CCRIF SPC
The Caribbean Catastrophe Risk Insurance Facility

The CCRIF Excess Rainfall (XSR 3.0) Model

PHOTO CREDIT: MINUSTAH

The CCRIF Excess Rainfall (XSR) Model and XSR Product

Caribbean and Central American countries are often exposed to the severe consequences of tropical cyclones and earthquakes. In addition to high winds and ground shaking, which are the primary effects of these events, secondary effects such as flooding, landslides, storm surge waves and tsunamis also pose a significant threat. Additionally, these countries are frequently affected by extreme precipitation events that are often, but not always, induced by tropical cyclones. The consequent losses are mostly caused by the accumulation of water over the land and, in the case of steep topography, by the high velocity of the water flowing over the land. These effects are further exacerbated by degraded ecosystems such as extensively urbanized areas or lands subject to intense deforestation.

Moreover, the vulnerabilities of these countries to weather-related natural hazards will likely worsen due to climate change. Climate change is expected to increase the average sea level, accelerate the erosion of coastal beaches, cause inundation of low-lying land and lead to the progressive loss of the protective coastal mangrove forests. Climate change also is expected to increase rainfall variability and rainfall extremes.

Since 2010, Caribbean governments have expressed strong interest in CCRIF developing and making available an excess rainfall insurance product to complement the existing hurricane and earthquake products and as a mean for reducing their rainfall risk. In 2013, CCRIF launched its excess rainfall product. Currently 20 member governments have purchased XSR coverage. Since the introduction of the product, CCRIF has made 34 payouts totalling US$66.4 million to 16 member countries on their XSR policies.

In 2016, CCRIF improved the existing rainfall model to achieve an increased accuracy of the near-real-time rainfall estimatesand to simplify the structure of the excess rainfall policy. The enhanced model was called the CCRIF Excess Rainfall (XSR) 2.0 Model. XSR 2.0, active since June 2016, has been partially updated to XSR 2.1 for the 2018/19 policy year, further updated to XSR 2.5 for the 2019/20 policy year, and finally updated to the XSR 3.0 model version for the 2023/24 policy year. XSR 3.0 model version introduces the following main improvements:

1) Updates of the **hazard** module which consist of: increased model resolution, inclusion of a satellite dataset, called IMERG, and two WRF[1] weather model configurations, called WRF11 and WRF15, respectively.
2) The update of the **exposure** module, which now includes cash crops.
3) The update of the **vulnerability** curves, which were adjusted to include the latest available data.
4) The introduction of a secondary vulnerability modifier to take into account **soil crusting.**
5) Review and optimization of the **loss** module to take into account the new rainfall datasets.
6) The development of two additional **policy features** to detect excess rainfall over saturated soil and extreme localized events.

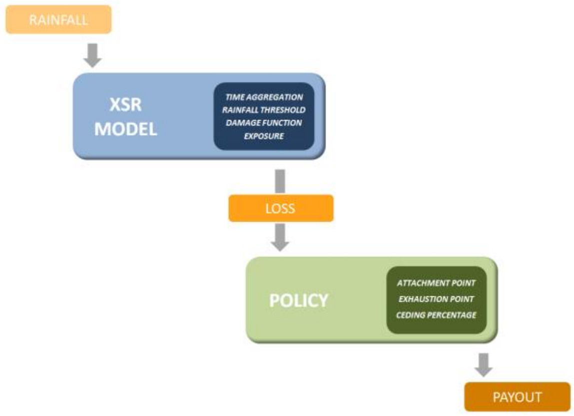
CCRIF's XSR model is aimed at reproducing the precipitation over a country in near real time and at estimating the potential consequent losses to the country assets such that, shortly after the end of an intense rainfall event, the country can receive a payout consistent with the CCRIF insurance policy conditions, whenever the XSR policy is triggered. Unlike traditional parametric insurance products, which are based only on rainfall parameters, the XSR model estimates rainfall-induced losses to the built environment. The XSR model is a flexible tool that provides options for managing the identified XSR risk according to the financial needs of each country.

Components of the CCRIF XSR Model 3.0

The XSR 3.0 Model is composed by the following modules:

- **Exposure Module**, which describes the built environment in each country;
- **Hazard Module**, which estimates the amount of rainfall over a country during the length of the storm;
- **Vulnerability Module**, which establishes relationships between aggregated rainfall and losses (i.e., the so-called vulnerability functions);
- **Loss Module,** which computes the modelled losses due to the rainfall event;
- **Insurance Module,** which – based on the policy conditions, specifically the attachment point, exhaustion point and ceding percentage – determines if a country policy is triggered and, if so, computes the payout to the country.

The conceptual flow of the XSR Model is shown in the figure below. The XSR model captures a rainfall event when the estimated rainfall threshold aggregated over a period of time (e.g., 12/48 hours) during the length of the rain event is exceeded on a sufficiently large portion of the exposure area.



The HAZARD Module: How frequent are XSR events?

The hazard module provides daily estimates of the precipitation over a large domain that includes the Caribbean and Central America regions. The daily estimates are derived in near real time through a combination of **numerical weather models** (the WRF Model initialized by the NCEP FNL[2] model, developed by the United States National and Oceanic and Atmospheric Administration - NOAA), which compute the amount of rainfall based on climate conditions, and of two **satellite-based precipitation models:** CMORPH[3], developed by the NOAA

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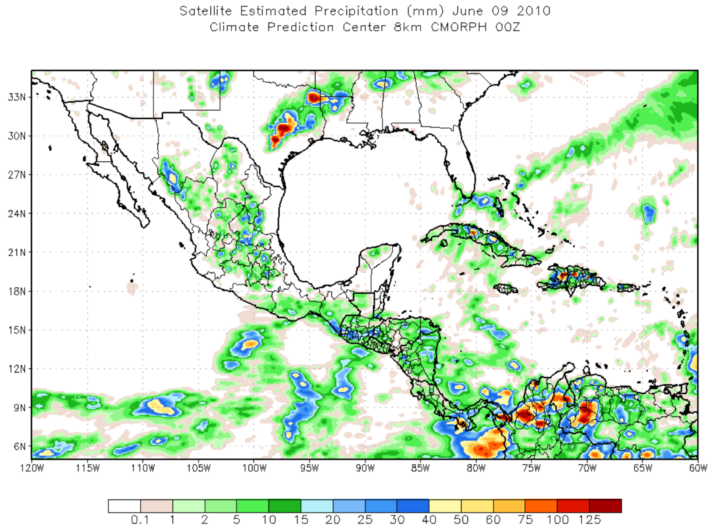
[1] *Weather Research and Forecasting*

