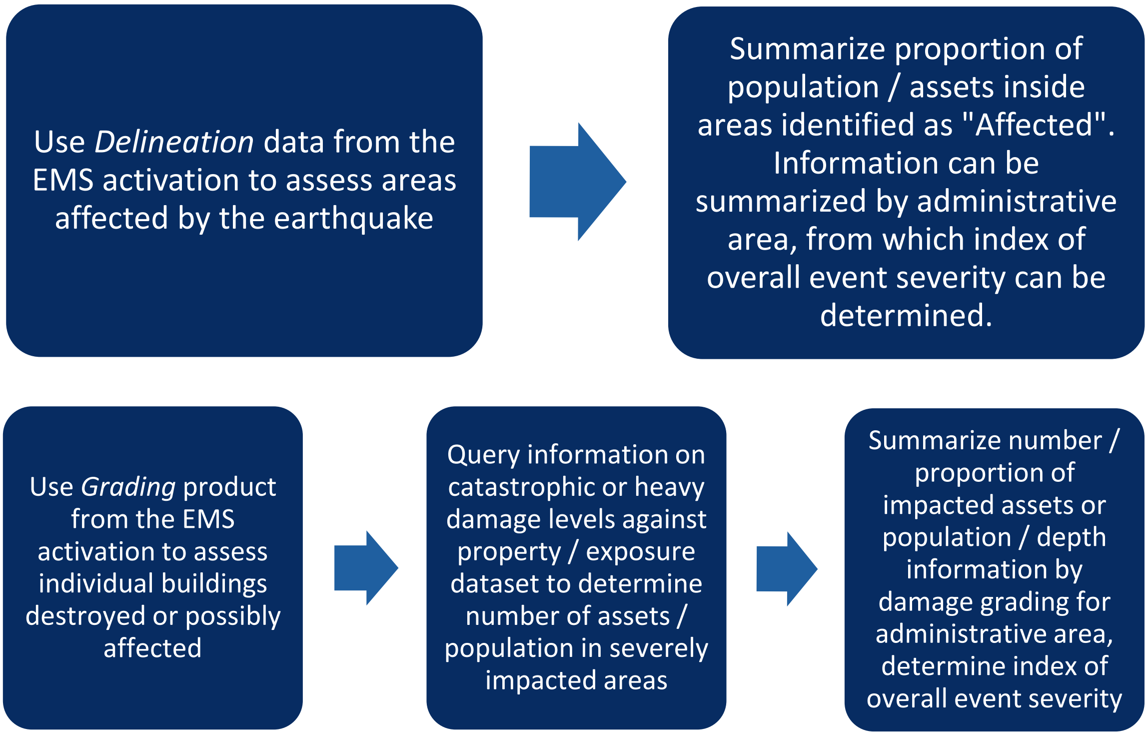
- GEM OpenQuake (Hazard model only)- global databases of instrumental catalogue (1900-2009) as well as a historical catalog (1000-1903) have been developed, as well as global database of ground motion prediction equations and an active fault database. So building blocks are there.
- INASAFE (Indonesia)
- RiskScape (Vietnam- platform only)
- Probabilistic earthquake model for Indonesia – AIR Worldwide, Catalytics, RMS, CoreLogic
- Probabilistic earthquake model for Pakistan – CoreLogic

POTENTIAL SETTLEMENT WINDOW:

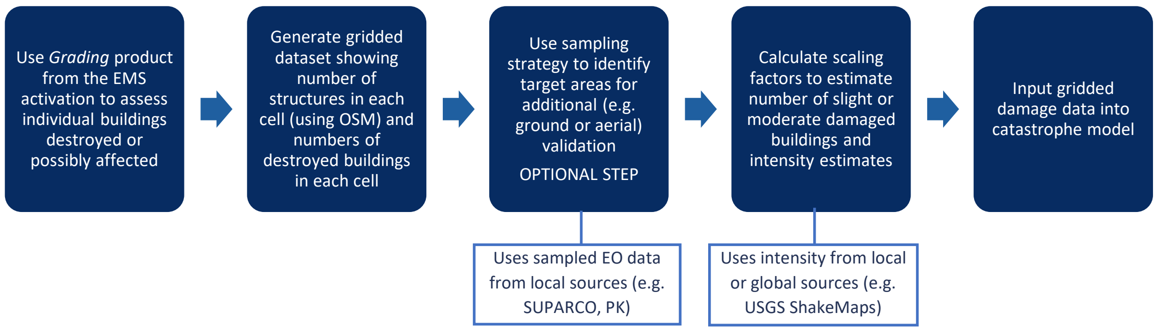
- Requests for satellite images are made based on specific contracts established for risk and recovery mapping or validation requests. Rapid Mapping consists of the on-demand and fast provision of geospatial information for emergency management activities immediately following an emergency event. The fastest delivery time (Service Level 1) is less than 1 day, but usually between 3 and 12 hours depending on the map type. Service Level 5 provide the map within 5 working days. Repetition (e.g. 3 maps in 2 weeks) can also be requested. Delivery Time is the time between receipt of satellite imagery by the service provider (for Rapid Mapping), or from the signature of the contract (Risk and Recovery Mapping), to the point at which the map(s) are delivered to the user.
- Greater certainty can be gained by integrating multiple sources of data – EO, aerial, and ground, which would delay the settlement window by days or weeks

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Global coverage but targeted for major (earthquake) disasters.
- Free and open licence.
- Full geographic coverage of the event may not be available at high (<10m) or very high (sub-meter) spatial resolution, may be limited to peak areas of exposure or areas where cloud-free data are available.
- Subjective damage grade assessments derived from post-event satellite imagery by means of visual interpretation. Copernicus appears to only identify structures that are Destroyed or Possibly Affected. Some types of structural damage (e.g. soft-storey collapse) is difficult to identify using EO imagery captured at nadir (i.e. vertically overhead). The integrity of low to moderate damage levels may be questionable (if provided by any satellite EO source).
- Additional in-situ data will be required to estimate the proportion of buildings unaffected, or with slight or moderate damage, and to validate levels of heavy damage and collapse. These are often time and financially expensive and involve collaboration at the local level to gain flight clearance and/or on-the-ground access to affected areas.
- 4 years of historic data record on the EMS platform is relatively short, and poses challenges to structuring and pricing of contract. Sentinel-1A was launched in 2014 and RADARSAT-2 in 2007. RADARSAT-1 was launched in 1995.
- Potential for failure for satellites missions or components within the satellite (e.g. antenna). However, Copernicus is not reliant on a single satellite platform or sensor. It uses multiple datasets through the ESA GSC-DA license and so there is redundancy in the amount of data available.
- Copernicus EMS has a mandated responsibility to produce rapid mapping products following major events and has dedicated on-call staff with 24/7 availability. It is therefore a reliable source. In addition, Copernicus data can be augmented with local data provision to provide a more refined damage product on which contracts can be based.

SCOPE OF LIVE DATA:

Key attributes:

- High-resolution post-event data of affected regions
- Rapid delineation of affected areas from which more detailed damage grading can be evaluated

EQ Index 7: Local Sources – Indonesia and Philippines

DATA SOURCES:

- International Seismic Network of NIED - the National Research Institute for Earth Science and Disaster Resilience: earthquake parameters and tsunami simulation results [23]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Shaking instrumentation data
- High resolution local geologic maps
- Regional empirical ground motion models

OVERVIEW:

The National Research Institute for Earth Science and Disaster Resilience (NIED) manages a seismograph network system over the Asian-Pacific area. Countries include Indonesia and the Philippines. (For this project - to capture tsunami simulations, it should be noted that Chile is also part of the "international" network).

COUNTRY COVERAGE:

Indonesia and Philippines

POTENTIAL PERIL COVERAGE:

- Earthquakes, magnitude, location, rupture information; Simulated tsunami inundation
- To estimate earthquake impacts, supplemental information will be required for exposure mapping, local geological mapping, and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings.
- Tsunami simulations via SWIFT system, provide rapid estimates of maximum tsunami heights and their projections, maximum tsunami heights along the coast and animated tsunami wave propagation. The system covers local tsunamis in Indonesia and Philippines.

POTENTIAL IMPACT COVERAGE:

- Near real time post-event (date, location, magnitude depth, and rupture orientation) acquired from regional sensors.
- Tsunami wave height ranges along coastal provinces.

SUPPLEMENTARY DATA SOURCE OPTIONS:

Indonesia

- Development of shaking intensity maps:
    - Local geological maps to create site classification maps. The effort of creating a local site classification map in Indonesia is being undertaken by local researchers in collaborating with the USGS. However, the timeline of completion is unknown.
    - Ground motion recordings captured through the network of seismic recording stations and analysed by seismologists from local networks
        - 148 broadband stations in Indonesia
    - Aftershock maps and local known faulting maps to determine the potential rupture plane.
- Property / exposure information to determine the number of assets at risk to ground shaking within the extent.

The Philippines has not been examined in-depth for this exercise, but supplementary data source options will be similar.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

The availability of probabilistic, event based, catastrophe models for all 14 countries in the region (Afghanistan, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam) is as follows:

- For the earthquake peril, full catastrophe models are available for the following countries:
- India (AIR, CL, RMS), Indonesia (AIR, CAT, CL, RMS), Malaysia (AIR, CAT, CL, RMS), Pakistan (CL), Philippines (AIR, CAT, CL, RMS), Thailand (AIR, CAT, CL, RMS) and Viet Nam (AIR, CAT, RMS).
- Afghanistan, Bangladesh, Cambodia, Lao PDR, Myanmar, Nepal and Sri Lanka do not have a probabilistic tropical cyclone models (or hazard event sets) available.

The following countries were shortlisted for in-depth examination: Indonesia, Pakistan, and Bangladesh.

Indonesia

- The AIR Earthquake Model for Southeast Asia is available and can model an earthquake based on moment magnitude, location, and rupture plane information. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can translate the footprint into an equivalent footprint that is compatible with the model’s analysis module. Insurance industry exposure data (i.e, property covered by earthquake insurance) is available.
- The Catalytics Earthquake model is available. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can likely translate the footprint into an equivalent footprint that is compatible with the model’s analysis model. Economic and infrastructure data is available.
- CoreLogic Indonesia Earthquake is available and the company is working on allowing a peak ground acceleration (PGA) footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

- The RMS Indonesia Earthquake (Version 16) model is available and can take peak ground acceleration (PGA) or Modified Mercalli Intensity (MMI) ShakeMap footprints as input into model. Exposure databases are not available.
- The RMS Indonesia Earthquake (Version 17) model will be available (2017) and can take Peak Ground Acceleration (PGA), Modified Mercalli Intensity (MMI), or Spectral Acceleration (SA) ShakeMap footprints as input into model. A high-resolution economic exposure database will be available.

Pakistan

- The CoreLogic Pakistan Earthquake model is available and the company is working on allowing a SA footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

Bangladesh

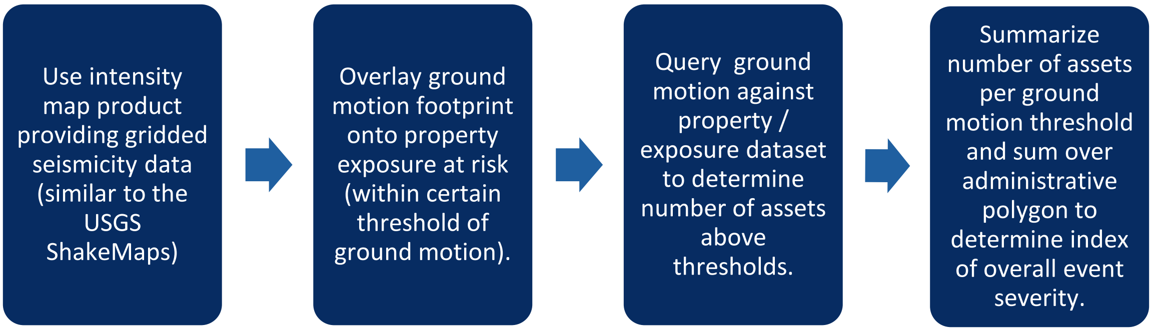
- A probabilistic earthquake catastrophe model is not available.

POTENTIAL SETTLEMENT WINDOW:

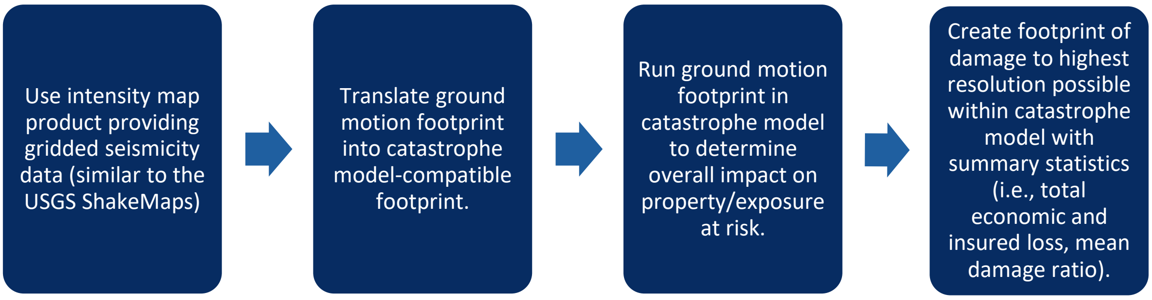
- Near real time post-event data (date, location, magnitude and depth) are acquired immediately after an event and available for settlement procedure.
- The time frame of the availability of local instrumental recordings is unknown.
- A supplemented modelled loss trigger would produce a longer duration settlement that could take days or weeks depending on availability of refined intensity maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



The capacity of creating the shaking intensity maps in near real-time using the recordings from the local ground motion networks, combined with finite fault rupture plane, regional GMPEs and site classification maps is unclear. 2nd and 3rd generation triggers may not be feasible for these sources under consideration alone.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available near real-time.
- Current ground motion instrumentation networks are lacking or limited, and may not be linked to the global sources such as USGS that produces ShakeMaps
- Lack of high-resolution local geological maps for site classification.
- Detailed exposure information may be difficult to obtain in some regions.
- Potential for inadequately representing the actual shaking intensity field
- Potential of systemically mischaracterizing the seismic performance of local constructions.

SCOPE OF LIVE DATA:

Key attributes for earthquake:

- Location, Magnitude, Depth, Dip, Strike, Rake

Key attributes for tsunami:

- Based on SWIFT- maximum tsunami heights and projections

EQ Index 8: Local Sources – Indonesia tsunami

DATA SOURCES:

- Indonesian Tsunami Early Warning System (InaTWES) from Badan Meterologi, Klimatologi, Dan Geofisika (BMKG) [24]
- United States Geological Survey (USGS) ShakeMaps [1]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- Shaking instrumentation data from recording networks (BMKG, NEIC)
- High resolution local geologic maps
- Regional empirical ground motion models

OVERVIEW:

BMKG provides real time data and information for tsunamis and earthquakes in and around Indonesia. The Indonesian Tsunami Early Warning System (InaTEWS) is a national project involving various institutions in the country under the coordination of the Ministry of Research and Technology.

COUNTRY COVERAGE:

Indonesia

POTENTIAL PERIL COVERAGE:

- Tsunami inundation, Earthquake ground shaking
- Earthquake ground shaking impact for a second generation parametric trigger if supplemented with exposure mapping, local geological mapping and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings. USGS ShakeMaps that are distributed through the site are generally preliminary in nature for the country of interest. Ground motion recording from the network have not been integrated into the USGS ShakeMap. Also, they may not be available rapidly or even consistently to enhance the ShakeMap information.
- Earthquake impact for a third generation parametric trigger if supplemented with denser ground motion instrumentation and high resolution geologic information for site classification to produce more reliable ground motion intensity maps as input to the catastrophe model.
- The tsunami early warning system identifies Indonesian provinces at risk of inundation. An estimated time of arrival and warning level are provided online. https://inatews.bmkg.go.id/new/saran_arahan.php

	WARNING LEVEL	BMKG FROM ADVICE TO LOCAL GOVERNMENT
NATIONAL TSUNAMI WARNING CENTER AT BMKG JAKARTA	MAJOR WARNING (Wave Height Greater than 3m)	Province / District / City Governments that are at "Major Warning" level are expected to pay attention to this warning and guide. Immediately Reviews their communities for full evacuation.
	WARNING (Wave Height Between 0.5m and 3m)	Province / District / City Governments that are at "Warning" level are expected to pay attention to this warning and guide. Immediately Reviews their communities for evacuation.
	ADVISORY (Wave Height Less than 0.5m)	Province / District / City Governments that are at "Advisory" level are expected to pay attention to this warning and guide. Immediately Reviews their communities to move away from the beach and river banks.
	EARTHQUAKE INFORMATION	Earthquake on land, with small magnitude earthquake or deep earthquake - no tsunami threat.

POTENTIAL IMPACT COVERAGE:

- Near real time post-event data (date, location, magnitude and depth) acquired from regional sensors.
- Tsunami warnings and range of modelled wave heights
- Near real time post-event ShakeMap (MMI, PGA, PGV maps) from USGS, additional recording information can be added from local recordings if not presented in the USGS ShakeMaps.
- In modelled loss trigger form, the earthquake size and origination – or a ground motion footprint - could be used as an input to a catastrophe model and capture impacts to physical assets.

SUPPLEMENTARY DATA SOURCE OPTIONS:

Indonesia

- Development of shaking intensity maps:
    - Local geological maps to create site condition maps.
    - Ground motion recordings captured through the network of seismic recording stations and analysed by seismologists from local networks, including the Seismic Network Stations of Meteorology and Geophysics Agency (BMKG), Indonesia; the International Seismic Network of National Research Institute for Earth Science and Disaster Resilience (NIED), Japan
    - Aftershock maps and local known faulting maps to determine the potential rupture plane.
- Property / exposure information to determine the number of assets at risk to ground shaking within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

Indonesia

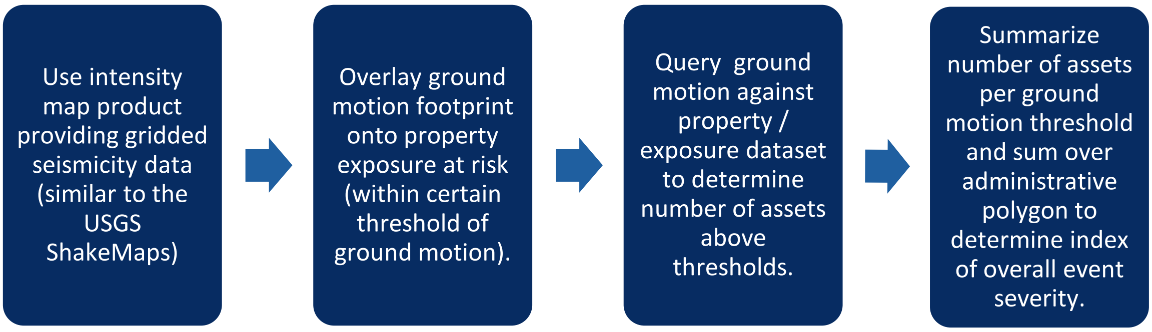
- The AIR Earthquake Model for Southeast Asia is available and can model an earthquake based on moment magnitude, location, and rupture plane information. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can translate the footprint into an equivalent footprint that is compatible with the model's analysis module. Insurance industry exposure data (i.e, property covered by earthquake insurance) is available.
- The Catalytics Earthquake model is available. It is not believed that the ShakeMap footprint (1-km gridded seismicity) can be input directly into model. However, a pre-processing tool can likely translate the footprint into an equivalent footprint that is compatible with the model's analysis model. Economic and infrastructure data is available.
- CoreLogic Indonesia Earthquake is available and the company is working on allowing a peak ground acceleration (PGA) footprint (in shapefile format) as input into its model. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.
- The RMS Indonesia Earthquake (Version 16) model is available and can take peak ground acceleration (PGA) or Modified Mercalli Intensity (MMI) ShakeMap footprints as input into model. Exposure databases are not available.
- The RMS Indonesia Earthquake (Version 17) model will be available (2017) and can take Peak Ground Acceleration (PGA), Modified Mercalli Intensity (MMI), or Spectral Acceleration (SA) ShakeMap footprints as input into model. A high-resolution economic exposure database will be available.

POTENTIAL SETTLEMENT WINDOW:

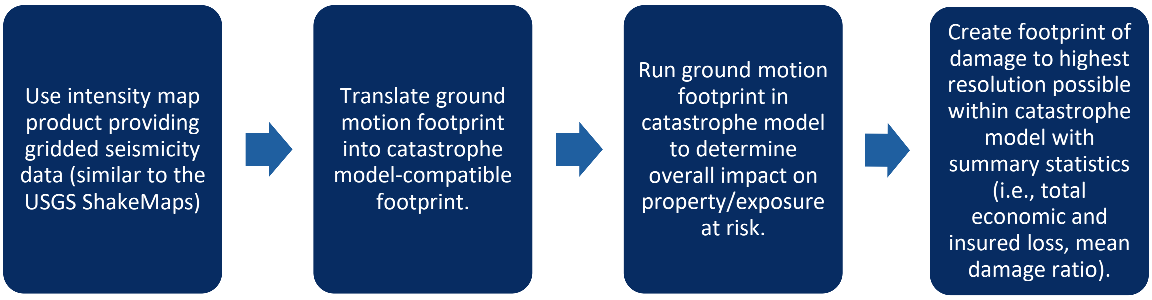
- Near real time post-event data (date, location, magnitude and depth) are acquired immediately after an event and available for settlement procedure; earthquake ground motion maps are acquired from USGS.
- The time frame of the availability of local instrumental recordings and tsunami inundation data is unknown.
- A supplemented modelled loss trigger would produce a longer settlement window and could take days or weeks depending on availability of refined intensity maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



The capacity of creating the shaking intensity maps in near real-time using the recordings from the local ground motion networks, combined with finite fault rupture plane, regional GMPEs and site classification maps is unclear. 2nd and 3rd generation triggers may not be feasible for these sources under consideration alone.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available near real-time.
- Current ground motion instrumentation networks are lacking or limited, and may not be linked to USGS ShakeMaps, time frame of the availability of tsunami inundation data unknown
- Lack of high resolution local geological maps for site classification.
- Detailed exposure information may be difficult to obtain in some regions.
- Potential for inadequately representing the actual shaking intensity field
- Potential of systemically mischaracterizing of the seismic performance of local constructions.

SCOPE OF LIVE DATA:

Key attributes:

- Location, date, time, depth, magnitude.
- Near real-time maps of ground motion and shaking intensity following significant earthquakes.
- Tsunami warnings and range of modelled wave heights.

EQ Index 9: Local sources – Pakistan

DATA SOURCES:

- Seismic data from the PMD, National Seismic Monitoring Centre, Islamabad [25]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- High-resolution local geologic maps
- Regional empirical ground motion models

OVERVIEW:

The PMD monitors seismic activity and early tsunami warnings for Pakistan. The PMD disseminates earthquake information to the government, non-government organizations and the public following the occurrence of an event.

COUNTRY COVERAGE:

Pakistan

POTENTIAL PERIL COVERAGE:

- Earthquake magnitude and location
- To estimate earthquake impacts, supplemental information will be required for exposure mapping, local geological mapping and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings. A seismic hazard analysis study was conducted by PMD and NORSAR of Norway in 2007 that produced probabilistic hazard maps (http://www.pmd.gov.pk/SeismicReport_PMD.pdf). This study may provide useful information about local faults and help select proper GMPEs for modelling intensity footprint post event.

POTENTIAL IMPACT COVERAGE:

- Near real time post-event data (date, location, magnitude and depth) acquired from local sensors.

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Development of shaking intensity maps.
  - Local geological maps to create site classification maps.
  - Ground motion recordings captured through the network of seismic recording stations and analysed by seismologists
  - A seismic network of 30 stations was spread over 400x300 km area from north to south of Pakistan. In 2005 it was decided to upgrade the seismic network with broadband sensors, accelerometers, 24 bit analogue to digital converters, radio and satellite digital telemetry. A high quality seismic network is now fully operational to monitor seismic data from 360 seconds to 50 Hz. The seismic noise characteristics of seismic stations sites indicate that these stations are capable of producing highly reliable seismic data from 360 seconds to 50 Hz and have a large amplitude dynamic range due to 24 bit analogue to digital converters. Aftershock maps and local known faulting maps to determine the potential rupture plane.
- Property / exposure information to determine the number of assets at risk to ground shaking within the extent.

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

Pakistan

- The CoreLogic Pakistan Earthquake model is available and can model an earthquake based on magnitude, location, and rupture plane information (if applicable) available from source. Insured, rather than economic, exposure data is available: i.e., property covered by earthquake insurance.