[2] *National Center for Environmental Prediction (Final)*

[3] *Climate Prediction Center Morphing Technique*

Climate Prediction Center and IMERG[4], developed by NASA. The WRF models, which are weather forecast models, are able to capture the intensity of the rainfall event, while CMORPH and IMERG, which are based on satellite data, re able to identify more precisely the location of the rainfall caused by the event. Therefore, to take advantage of the strengths of both approaches, both satellite-based and model-based rainfall estimates are utilized. An example of daily rainfall estimates for June 9, 2010 estimated by NOAA using CMORPH is shown in the figure below.



An XSR event is determined by the amount of average rainfall over a sufficiently large portion of the exposure area that fell during an accumulation period of 12-48 hours in the Caribbean countries and of 24-72 hours in Central American countries. The number of accumulation hours and the value of the average rainfall amount are country-specific and were optimized to increase the likelihood that severe XSR events are captured by the model and moderate events are not falsely detected.

This procedure yields global precipitation estimates at low and medium resolution (8 and 4 km^2), which are subsequently downscaled to a higher resolution of 1 km^2 over the entire domain prior to their use as input to the loss computations for XSR events. The downscaling brings the precipitation at a level of granularity consistent with that of the exposure database of the XSR Model.

Methodology

Spatial domain

The spatial domain of the model comprises all the Caribbean and Central American countries.

The geographic boundaries are:

North	36.0°
South	0.0°
East	-49.0°
West	-98.0°

Model framework

The hazard module of the XSR 3.0 Model uses a probabilistic approach to reduce the inevitable inaccuracies associated with the rainfall estimates of the satellite-based and weather-forecast-based models. The hazard model produces six sets of rainfall estimates: four from different parameter configurations of the WRF model, one from CMORPH and one from IMERG respectively.

More precisely, a global climate model (NCEP FNL, see next paragraph for the details) initializes the regional weather forecast model (WRF, see next paragraph for the details),

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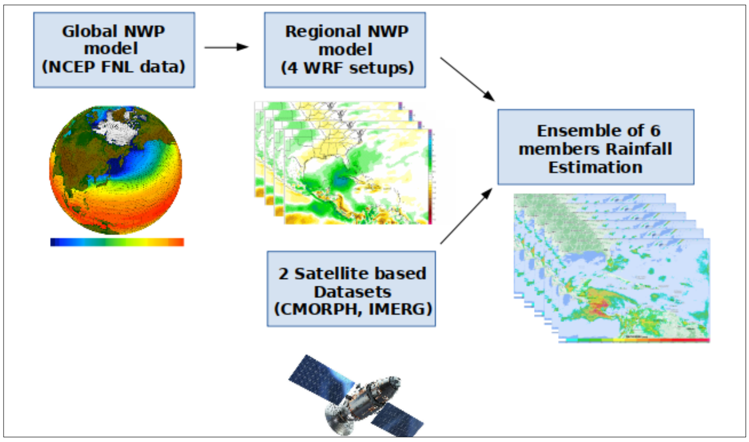
[4] *Integrated Multi-SatellitE Retrievals for the Global Precipitation Mission (GPM)*

which is run with four different configurations, called WRF5, WRF7, WRF11 and WRF15. The WRF7 and WRF15 configurations include the assimilation of observed ground and atmospheric data for an enhanced prediction of the precipitation. The WRF11 and WRF15 configurations are based on the standard setups provided by local hydro-meteorology agencies from the Caribbean and Central America[5], which complement the global input data already included in the XSR model.

The WRF configurations produce four rainfall estimates on a 3-hourly basis at a grid resolution of 8 km (WRF5 and WRF7) and 4 km (WRF11 and WRF15). Independently, the IMERG and CMORPH datasets provide precipitation estimates derived from satellite observations. These estimates are available on a grid with a spacing of 8 km and 10 km, for CMORPH and for IMERG respectively, and provide 3-hourly accumulated rainfall.



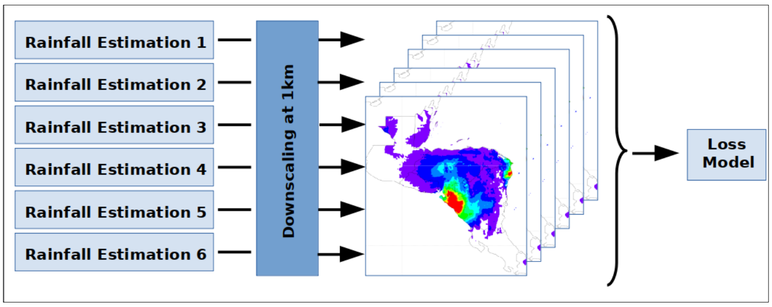
The six rainfall estimates are downscaled to a grid resolution of 1 km by means of an interpolation approach, based on revised Akima's method. The method is based on a piecewise function composed of a set of polynomials, each of degree three at most, and applicable to successive intervals of the given points. In this method, the slope of the curve is determined at each given point locally, and each polynomial representing a portion of the curve between a pair of given points is determined by the coordinates of and the slopes at the points.

The downscaled rainfall estimates are then passed to the loss module for the computation of the rainfall index loss.