POTENTIAL SETTLEMENT WINDOW:

- Near real time post-event data (date, location, magnitude and depth) are acquired immediately after an event and available for settlement procedure; ground motion maps are acquired from USGS source.
- The time frame of the availability of local instrumental recordings is unknown.
- A supplemented modelled loss trigger would produce a longer settlement window and could take days or weeks depending on availability of refined intensity maps and model loss runs.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:

Use intensity map product providing gridded seismicity data (similar to the USGS ShakeMaps) → Overlay ground motion footprint onto property exposure at risk (within certain threshold of ground motion). → Query ground motion against property / exposure dataset to determine number of assets above thresholds. → Summarize number of assets per ground motion threshold and sum over administrative polygon to determine index of overall event severity.

Third generation parametric trigger:

Use intensity map product providing gridded seismicity data (similar to the USGS ShakeMaps) → Translate ground motion footprint into catastrophe model-compatible footprint. → Run ground motion footprint in catastrophe model to determine overall impact on property/exposure at risk. → Create footprint of damage to highest resolution possible within catastrophe model with summary statistics (i.e., total economic and insured loss, mean damage ratio).

The capacity of creating the shaking intensity maps in near real-time using the recordings from the local ground motion networks, combined with finite fault rupture plane, regional GMPEs and site classification maps is unclear. 2nd and 3rd generation triggers may not be feasible for these sources under consideration alone.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available near real-time.
- Current ground motion instrumentation networks are limited, and it is not known whether linked to the USGS ShakeMaps
- Lack of high resolution local geological maps for site classification.
- Detailed exposure information needed.
- Potential for inadequately representing the actual shaking intensity field
- Potential of systemically mischaracterizing of the seismic performance of local constructions.

SCOPE OF LIVE DATA:

Key attributes:

- Near real-time acquisition of date, location, magnitude and depth of seismic event.

EQ Index 10: Local Sources - Bangladesh

DATA SOURCES:

- Bangladesh University of Engineering and Technology, Dhaka (BUET) Bangladesh Strong Motion Network (as part of COSMOS-WSSI) [26]

RELEVANT SUPPLEMENTARY DATA SOURCES:

- US Geological Survey ShakeMap
- High-resolution local geologic maps
- Regional empirical ground motion models

OVERVIEW:

Installation of a seismic network system to record earthquakes, within Bangladesh and its neighbouring regions, which have experienced several large earthquakes in the past. The peak ground accelerations of these earthquakes have been estimated using different existing attenuation laws for different parts of the world, however the current research presents an opportunity for development of a specific attenuation law of Bangladesh.

COUNTRY COVERAGE:

Bangladesh

POTENTIAL PERIL COVERAGE:

- Earthquakes ground shaking
- Earthquake ground shaking impact for a second generation parametric trigger if supplemented with exposure mapping, local geological mapping and regional empirical ground motion prediction equations (GMPEs) derived from local historical events or similar tectonic settings. USGS preliminary ShakeMaps for the region can be improved with near-real time feedback from local ground motion recordings captured through the network of seismic recording stations but may not be available rapidly or even consistently to enhance the ShakeMap data.
- Earthquake impact extent for a third generation parametric trigger would require a probabilistic model for Bangladesh which is currently unavailable from the known vendors and sources.

POTENTIAL IMPACT COVERAGE:

- Near real time post-event (date, location, magnitude and depth) acquired from national sensors.
- Peak Ground Acceleration (PGA) obtained from 60 accelerographs provided as a part of the SAFER cities project of COSMOS-WSSI and deployed in the free-field at different locations of Bangladesh (per 2006 report 38 instruments were in place- http://www.cosmos-eq.org/SAFER/SAFER-Bangladesh.pdf, pg. 11, section 8).

SUPPLEMENTARY DATA SOURCE OPTIONS:

- Development of shaking intensity maps:
  - Local geological maps to create site condition maps (i.e., amplification from soft soils, etc.).
  - Ground motion recordings captured through the network of seismic recording stations and analysed by seismologists from local networks
    - 60 accelerographs deployed* across Bangladesh
  - Aftershock maps and local known faulting maps to determine the potential rupture plane.
- Enhancement of USGS ShakeMaps
- Property / exposure information to determine the number of assets at risk to ground shaking within the extent.

** 38 instruments confirmed to be in place*

RELEVANT CATASTROPHE MODELS (AND AVAILABLE EXPOSURE DATA):

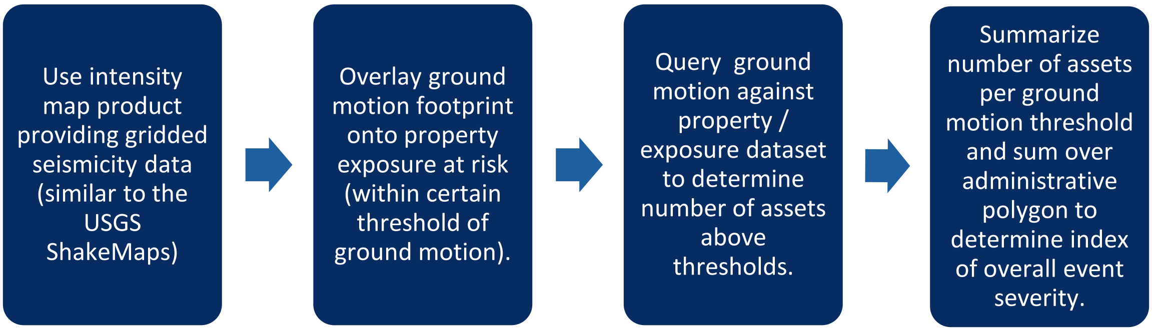
- A probabilistic earthquake catastrophe model is not available

POTENTIAL SETTLEMENT WINDOW:

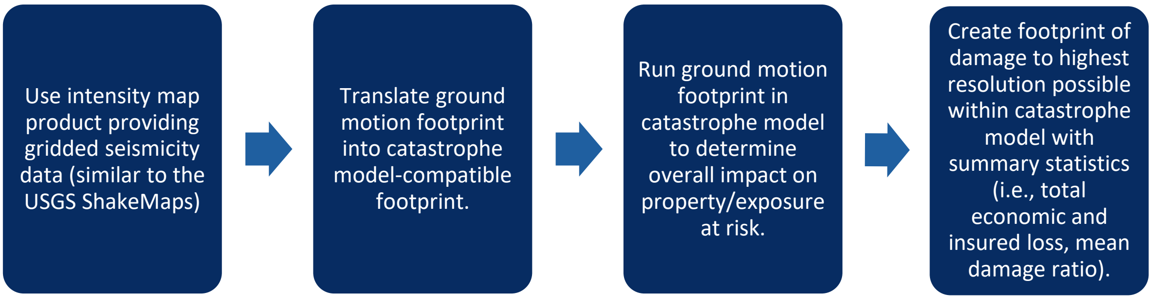
- The time frame of the availability of local instrumental recordings is unknown.
- Near real time post-event data (date, location, magnitude and depth) may be acquired immediately after an event and available for settlement procedure; intensity maps are acquired from USGS source. However, supplementing of this with local instrumentation recordings would extend the settlement timeframe.

PROPOSALS FOR INDEX DEVELOPMENT METHODOLOGY:

Second generation parametric trigger:



Third generation parametric trigger:



The capacity of creating the shaking intensity maps in near real-time using the recordings from the local ground motion networks, combined with finite fault rupture plane, regional GMPEs and site classification maps is unclear. 2nd and 3rd generation triggers may not be feasible for these sources under consideration alone.

NOTES ON STRENGTHS AND WEAKNESSES OF DATA SOURCE FOR LIVE CONTRACT SETTLEMENT:

- Free and open licence.
- Important earthquake rupture source (magnitude, location and focal depth) information available near real-time.
- Current ground motion instrumentation networks are lacking or limited, and it is not known whether linked to ShakeMaps
- Lack of high resolution local geological maps for site classification.
- Detailed exposure information needed in some countries or regions.
- Potential for inadequately representing the actual shaking intensity field.
- Potential of systemically mischaracterizing of the seismic performance of local constructions.

SCOPE OF LIVE DATA:

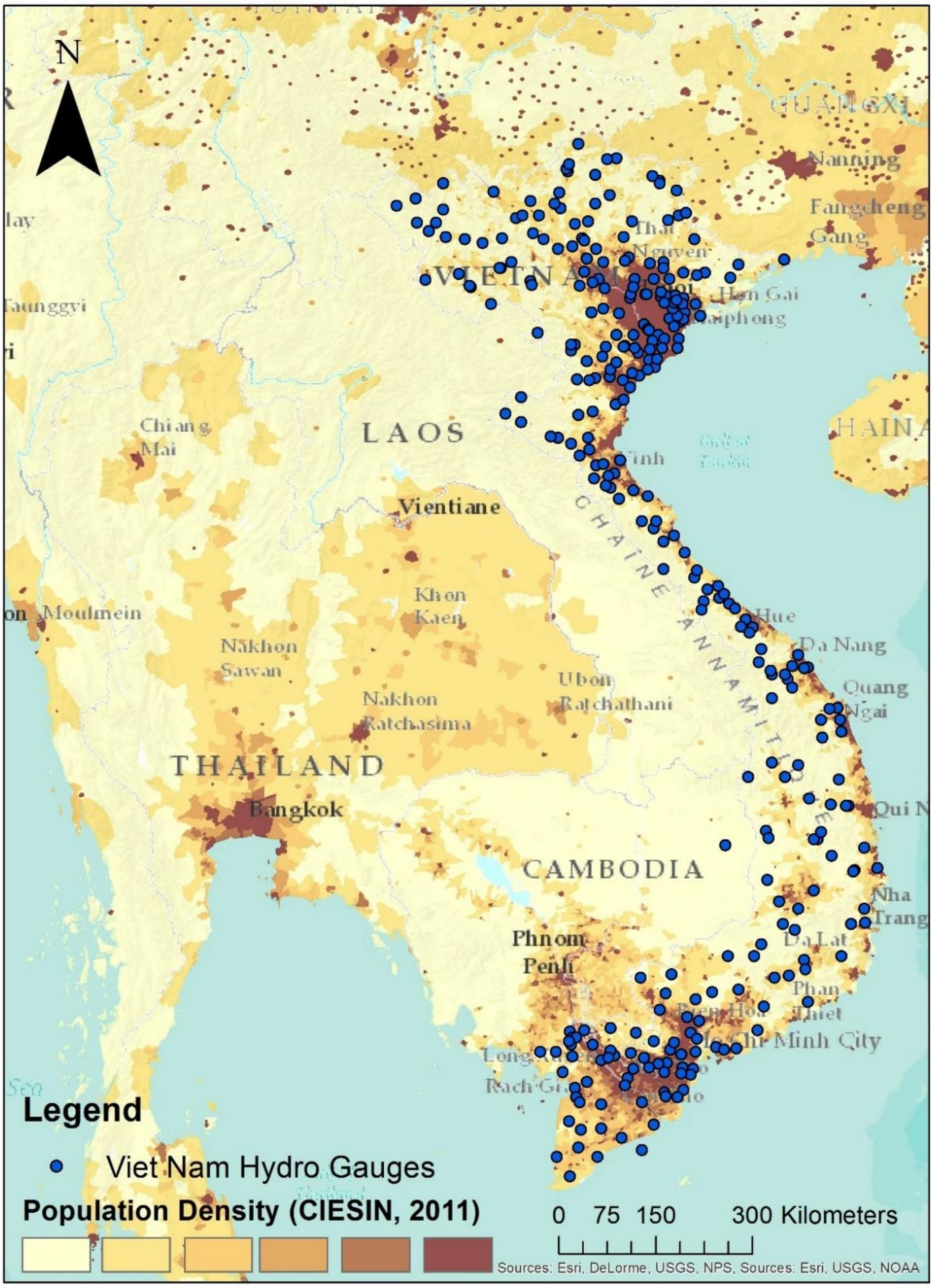
Key attributes:

- Near real-time acquisition of date, location, magnitude and depth of seismic event.