The datasets and models

The initialization dataset: NCEP FNL

The NCEP FNL (Final) Operational Global Analysis data are available on 1-degree by 1-degree grid prepared operationally every six hours (see http://rda.ucar.edu/datasets/ds083.2/). This product is provided by the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources. The FNL data are made with the same model used by NCEP in the Global Forecast System (GFS) but are prepared approximately one hour after the GFS is initialized. The FNL data are delayed so that more observational data can be used. The GFS is run earlier in support of time-critical forecast needs and uses the FNL data from the previous 6- hour cycle as part of its initialization. The results are available on the surface, at 26 pressure levels from 1,000 millibars to 10 millibars in the surface at the boundary layer and at some sigma layers, the tropopause and a few others. Parameters include surface pressure, sea level pressure, geopotential height, temperature, sea surface temperature, soil values, ice cover, relative humidity, u- and v- winds, vertical motion, vorticity and ozone concentration.



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[5] *The Caribbean Institute for Meteorology and Hydrology (CIMH) and the Instituto National de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) of Guatemala respectively.*

Spatial resolution	1° (about 100 km)
Temporal resolution	6 hours
Time availability	-12 h
Inception year	1998
Precipitation estimation	NO

The weather forecast model: WRF model

The Weather Research and Forecasting (WRF) Model (http://wrf-model.org) is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It features two dynamic cores, a data assimilation system, and a software architecture that facilitates parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of metres to thousands of kilometres. The effort to develop WRF began in the latter part of the 1990s and was a collaborative partnership principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the (then) Forecast Systems Laboratory (FSL)), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA).

Main parameters
Advanced Research WRF version
641 x 481 horizontal points
30 vertical levels
Standard configuration
Different convection schemes

Spatial resolution	8 km/4km
Temporal resolution	3 hours

Satellite-based precipitation dataset: CMORPH

CMORPH (CPC MORPHing technique), whose detailed description can be found at http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html, produces global precipitation analyses at a very high spatial (8 km) and temporal (30 min) resolution. This technique uses precipitation estimates derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data." (source: RDA abstract on CMORPH). The rainfall data produced by CMORPH are available at ftp://ftp.cpc.ncep.noaa.gov/precip/global_CMORPH/30min_8km/.

Spatial resolution	0.077° (about 8 km)
Temporal resolution	30 min
Time availability	+18 h
Since year	1998
Precipitation estimation	YES

Satellite-based precipitation dataset: IMERG

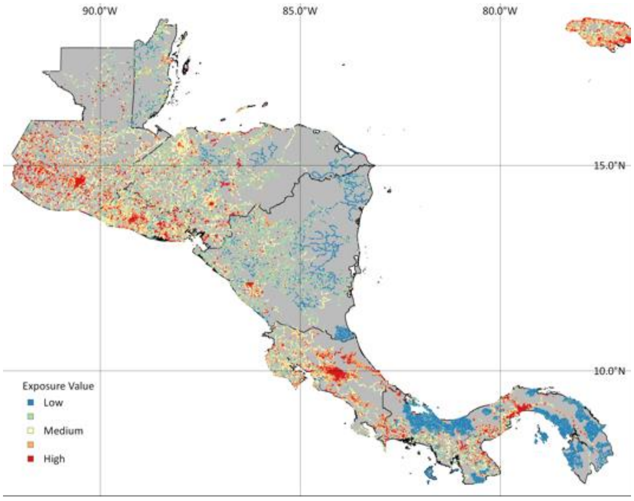
The Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm combines information from the GPM satellite constellation to estimate precipitation over the majority of the Earth's surface. This GPM satellites belongs to an international satellite mission led by NASA and the Japan Aerospace and Exploration Agency -JAXA, specifically designed to unify and advance precipitation measurements from research and operational microwave sensors for delivering next-generation global precipitation data products. Similarly to CMORPH, IR data from geosynchronous satellites is used to fill the gaps when the microwave data is not available for a long period of time. Finally, the native spatial resolution of the constellation is 0.1° x 0.1° (about 10km x 10km) with a 30-minute temporal resolution. The rainfall data produced by IMERG are available at: https://jsimpsonhttps.pps.eosdis.nasa.gov/imerg/late.

Spatial resolution	0.1° (~10 km)

Temporal resolution	30 min
Time availability	+14 h
Since year	2000
Precipitation estimation	YES

The EXPOSURE Module: Which assets are at risk and what are their values?

The exposure database is a comprehensive and spatially distributed list of vulnerable assets. Several attributes are associated with each asset, such as its physical characteristics (e.g., construction type and material and height classification), geographic location, use and replacement cost (or production value for crops). The exposure dataset has been enhanced by collating several sources of data up to 2017 related to the built environment and the surrounding topography, including the most recent available local data such as national building and population census surveys and land use/land cover maps, night-time lights maps, digital elevation maps and satellite imagery. The database provides estimates of the ***asset count and replacement cost*** **by structure class at a 30 arc second resolution (approximately 1x1 km^2).**



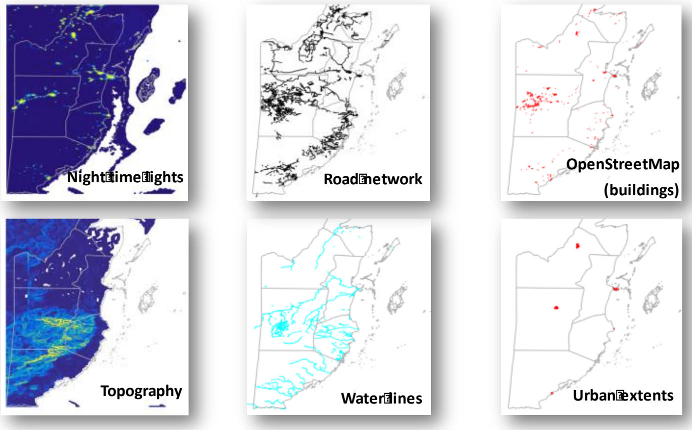
Methodology and datasets

The XSR 3.0 exposure module includes information about:

- Building stock:
  - Residential buildings
  - Commercial buildings
  - Industrial facilities
  - Public buildings
  - Hotels and restaurants
  - Healthcare infrastructure
  - Education infrastructure
- Infrastructure:
  - Energy facilities
  - Airports and ports
  - Transportation (road) network
- Crops:
  - 6 different crops (banana, maize, coffee, rice, sugar cane, and generic)

XSR exposure database is fully consistent with the exposure databases used in the other parametric insurance coverages offered by CCRIF (for example, the tropical cyclone and earthquake products).

The process by which the building stock and infrastructure exposure database was developed involves a number of steps, many of which leverage GIS tools and datasets. First, construction types are identified in each country. Next, a building inventory is carried out and economic values are assigned to the buildings on a country basis. The economic value, defined as the "replacement cost", which means the cost of returning the building to the conditions it was before the occurrence of an event, is usually not available and thus it is estimated through the use of proxy data such as technical studies and post-event reports. For example, reports compiled by local or sub-regional institutions about costs of construction are used to estimate the unit replacement costs for residential assets. Lastly, the distribution of exposure is estimated using independent data sources such as population. This process results in a gridded representation of the exposure distributed across each participating country.



Nighttime lights

A common dataset to distribute buildings within a given region is the nighttime lights layer (i.e., data regarding the light intensity during the night at a 30 arc-second resolution grid). This dataset is particularly useful to spatially distribute the commercial and industrial building stock, as there is a strong correlation between electrification and industrialization.

Land use

These datasets usually classify the territory of each country according to its use. Common categories are residential, industrial, commercial, farmland (agriculture), infrastructure and governmental/public facilities. Land use datasets are usually produced at a local level for urban planning purposes, at a regional level by request from a local government, or at a national level by open-access initiatives such as OpenStreetMap.

Digital Elevation Map (DEM)

The topography of a certain region has been used in the development of exposure information and risk models in three ways. Firstly, the elevation (usually relatively to the closest waterline) can be an important parameter in the assessment of losses due to floods or storms. Secondly, the slope of the terrain might be used as a proxy for human activity, as urban settlements tend to exist in flat areas (e.g., valleys and plains) as opposed to steep areas.

Roads

Datasets regarding transportation network for each country were collected. These datasets contain the spatial distribution of railways and roads, and the latter component is usually sub-divided into primary, secondary and tertiary roads. With the exception of the first type of roads (which are usually used to connect large urban centres), there is a strong correlation between the density of these roads and the presence of buildings. Several sources for this type of information can be found, from private companies (usually responsible for updating GPS maps) to publicly open initiatives such as Bing, Google, Digital Chart of the World, and OpenStreetMap.

Satellite imagery

The remote sensing data played a fundamental role in the urban density mapping. The images used in this exposure database were acquired by the optical ‘Landsat-8’ satellite. These are composed as follows: 8 multispectral bands at 30 m spatial resolution, 1 panchromatic band at 15 m spatial resolution, and 2 further thermal bands at 100 m spatial resolution (resampled at 30 m).

The method used to map urban density can be divided into three phases. The first phase consisted of collection of cloud-free data for the entire region of interest. In the second phase, the collected remotely sensed data were used to carry out the urban density mapping procedure. Finally, in the third phase, manual refining was performed over the entire region of interest.

OpenStreetMap data

OpenStreetMap (OSM) is a collaborative project founded in 2004 by the University College London, with the aim of creating a free geographic database of the entire world. Because many sources of geographic data are provided with licenses restricting its use, OSM’s data are distributed under the “Creative Commons Attribute-ShareAlike 2.0 license”, which allows freedom of use by the public. OSM is probably the most popular and successful volunteered geographic information initiative, as supported by recent investigations on its completeness and quality. OSM contains a plethora of spatial data such as roads, buildings, land use areas and points of interest, emphasizing the potential of its use in the development of exposure models globally.

Rivers and inland water

Areas where no buildings exist due to the presence of rivers or other inland water bodies (lakes, lagoons, etc.) need to be considered when defining the distribution of assets in space. This information can be found in several publicly-available datasets, suc ash the Digital Chart of the World, which was utilized for this effort.

Assessment of Crops

The XSR model exposure database also includes cash crops. Whereas subsistence crops are meant to support the producers or their livestock, cash crops are agricultural crops grown with the intended purpose of selling them for profit. Since cash crops are destined for future sale, they hold a relevant financial potential during their growth season, which is constantly in danger due to various types of threats, including weather-related threats.

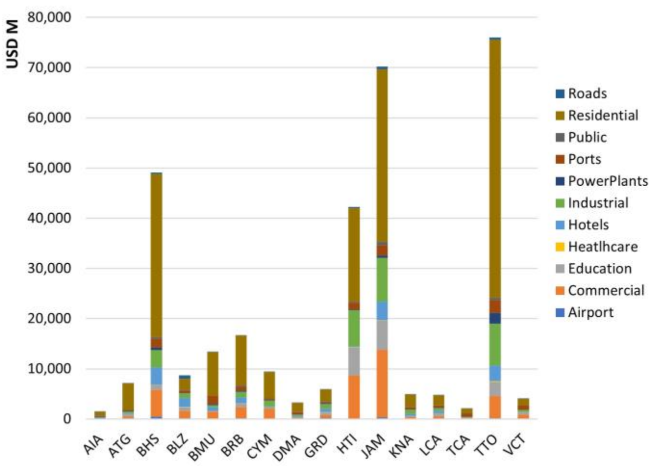
Within this framework, the XSR 3.0 aims at computing the losses caused by a rainfall event to the crop production of a country. In particular, XSR computes the direct losses in terms of lack or reduction of annual harvest, i.e., the difference between the expected annual crop production and the actual annual production, given that a rainfall event occurred and had an impact on agricultural areas. Losses to livestock are not included in XSR.

The implementation of a crop exposure database requires three basic steps:

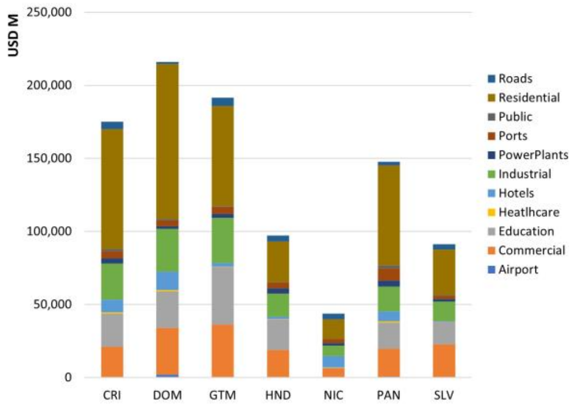
- Identification and geolocalisation of cultivated areas.
- Estimation of the expected crop yield.
- Estimation of the crop value.