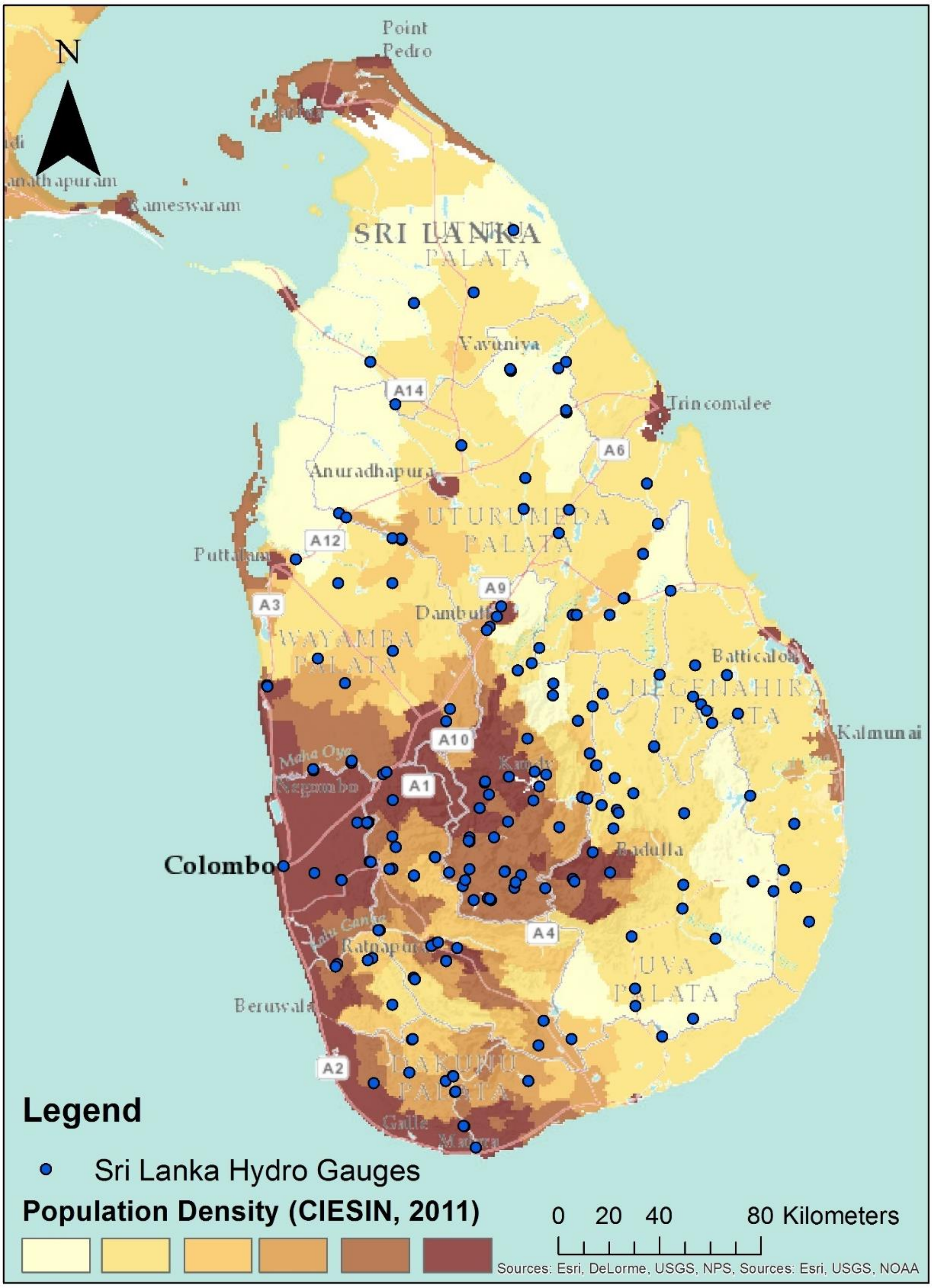
Appendix

Appendix I. National river gauges: Location maps

VIET NAM

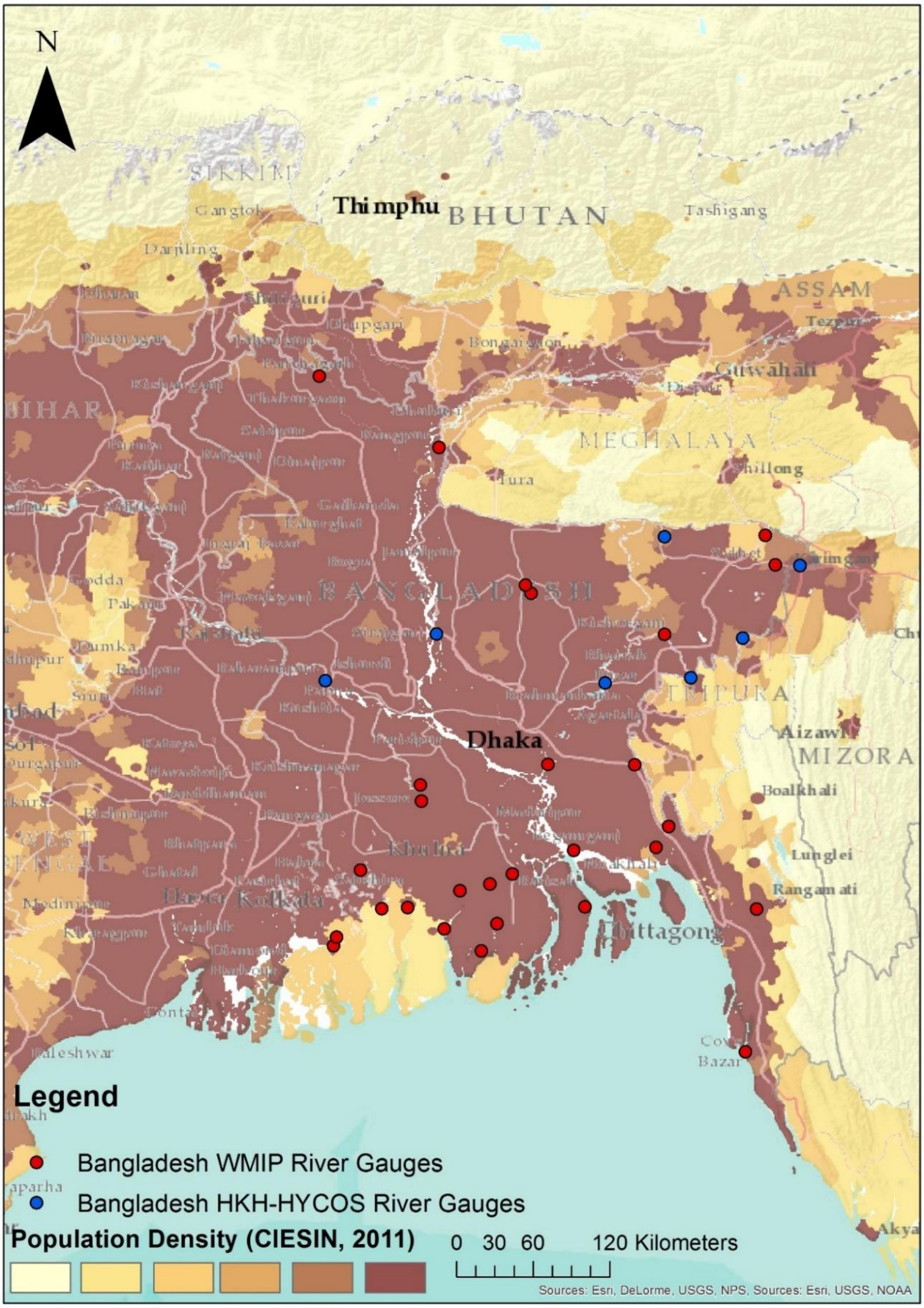


SRI LANKA

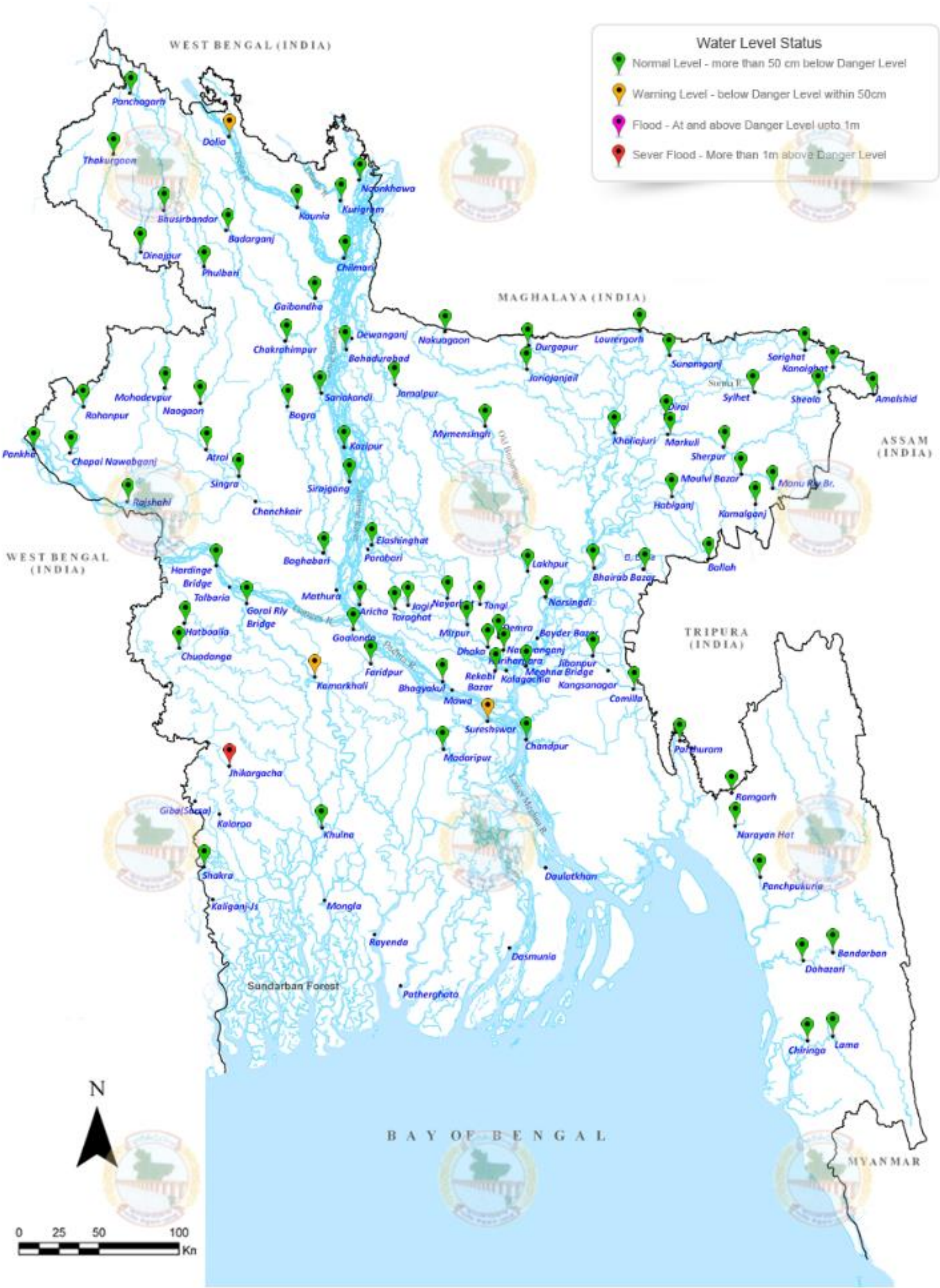

N
Point
Pedro
Rameswaram
SRI LANKA
Vavuniya
A14
Trincomalee
A6
Anuradhapura
UTURUMEDA
PALATA
A12
Puttalam
A9
A3
Dambulla
WAYAMBA
PALATA
Batticaloa
NEGENAHIRA
PALATA
Kalmunai
A10
Kandy
A1
Negombo
Colombo
Badulla
A4
Ratnapura
UVA
PALATA
Beruwala
A2
DAKUNU
PALATA
Galle
Matara
Legend
Sri Lanka Hydro Gauges
Population Density (CIESIN, 2011)
0 20 40 80 Kilometers
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