Total exposure values

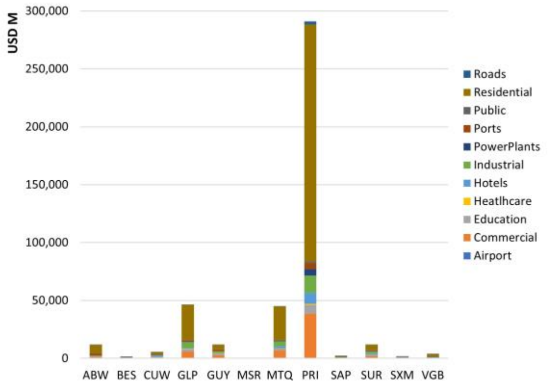
The resulting exposure values are displayed in the following figures.



Group 1 (CCRIF Caribbean member countries): replacement costs of the XSR 3.0 model partitioned in the different assets.



Group 2 (COSEFIN countries): replacement costs of the XSR 3.0 model partitioned in the different assets.



Group 3 (Other select countries): replacement costs of the XSR 3.0 model partitioned in the different assets.

The VULNERABILITY Module: What happens to the built environment in case of high-intensity rainfall?

The **archive of historical rainfall-induced regional losses** assembled by CCRIF provides useful information both on the severity and on the spatial and temporal distributions of such losses over different countries. Based on this database, **vulnerability analyses** were carried out to identify the consequences to the built environment when an excess rainfall event occurs.

The consequences of rainfall are modelled in mathematical terms by means of so-called **vulnerability functions**, which are relationships that provide estimates of the losses caused by different amounts of precipitation to the assets affected.

Methodology

The vulnerability functions developed for XSR 3.0 leverage country-level loss estimates from a variety of sources including some of the top providers of observed loss information such as Munich Re, Swiss Re, and Aon. In some cases, reported losses were adjusted for inflation and other economic factors (using the widely accepted Pielke scheme) and to account for the flood-induced portion of total loss for a multi-peril event (the other major peril being wind).

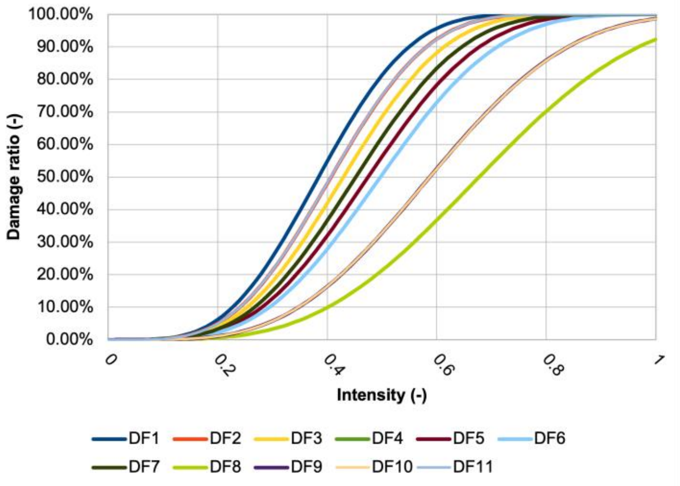
A vulnerability function for each level of vulnerability of building class was implemented to estimate the total loss due to an excess rainfall event using the metric of average rainfall intensity over the duration of the event. The vulnerability functions in XSR 3.0 were calibrated by means of observed data and vary as a function of the time aggregation period, the vulnerability class and the country. In the historical analysis, the reported country loss is divided by the replacement cost of the industry exposure database IED to obtain a regional loss ratio for each event corresponding to the average aggregated precipitation (mm/day) observed for that event.

Vulnerability functions

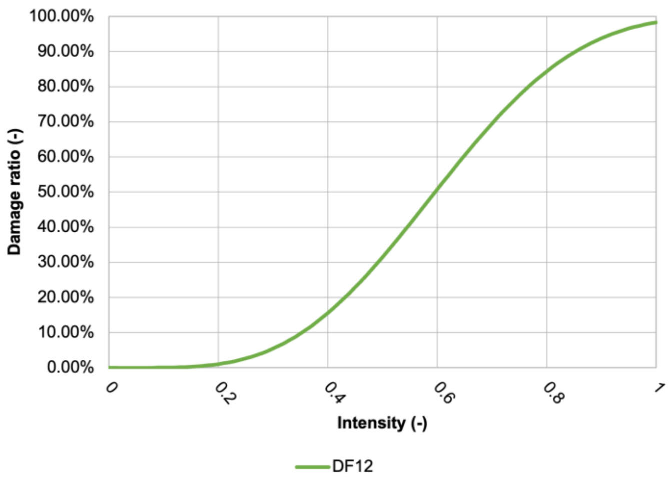
The damage functions were developed grouping the different building classes defined in the Exposure module, considering their behaviour in cases of extreme rainfall events. The building types with similar vulnerability to rainfall events were grouped, defining 11 different damage functions. An additional damage function is reserved to cash crops, for a total of 12 different damage functions.

Because the flooding characteristics of the Caribbean region (smaller countries surrounded by water with small flood plains) differ from those of Central America (larger regions with larger flood plains), the averaging time for rainfall accumulation is set to 12 - 48 hours for the Caribbean countries and to 24 - 72 hours for Central American countries (two different aggregation periods are employed, as explained in the Methodology section). The different rainfall accumulation time leads to a different maximum damage ratio value.

The two panels below show the standardised vulnerability curves differentiated by asset category (DF1-11) and for crops (DF12) respectively.



Standardised vulnerability curves, differentiated by asset category.



Standardised vulnerability curve for the crops category.

Soil Oversaturation

Extremely wet periods may lead to unexpected levels of damages due to the quick response of the soils. In fact, long periods of rainfall cause the soils to be saturated or close to saturation, if a rainfall event occurs when the soils are almost saturated only a small portion of the precipitation is able to infiltrate into the soils, while most of it quickly flows on the surface and the rivers, significantly increasing the probability of catastrophic floods.

To account for soil oversaturation prior to an extreme rainfall event, a secondary vulnerability modifier was introduced. This modifier is activated when the SPI-1[6] is above a certain threshold, indicating that the soil might be saturated due to antecedent rainfall and the rainfall might cause more damage than expected. When the SPI-1 is above the SPI-1 threshold, the damage factor is multiplied by the secondary modifier.

Soil Crusting

Soil crusting refers to the condition where, following an exceptionally dry period, the top layer of soil becomes compact and hard, reducing its ability to absorb water. During heavy rainfall, soil crusting prevents the infiltration of water leading to increased runoff and the formation of flash floods which can cause significant damage to buildings, infrastructure, and crops.

To account for soil crusting prior to an extreme rainfall event, the XSR 3.0 model introduces a secondary vulnerability modifier activated by the SPI-6[7]. A low SPI-6 value indicates that prolonged dry conditions may have reduced the soil's absorption ability and increased the risk of flash floods and related damage during extreme rainfall events. When the SPI-6 is below the SPI-6 threshold, the damage ratio is multiplied by the secondary modifier.

The LOSS Module: What are the losses caused by an XSR event?

The loss module computes in near real time after an XSR event has ended whether the precipitation estimated by the hazard module could potentially cause significant losses to the exposure assets that are located in the footprint of the event. Based on rainfall estimates, exposure values in the event footprint and vulnerability functions, the XSR model computes for significant events a synthetic loss index called the **Rainfall Index Loss (RIL)**, which represents the modelled total loss due to the XSR event.

Methodology

The loss module is structured in 2 steps

1. Covered Area Rainfall Event (CARE) definition
2. Rainfall Loss Index (RIL) computation

1. Event Definition

In normal conditions, the CARE (Covered Area Rainfall Event) definition is based only on rainfall estimates from CMORPH, which is the dataset most likely to detect an excess rain event. However, if a Disaster Alert is issued by ReliefWeb and CMORPH does not identify a CARE within a window of 7 days around the date of the Disaster Alert issuance, the model allows the CARE to be triggered also by one of these three datasets: IMERG, WRF11 and WRF15. A CARE occurs for a given country if threshold values of the following two parameters are jointly exceeded during a country-specific aggregation period:

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[6] *The Standardized Precipitation Index calculated over 1 month*

[7] *The Standardized Precipitation Index calculated over 6 months*

- Aggregation period (e.g., 12/48 hours for Caribbean countries and 24/72 hours for Central American countries)
- Rainfall depth (e.g., 40 mm over 12 hours).
- Area threshold (e.g., 15% of all the 1km x 1km exposure cells in a country with rainfall intensity above threshold for the aggregation period).

Two aggregation periods are used, i.e., the CARE can be activated either by a short (12 hours in the Caribbean, 24 hours in Central America) and very intense precipitation or by a longer and less intense event (24 hours in the Caribbean, 72 hours in Central America).

This set of threshold values is collectively called CARE criteria. Once the CARE criteria are met the CARE starts. This is called the CARE start date. The CARE ends when the CARE criteria are no longer met. The day on which the CARE terminates is called the CARE end date. Note that the CARE is not interrupted if the CARE criteria are not met for a country-specific tolerance period (TP) after the CARE start date. The number of days between the CARE start date and the CARE end date is called the CARE length.

Hence, for each country the definition of a CARE is fully and unambiguously defined by four values: the aggregation period, the rainfall intensity, the minimum cell fraction and the tolerance period.

If a Disaster Alert is issued and CMORPH does not meet the criteria to trigger a CARE within a window of 7 days around the Disaster Alert date, the same procedure is repeated using the precipitation estimated by IMERG, WRF11 and WRF15. Therefore, the CARE is triggered if any of the three precipitation models meet the conditions mentioned above.

The CARE criteria essentially serve the purpose of a primary trigger. If an XSR event does not meet the CARE criteria, the second and the third steps of the methodology will not be executed.

2. Rainfall Loss Index (RIL) Computation

RIL computations are performed only for CAREs. The RIL is not computed for rainfall events that do not meet the CARE criteria.

RIL computations are carried out using three rainfall estimates extracted from the following models:

1. CMORPH
2. IMERG
3. WRF Configuration 5, called WRF5
4. WRF Configuration 7, called WRF7
5. WRF Configuration 11, called WRF11
6. WRF Configuration 15, Called WRF15

For each one of the six sets of rainfall estimates the RIL computations are performed according to the procedure described below.

For each exposure cell in the country (not only those that activated the CARE) the amount of rain in each aggregation period during the CARE length is extracted from CMORPH and the maximum value is stored (e.g., 120 mm in 2 days). This maximum value averaged over the aggregation period (e.g., 60 mm/day) is retained for the RIL computation. This value is called the Cell Rainfall Index. This value is used to compute the Cell Loss Rate from the Loss Rate table (which simply reproduces the vulnerability function in tabular form) published in the policy document. Two cell loss rates are computed for each cell, one for each of the two aggregation periods. Only the maximum value is retained. The Cell Loss Rate is multiplied by the value of the public asset exposure in that cell to produce the Cell Loss value. This procedure is repeated for each exposure cell in the country (note that for some cells the Cell Loss value may be zero if the rainfall was low or absent). The RIL for this CARE is simply the sum of the Cell Loss values for all the exposure cells in the country.