BANGLADESH

I - River gauges with location provided

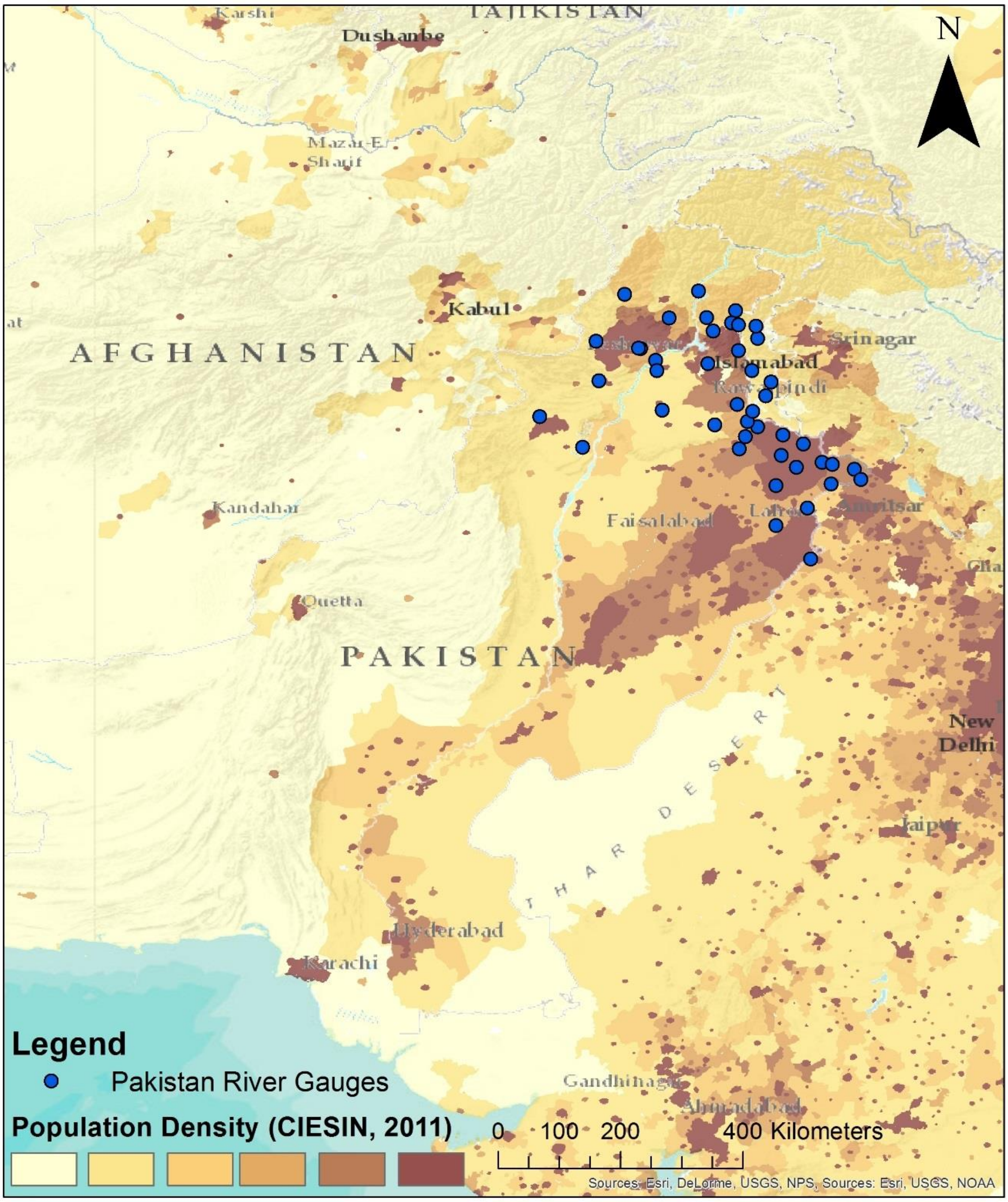


- Additional river gauges exist by location was not provided


Water Level Status
Normal Level - more than 50 cm below Danger Level
Warning Level - below Danger Level within 50cm
Flood - At and above Danger Level upto 1m
Sever Flood - More than 1m above Danger Level
WEST BENGAL (INDIA)
MAGHALAYA (INDIA)
ASSAM (INDIA)
TRIPURA (INDIA)
MYANMAR
BAY OF BENGAL
Sundarban Forest
N
0 25 50 100
Km

PAKISTAN

I – River gauges



II - Additional river gauges for Pakistan on the lower catchments. Latitude and Longitude not provided, but spatial location available from data provider on image below.


Uzbekistan
Tajikistan
Turkmenistan
Afghanistan
India
Disputed Area
Peshawar
Islamabad
Quetta
Lahore
Karachi
Hunza-Nagar
Gilgit
Ghizer
Diamir
Skardu
Ghanche
Astore
Chitral
Mastuj
Kumar
Indus
Kabul River
Kunhar River
Poonch
Soan River
Jhelum River
Chenab River
Ravi River
Sutlej
B.R.B Canal
Nara Canal
Dasht
Kech
Upper Dir
Lower Dir
Swat
Kohistan
Shangla
Mansehra
Neelum
Buner
Swabi
Haripur
Hattian
Muzaffarabad
Bagh
Haveli
Kotli
Mirpur
Bhimber
Bajaur Agency
Mohmand Agency
Khyber Agency
Nowshera
Attock
Chakwal
Kurrum Agency
Hangu
Kohat
Karak
FR Bannu
North Waziristan Agency
FR Lakki Marwat
Bannu
FR Tank
Lakki Marwat
Mianwali
South Waziristan Agency
Tank
Khushab
Sargodha
Jhelum
Gujrat
Sialkot
Narowal
Gujranwala
Hafizabad
Chiniot
Faisalabad
Jhang
Kasur
Okara
Toba Tek Singh
Sahiwal
Pakpattan
Khanewal
Vehari
Multan
Lodhran
Muzaffargarh
Bahawalnagar
Bahawalpur
Leiah
Bhakkar
D. I. Khan
Sherani
FR D. I. Khan
Zhob
Killa Saifullah
Musakhel
Pishin
Killa Abdullah
Ziarat
Harnai
Loralai
Barkhan
D. G. Khan
Mastung
Sibi
Kohlu
Nushki
Kalat
Bolan
Dera Bugti
Rajanpur
Chagai
Nasirabad
Jhal Magsi
Jaffarabad
Jacobabad
Kashmore
Rahim Yar Khan
Kharan
Shikarpur
Ghotki
Washuk
Qambar and Shahdadkot
Larkana
Sukkur
Khuzdar
Naushahro Feroze
Dadu
Khairpur
Panjgur
Nawabshah
Sanghar
Kech
Awaran
Lasbela
Jamshoro
Matiari
Tando Allahyar
Umerkot
Hyderabad
Mirpur Khas
Tando Muhammad Khan
Gwadar
Thatta
Badin
Tharparkar

INDONESIA

Currently only name, ID, and data range for all stations (river gauges). Latitude and Longitude not provided.

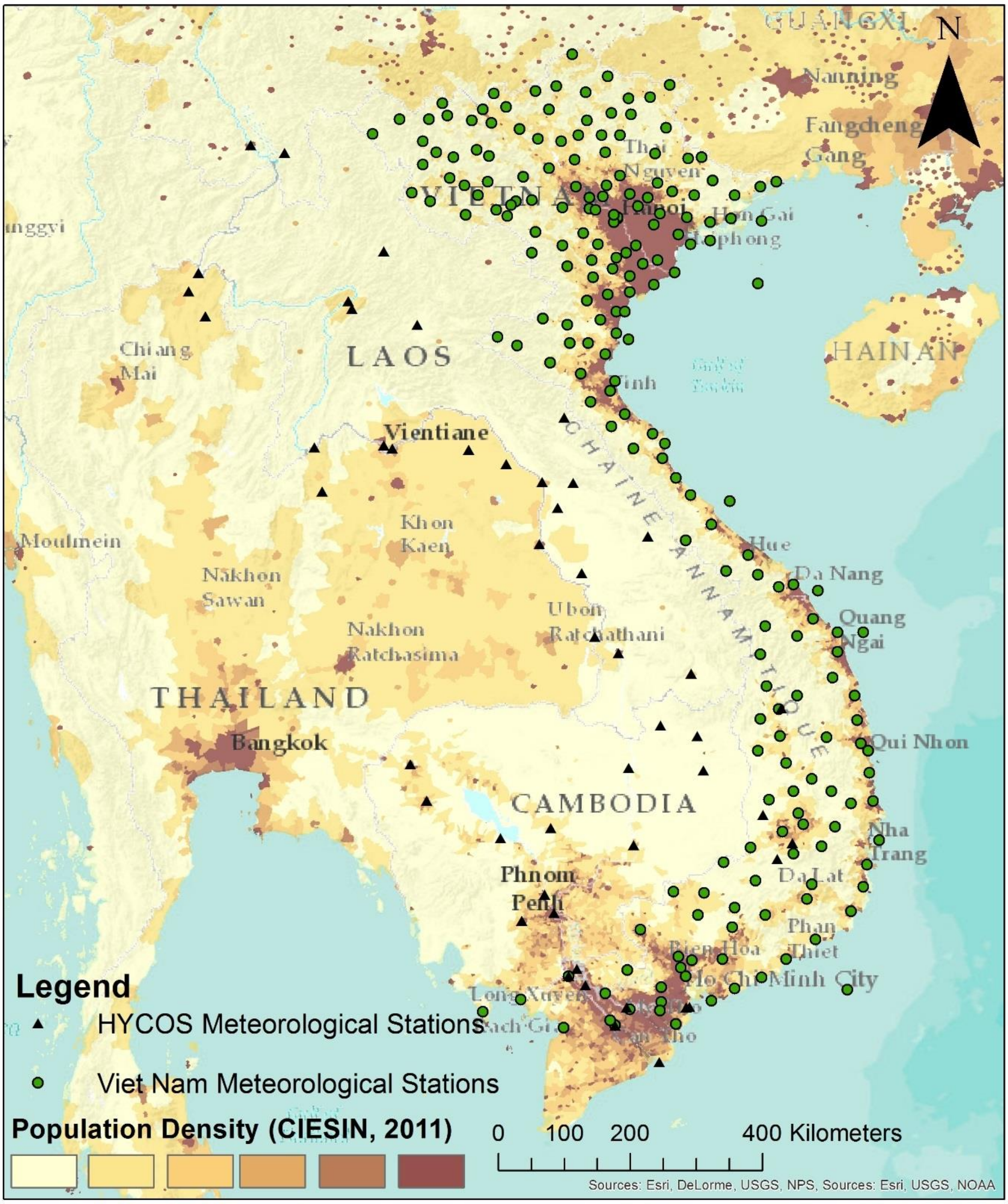
Tech4water group

West:

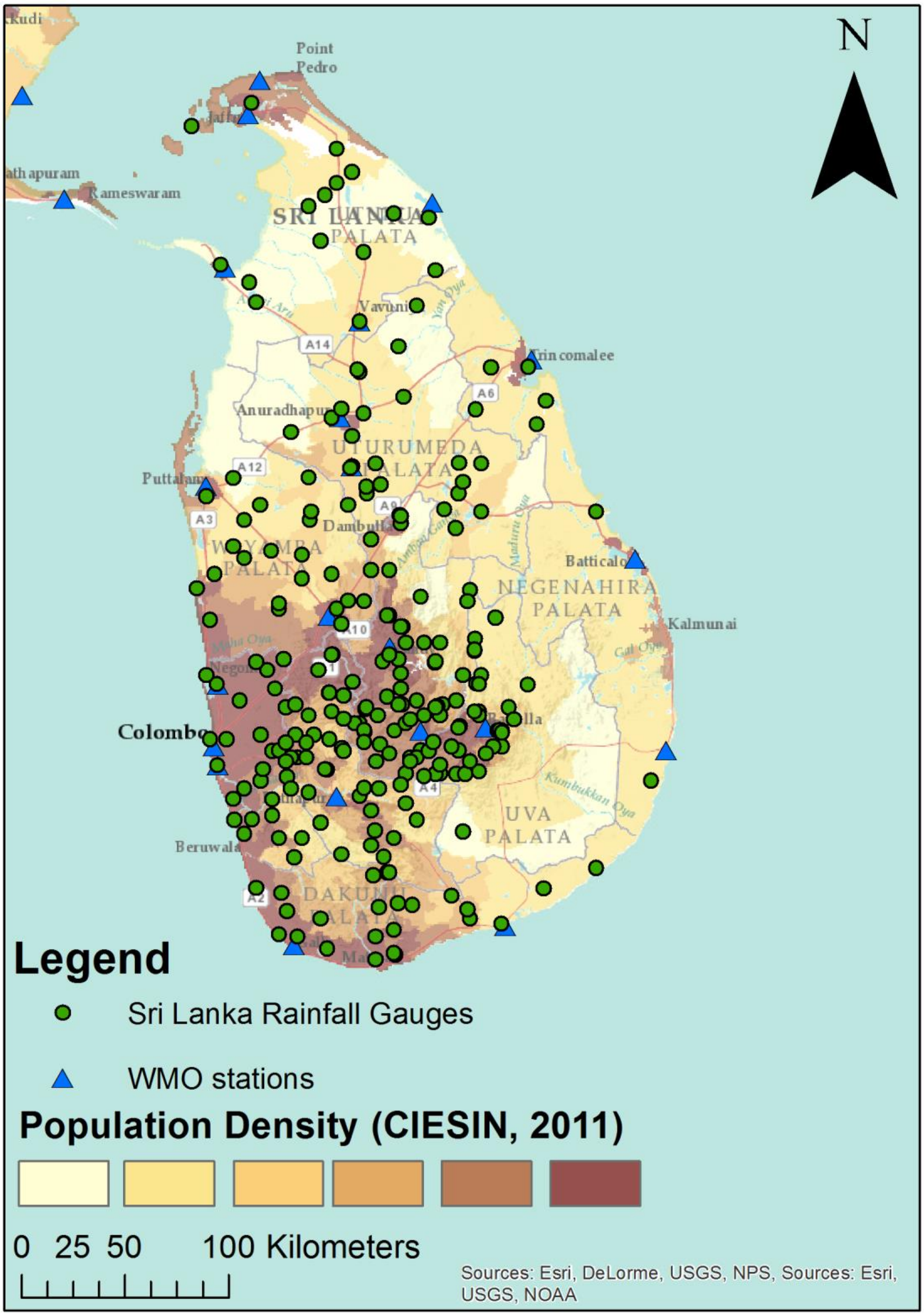
East:

Appendix II. National meteorological gauges: Location maps

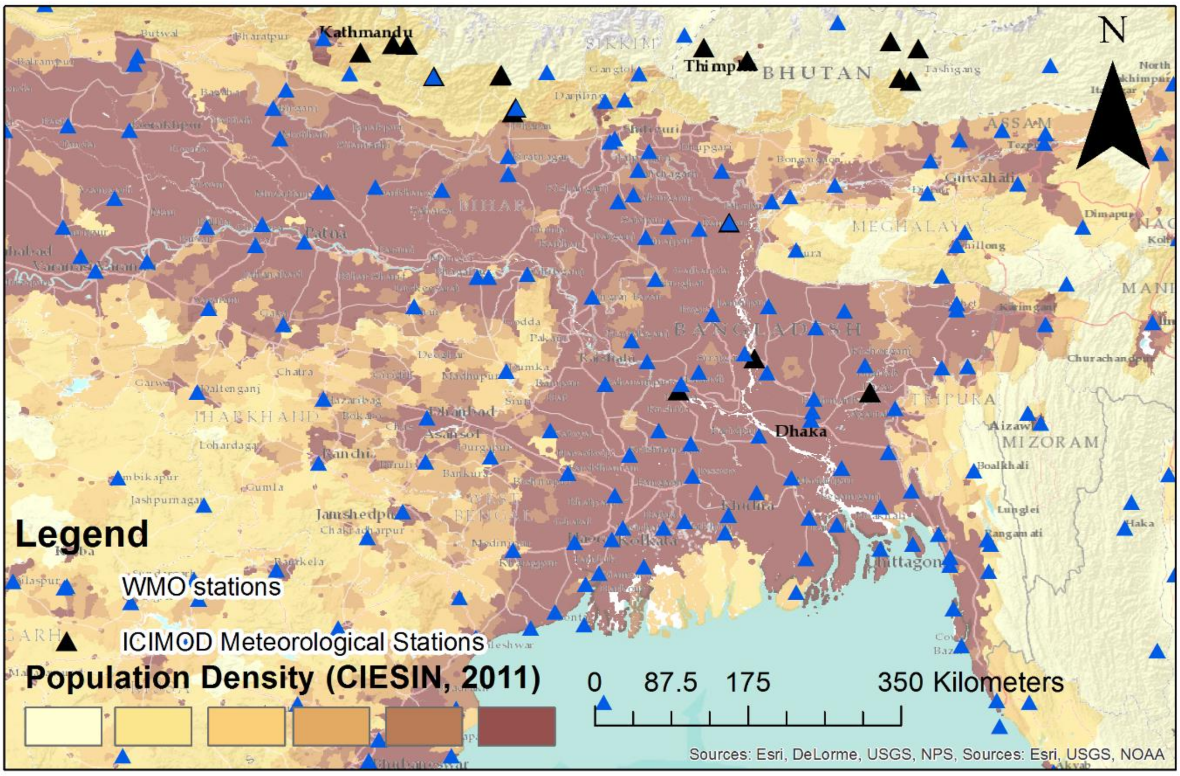
VIET NAM

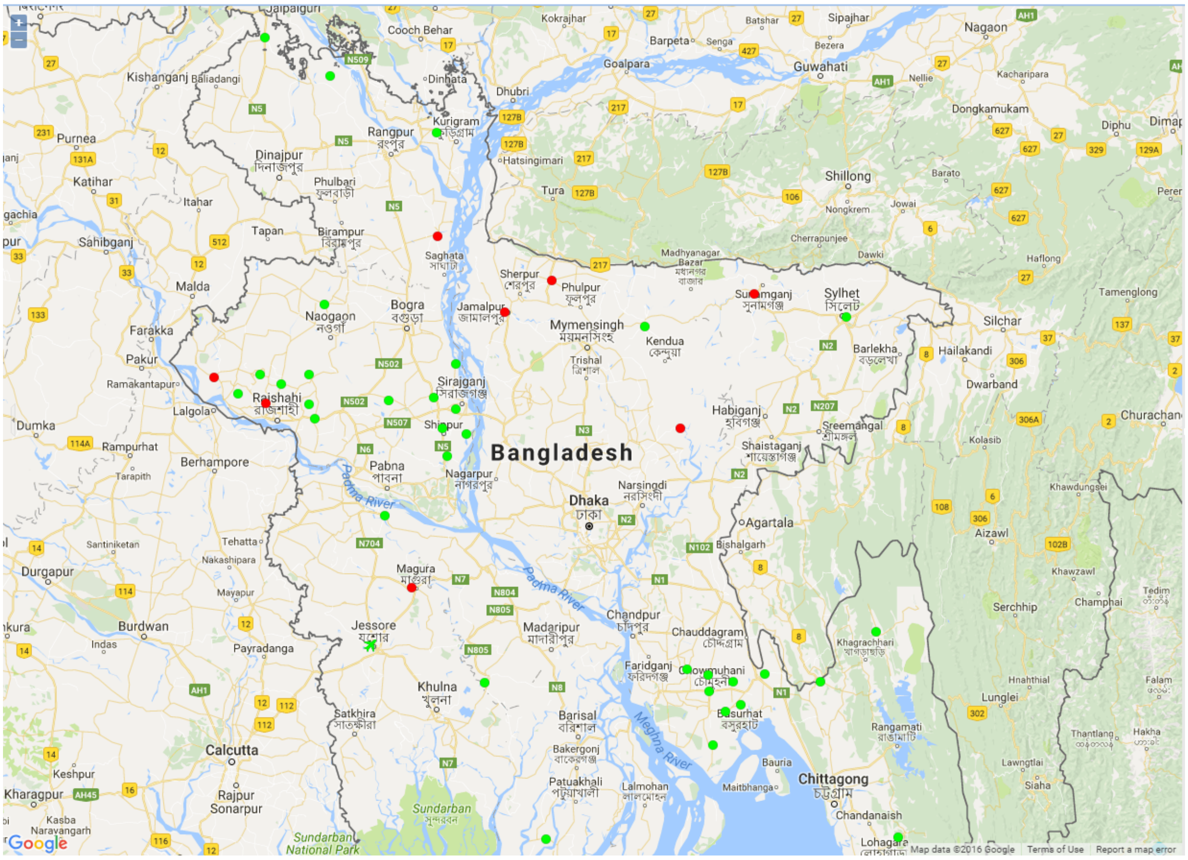


SRI LANKA

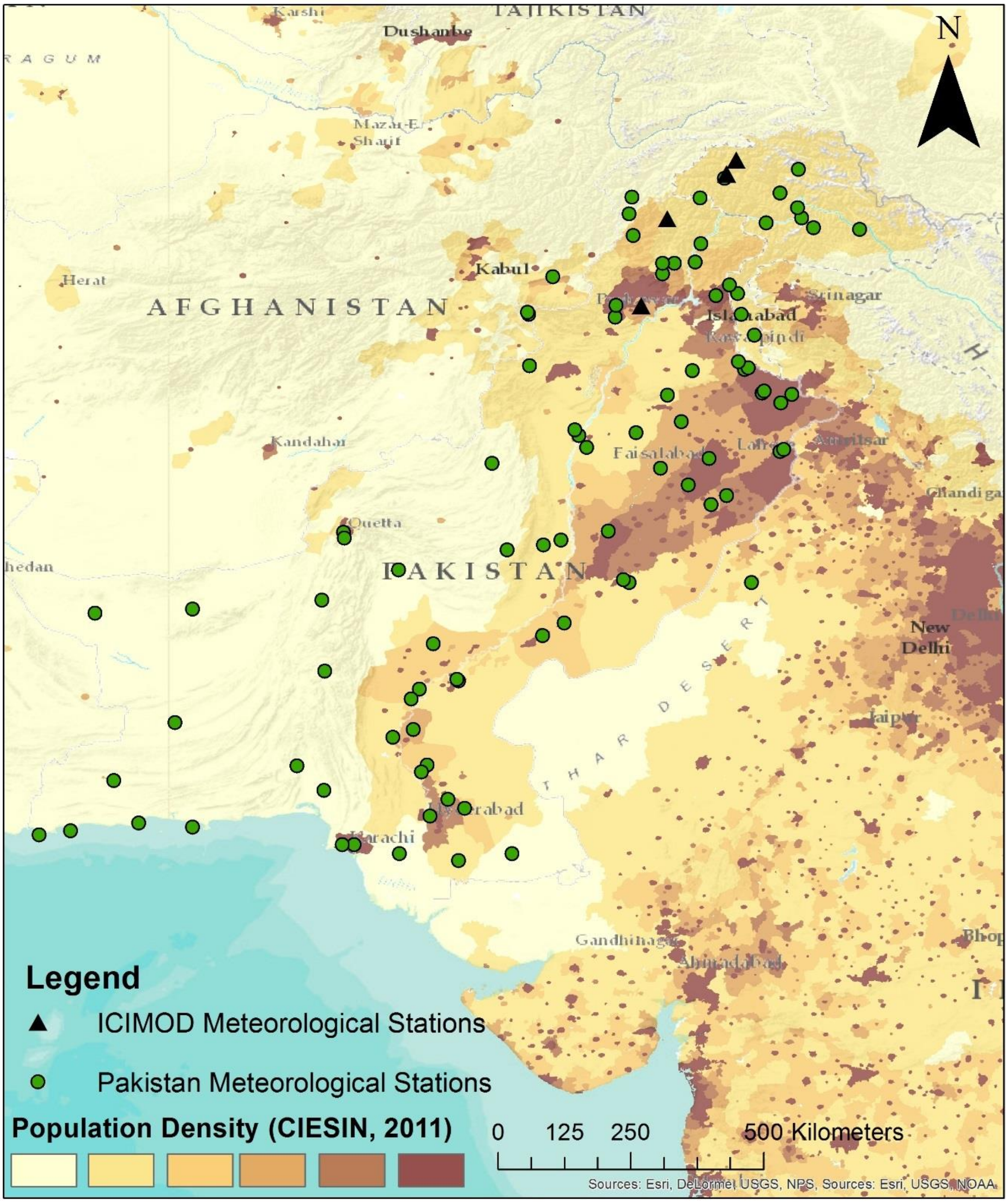

N
Point
Pedro
Rameswaram
Vavuni
Trincomalee
Anuradhapu
UTURUMEDA
Puttalam
Dambulla
NEGENAHIRA
PALATA
Batticalo
Kalmunai
Colombo
Beruwala
UVA
PALATA
Legend
Sri Lanka Rainfall Gauges
WMO stations
Population Density (CIESIN, 2011)
0 25 50 100 Kilometers
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

BANGLADESH

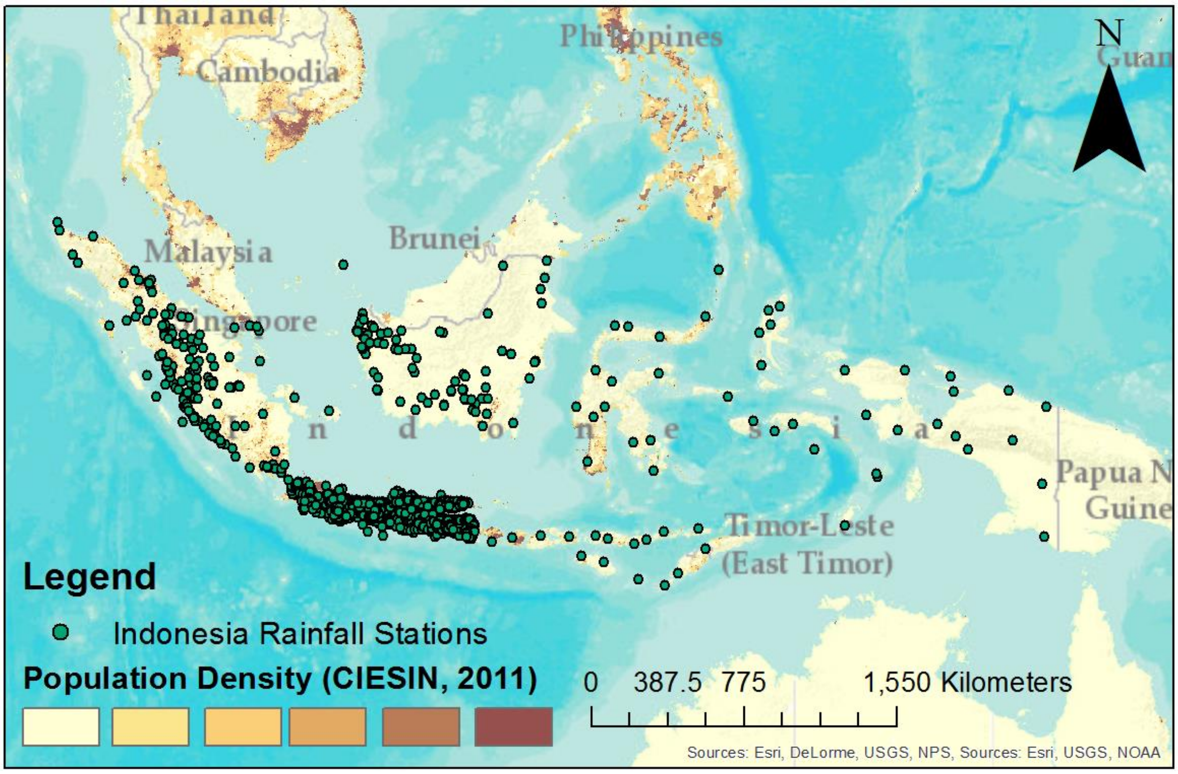

N
Legend
WMO stations
ICIMOD Meteorological Stations
Population Density (CIESIN, 2011)
0 87.5 175 350 Kilometers
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA
Kathmandu
BHUTAN
Dhaka


Bangladesh
Dhaka
Chittagong
Rajshahi
Khulna
Sylhet
Map data ©2016 Google

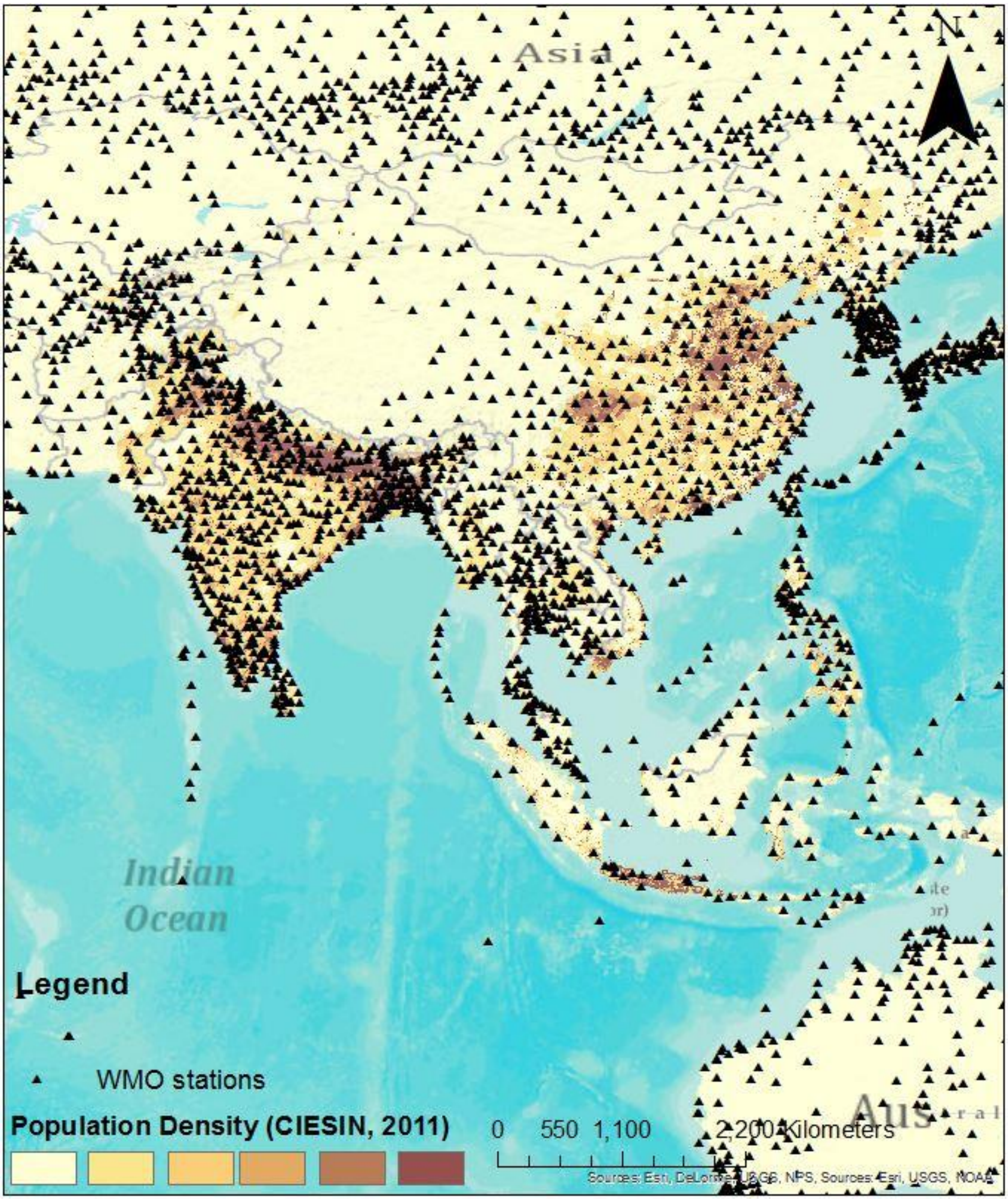
PAKISTAN


N
TAJIKISTAN
Dushanbe
Mazar-E Sharif
Kabul
Herat
AFGHANISTAN
Kandahar
Quetta
PAKISTAN
Islamabad
Rawalpindi
Srinagar
Faisalabad
Lahore
Amritsar
Chandigarh
New Delhi
Jaipur
THAR DESERT
Hyderabad
Karachi
Gandhinagar
Ahmadabad
Legend
ICIMOD Meteorological Stations
Pakistan Meteorological Stations
Population Density (CIESIN, 2011)
0 125 250 500 Kilometers
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

INDONESIA

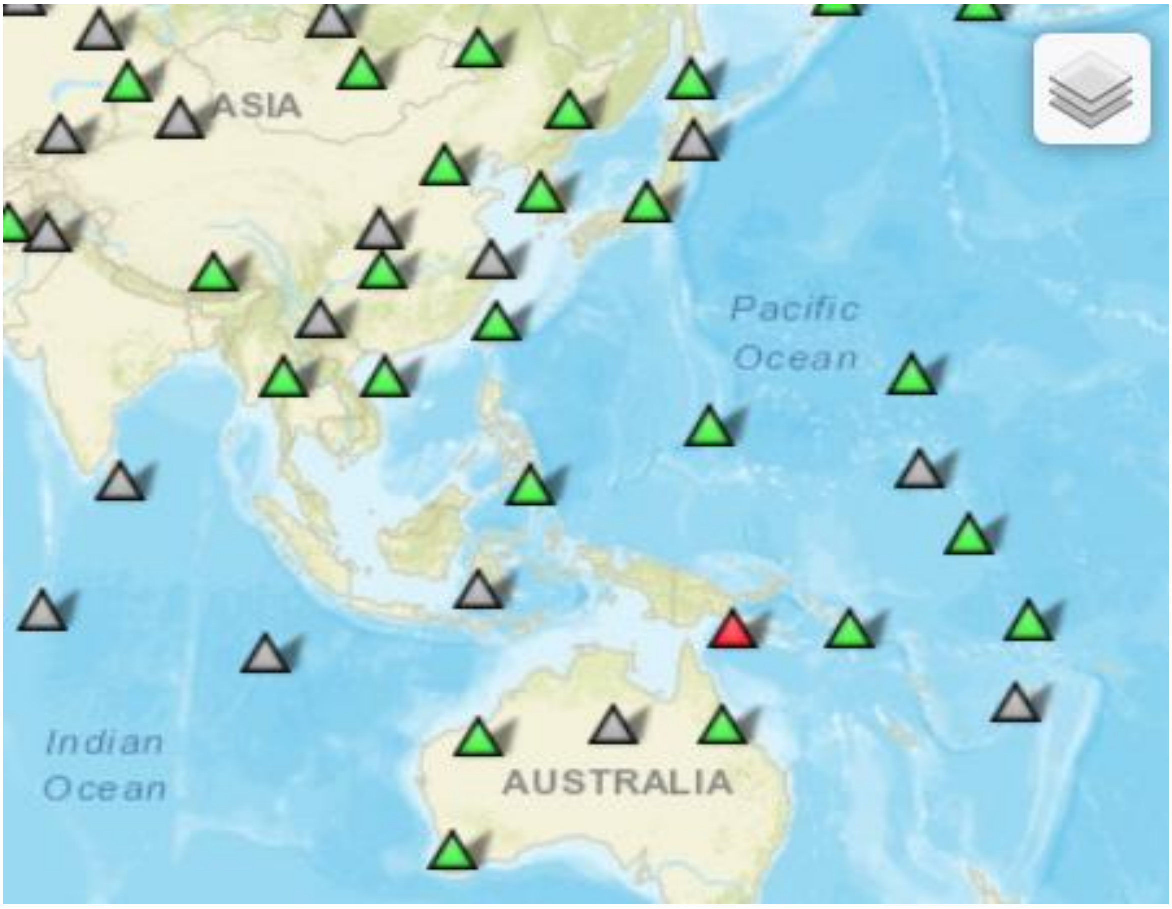

Thailand
Cambodia
Philippines
Guam
N
Malaysia
Brunei
Singapore
Indonesia
Timor-Leste
(East Timor)
Papua N
Guine
Legend
Indonesia Rainfall Stations
Population Density (CIESIN, 2011)
0 387.5 775 1,550 Kilometers
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

GLOBAL MET DB MIDAS WMO



Appendix III. Seismic network maps

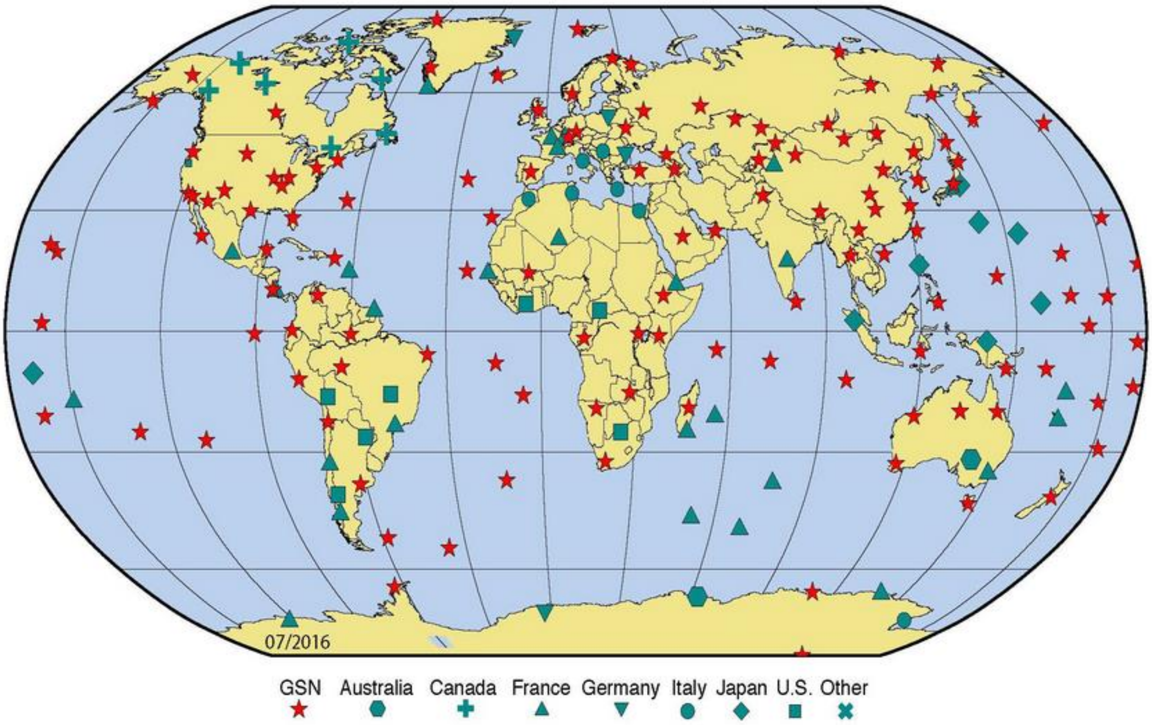
USGS SEISMIC NETWORK OPERATIONS (EQ INDEX 1,2)