The procedure above produces six RILs, one for each of the six rainfall prediction models, namely $\text{RIL}_{\text{CMORPH}}$, $\text{RIL}_{\text{IMERG}}$, RIL_{WRF5}, RIL_{WRF7}, $\text{RIL}_{\text{WRF11}}$ and $\text{RIL}_{\text{WRF15}}$ that are used as input to the final loss index (RIL_{Final}) computation procedure. The final loss index computation is based on two factors:

1. Loss Threshold (LT): a country-specific loss threshold, which is calibrated in order to minimise the basis risk and to discard false positive events. It is also set such that a significant number of events (typically, more than one every two years) is produced.
2. Disaster Alert (DA): this is an official alert issued by ReliefWeb (http://reliefweb.int/) for events of

different kinds that occur around the world. ReliefWeb issues alerts for more than 20 types of events ranging from epidemic outbursts to earthquakes. ReliefWeb's archive of disaster alerts starts in 1981 although in the 1990s the number of alerts issued significantly increased. The types of events that are relevant to the CCRIF XSR product are: tropical cyclone, flood, flash flood and severe local storm. All major XSR-related events that affected Caribbean and Central American countries have had disaster alert issued by ReliefWeb.

In essence, *LT* and *DA* serve as secondary triggers, together with the estimation of the RIL_{CMORPH}, RIL_{IMERG}, RIL_{WRF5}, RIL_{WRF7}, RIL_{WRF11} and RIL_{WRF15} values. The RIL_{Final} is computed as follows:

1. If a Disaster Alert is not issued:

   If $RIL_{CMORPH} > LT$ and/or $RIL_{IMERG} > LT$, and

$$\sum_{i}^{6} f(RIL_i) \geq 3\,,$$

where RIL_i is the Rainfall Index Loss given by the *i*-th of the six adopted rainfall datasets and

$$f(RIL_i) = \begin{cases} 1, RIL_i > LT \\ 0, RIL_i \leq LT \end{cases},$$

then

$$RIL_{Final} = \sum_{j}^{N} \frac{RIL_j}{N}\,,$$

where RIL_j is the Rainfall Index Loss given by the *j*-th of the *N* rainfall datasets where $RIL_j > LT$. Therefore, if the Rainfall Index Losses given by at least 3 of the 6 rainfall datasets, among which CMORPH and/or IMERG, are greater than *LT*, RIL_{Final} is computed as the average of the *RIL*s that exceed *LT*.

2. If a Disaster Alert is issued:

   a. If

$$\sum_{i}^{6} f(RIL_i) \geq 1\,,$$

where RIL_i is the Rainfall Index Loss given by the *i*-th of the six adopted rainfall datasets and

$$f(RIL_i) = \begin{cases} 1, RIL_i > LT \\ 0, RIL_i \leq LT \end{cases},$$

then

$$RIL_{Final} = \sum_{j}^{N} \frac{RIL_j}{N}\,,$$

where RIL_j is the Rainfall Index Loss given by the *j*-th of the *N* rainfall datasets where $RIL_j > LT$.

   b. If

$$\sum_{i}^{6} f(RIL_i) = 0\,,$$

where RIL_i is the Rainfall Index Loss given by the *i*-th of the six adopted rainfall datasets and

$$f(RIL_i) = \begin{cases} 1, RIL_i > LT \\ 0, RIL_i \leq LT \end{cases},$$

then

$$RIL_{Final} = \sum_{i}^{6} \frac{RIL_i}{6}.$$

Therefore, RIL_{Final} is computed as the average of the *RIL*s that exceed *LT*, except in the case where no value of *RIL* is greater than *LT*, in which RIL_{Final} is computed as the average of all *RIL*s. A simplified version of the RIL calculation scheme is shown in the panel below.

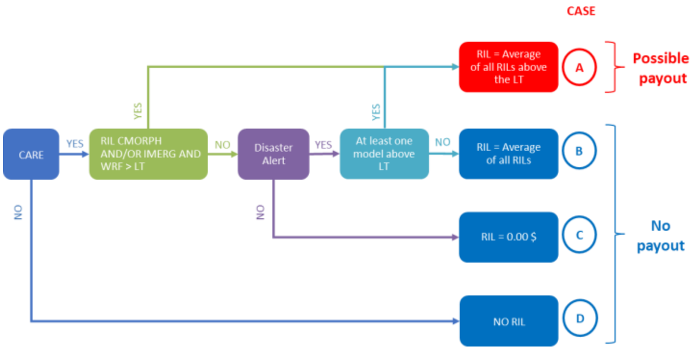


Diagram of loss calculation with all possible cases

The INSURANCE Module: Which parameters determine the payout of an XSR event?

The insurance module uses the model loss estimates to compute the payout to each country affected by an XSR Loss Event. In all the three cases (a, b and c) of the RIL computation as described in the previous section, the final RIL is compared with the values of the Attachment Point and Exhaustion Point of the policy. If RIL<AP then the payout is zero otherwise the payout is computed using the approach described below.
The payout depends on the values of a set of four parameters specified in the XSR insurance policy of each insured country:

The **Attachment Point (AP)** represents the loss that a country decides to retain before any insurance payout begins and is similar to a “deductible” in a standard insurance policy.

The **Exhaustion Point (EP)** is the loss value at which the full insurance payout is due.

The **Ceding Percentage (CP)** is the fraction of the difference between the exhaustion point and the attachment point that the insured country transfers to CCRIF.