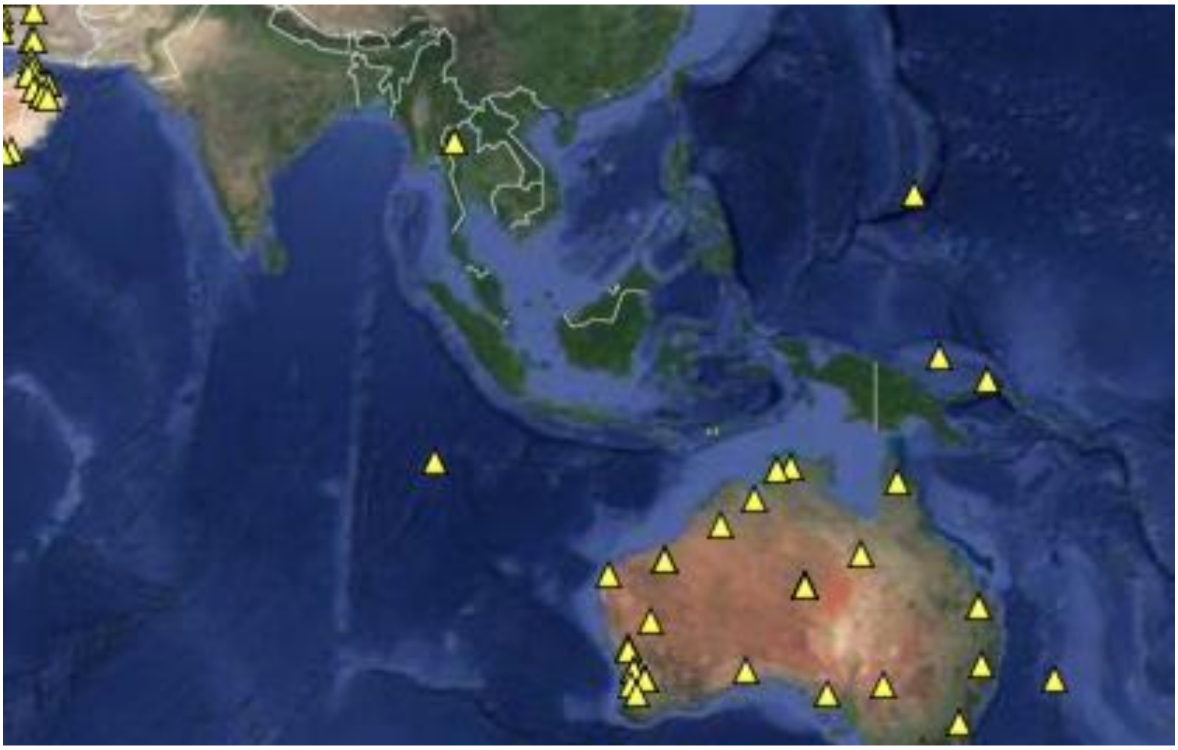
Telemetry Status - Network Code

Telemetry Undefined
No Data In More Than 24 Hours
Last Data In Less Than 24 Hours And More Than 10 Minutes
Last Data In Less Than 10 Minutes

IRIS GLOBAL SEISMOGRAPHIC NETWORK (GSN) (EQ INDEX 3,4,5)

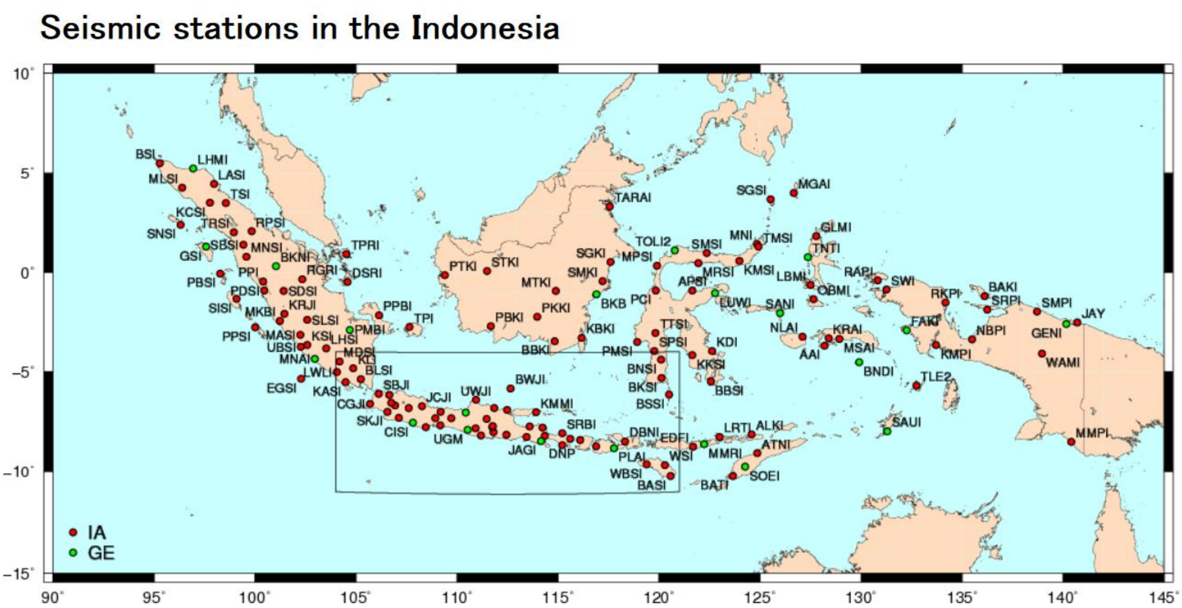


EQ INDEX 10

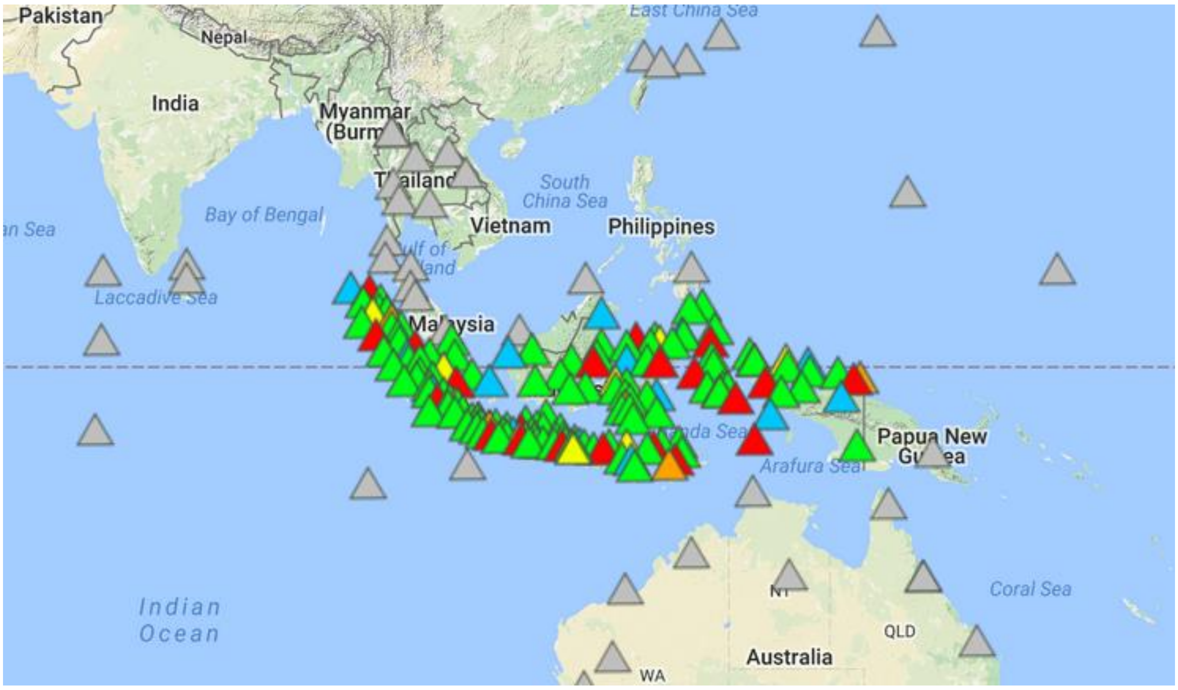


GEOFON NETWORK STATION MAP (EQ INDEX 12)

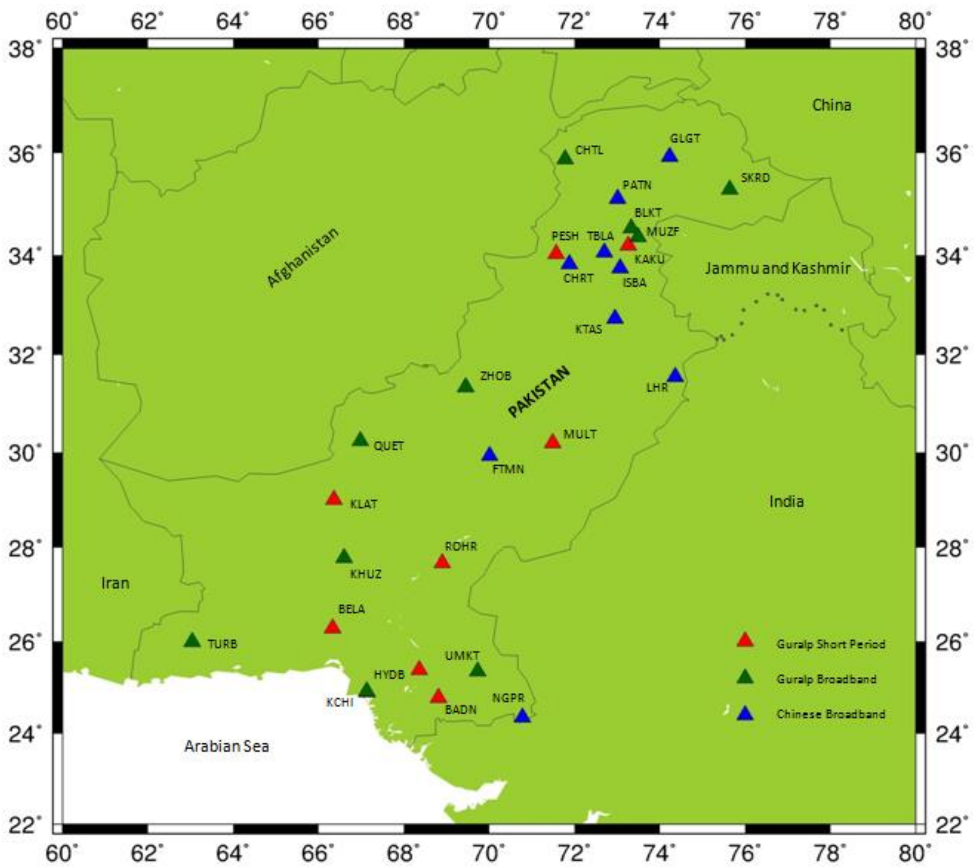
EMSC (EQ INDEX 10)



PETA SEISMIC STATION NETWORK USED BY BMKG (EQ INDEX 25)



PMD (EQ INDEX 26)



BMD DIGITAL SEISMIC REAL TIME MONITORING NETWORK (EQ INDEX 28)