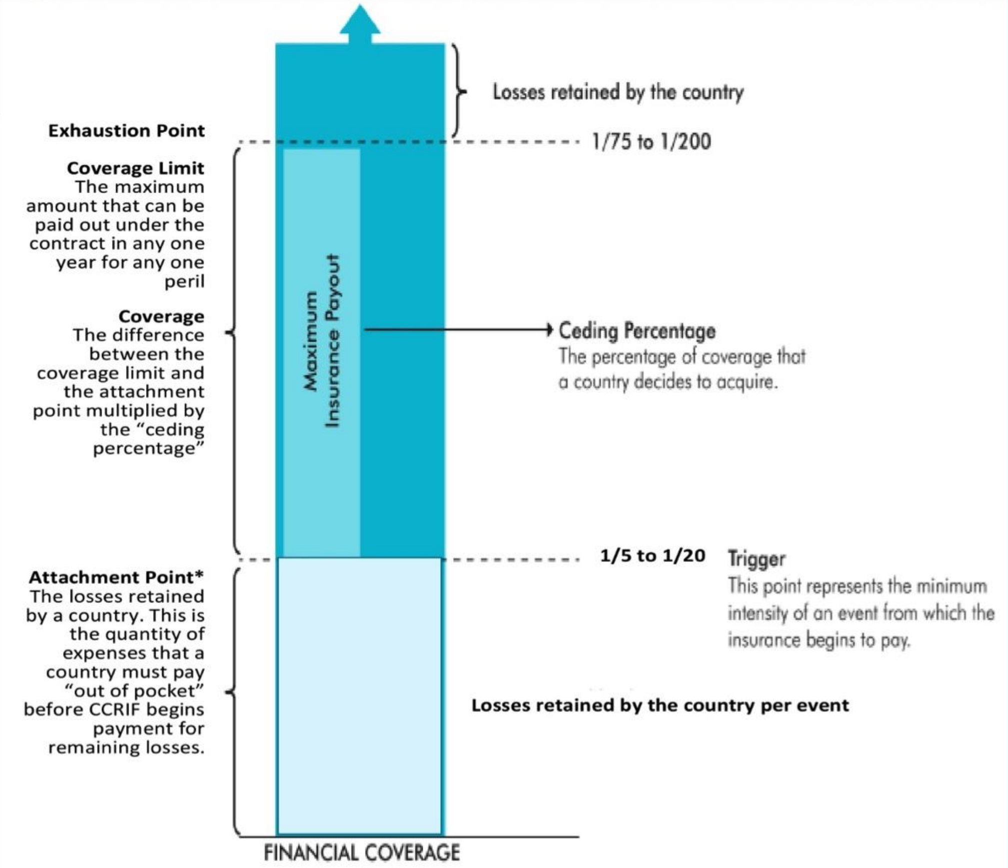
The **Coverage Limit (CL)** is the maximum amount that can be paid out to an insured country in any one year of coverage.

A country’s policy is triggered only when the RIL_{Final} for the XSR event is equal to or exceeds the attachment point and, therefore, there is no payout below this point. If the RIL_{Final} is greater than the AP then the payout is computed in two steps. First the Event Payout Rate is calculated as follows:

$$Event\ Payout\ Rate = \frac{RIL_{Final} - AP}{EP - AP}$$

Then the payout equals the lesser of: (a) the Event Payout Rate multiplied by the Coverage Limit, or (b) the Event Payout Limit. In respect of any Insured Event, the Event Payout Limit is defined as the Coverage Limit less any policy payments previously made during the policy period. The maximum payout that an insured country can receive after any XSR event is equal to the exhaustion point minus the attachment point times the ceding percentage (see figure below).

The values of these four insurance policy parameters are crafted to provide the best possible coverage that meets the country’s risk mitigation needs. Once the attachment point and exhaustion point are chosen, there is a one-to-one relationship between the amount of premium paid and the ceding percentage – a higher ceding percentage means a higher premium. CCRIF insurance covers only the government losses, which are determined as a percentage of the national losses.



*The attachment point can be described as the minimum severity of the event loss which gives rise to a payment and therefore is the loss value at which the policy contract is triggered. The attachment point therefore functions like a deductible in a standard insurance policy.

Why are risk transfer tools becoming increasingly important?

Risk transfer mechanisms constitute an important part of disaster risk management (DRM) and climate resilience strategies. It is important for countries to engage in a range of strategies to reduce their vulnerabilities and to develop dynamic and first-class DRM policies and strategies. Risk transfer mechanisms must therefore be seen as one part of a country's broader DRM policy mix.

The use of risk transfer mechanisms constitutes pre-event planning and ensures that countries take a proactive, comprehensive and sustained approach to DRM. These types of mechanisms are becoming increasingly important and are an indispensable component of economic policy and disaster risk management strategies as countries seek to grow their economies, reduce poverty and become internationally competitive.

About CCRIF

In 2007, the Caribbean Catastrophe Risk Insurance Facility was formed as the first multi-country risk pool in the world and was the first insurance instrument to successfully develop parametric policies backed by both traditional and capital markets. It was designed as a regional catastrophe fund for Caribbean governments to limit the financial impact of devastating hurricanes and earthquakes by quickly providing financial liquidity when a policy is triggered.

In 2014, the facility was restructured into a segregated portfolio company (SPC) to facilitate offering new products and expanding into geographic areas and is now named CCRIF SPC. The new structure, in which products are offered through a number of segregated portfolios, allows for total segregation of risk.

In 2015, CCRIF expanded to Central America, when CCRIF and COSEFIN (the Council of Ministers of Finance of Central America, Panama and the Dominican Republic) signed a Memorandum of Understanding to provide catastrophe insurance to Central American countries. Also at that time, Nicaragua signed a Participation Agreement, becoming the first CCRIF member from Central America.

CCRIF currently offers earthquake, tropical cyclone and excess rainfall policies to Caribbean and Central American governments. Since the inception of CCRIF in 2007, the facility has made 58 payouts totalling approximately US$260 million to 16 member governments.

CCRIF was developed under the technical leadership of the World Bank and with a grant from the Government of Japan. It was capitalized through contributions to a Multi-Donor Trust Fund by the Government of Canada, the European Union, the World Bank, the governments of the UK and France, the Caribbean Development Bank and the governments of Ireland and Bermuda, and membership fees paid by participating governments.

In 2014, another MDTF was established by the World Bank to support the development of CCRIF SPC's new products for current and potential members, and facilitate the entry for Central American countries and additional Caribbean countries. The MDTF currently channels funds from various donors, including: Canada, through Global Affairs Canada; the United States, through the Department of the Treasury; the European Union, through the European Commission; Germany, through the Federal Ministry for Economic Cooperation and Development and KfW; and Ireland. In 2017, the Caribbean Development Bank, with resources provided by Mexico, approved a grant to CCRIF SPC to provide enhanced insurance coverage to the Bank's Borrowing Member Countries.

The current members of CCRIF are:
Caribbean – Anguilla, Antigua & Barbuda, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts & Nevis, Saint Lucia, Saint Vincent & the Grenadines, Sint Maarten, The Bahamas, Trinidad & Tobago and Turks & Caicos Islands
Central America – Guatemala, Nicaragua and Panama