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Dream project: Applications of earth observations to disaster risk management[☆]

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ABSTRACT

The field of disaster risk management is relatively new and takes a structured approach to managing uncertainty related to the threat of natural and man-made disasters. Disaster risk management consists primarily of risk assessment and the development of strategies to mitigate disaster risk. This paper will discuss how increasing both Earth observation data and information technology capabilities can contribute to disaster risk management, particularly in Belize. The paper presents the results and recommendations of a project conducted by an international and interdisciplinary team of experts at the 2009 session of the International Space University in NASA Ames Research Center (California, USA). The aim is to explore the combination of current, planned and potential space-aided, airborne, and ground-based Earth observation tools, the emergence of powerful new web-based and mobile data management tools, and how this combination can support and improve the emerging field of disaster risk management. The starting point of the project was the World Bank's Comprehensive Approach to Probabilistic Risk Assessment (CAPRA) program, focused in Central America. This program was used as a test bed to analyze current space technologies used in risk management and develop new strategies and tools to be applied in other regions around the world.

1. Introduction

Every year, disasters of high severity occur that destroy lives and impoverish communities. The field of disaster risk management is a key component in management of these events.

To address this issue, this paper summarizes the findings of the ISU SSP 2009 Team Project, titled Disaster Risk Evaluation And Management (DREAM) which has established as a goal the extension of the current capabilities of World Bank's Comprehensive Approach to Probabilistic Risk Assessment (CAPRA) initiative by employing both space-aided and ground-based technologies to evaluate risk, minimize vulnerability, and mitigate the adverse effects of disasters in Central America. A cost–benefit analysis identifies available space-, ground-based and in-situ sensors, systems and technologies best suited for providing raw data to the CAPRA modules. A risk assessment is performed generating outputs that are fed back to public and

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governmental outreach programs as well as providing inputs to key decision-making policies.

This project provides the World Bank with a set of recommendations to enhance the capabilities of the CAPRA initiative that was launched in 2007. CAPRA initially targeted Central American countries. It is our hope that these disaster risk management (DRM) strategies may eventually be applied on a global scale. In particular, Belize, as seen in Fig. 1, has been chosen as a manageable, yet representative test bed for the project approach that can be extended to other disaster-prone regions.

Fig. 1. Belize and Central America (CIP, 2009).

This paper is organized as follows. Section 2 describes the scope and approach of the DREAM project. Section 3 gives an overview of hazards, exposure and vulnerability and how this is being used in CAPRA. Section 4 defines the risk evaluation strategies and Section 5 gives an overview of the computer applications to be used in DRM. Section 6 discusses business development and the DRM strategy. Section 7 deals with policy and law issues on data ownership. Section 8 presents an outreach strategy. Section 9 discusses the Belize case study. The report concludes with the recommendations presented in Section 10.

2. Dream project–scope and approach

The approach to be taken in this project is depicted in Fig. 2 showing the overall scenario of information flow across each important block in what is called the CAPRA 2.0 architecture after the original work (CAPRA 1.0).

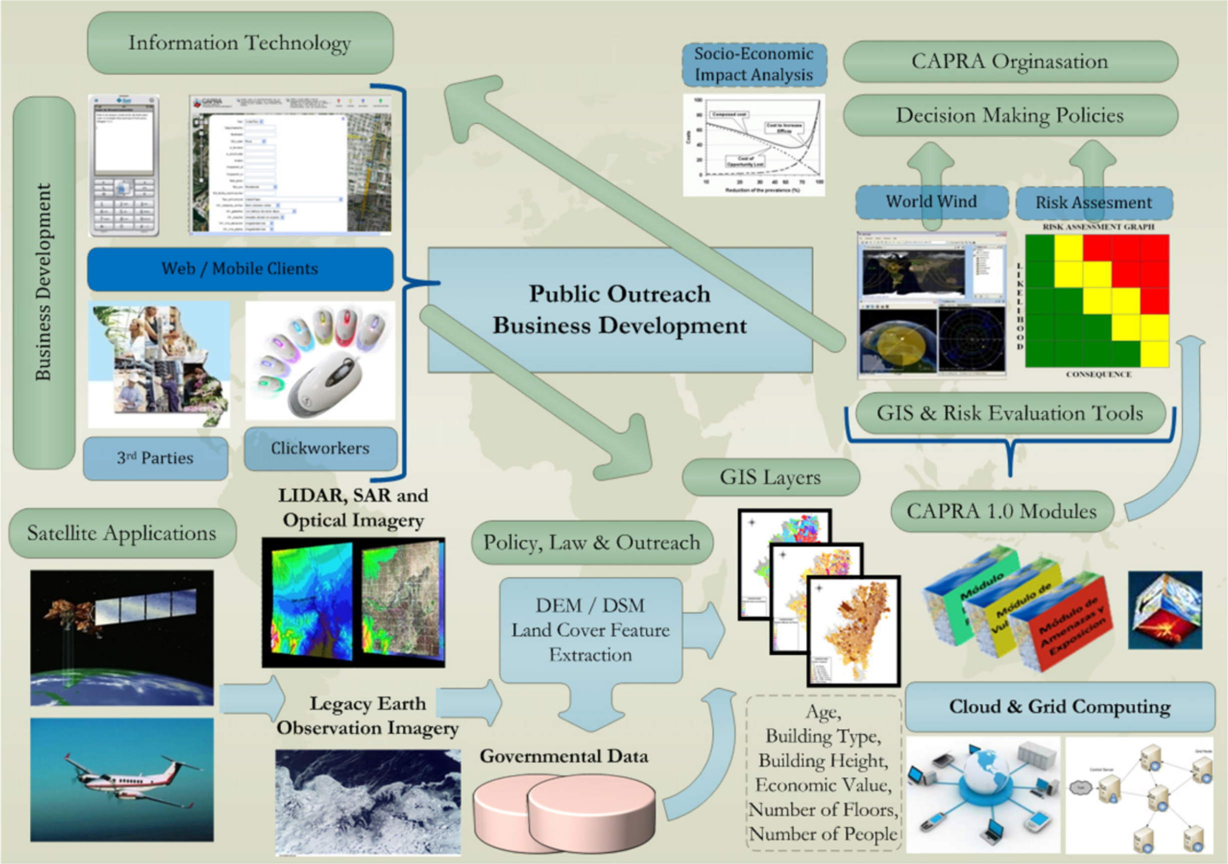

Fig. 2. CAPRA 2.0 architecture.

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The approach taken involves:

- An identification of space-aided, airborne, ground-based, and in-situ sensors, systems, and technologies best suited to provide raw data to CAPRA models.
- A review of the existing parameters for performing the risk analysis with CAPRA 1.0 and an identification of new parameters.
- A review of software requirements for integrating web-based and mobile-based applications into CAPRA 1.0.
- Guidelines for promotion of training and education in the areas of disaster prevention and mitigation.
- A strategic plan for collaboration between companies, agencies, organizations, and governments.
- A road-map to address the legal issues concerning data ownership.
- A road-map for public and governmental outreach as well as awareness concerning the usefulness of investing in risk assessment.
- A case study on Belize applying the findings of this report to this region.

The current capabilities of CAPRA have been extended in several ways. The key parameters necessary for DRM will be evaluated and new parameters have been identified. These parameters describe exposure and vulnerability for hazards and assets that are essential to characterize the models used for DRM. Afterwards, current and future technologies have been identified to determine the data that can be used as input parameters to describe risk model input data. These technologies cover space-aided, airborne, and ground-based assets. As each method has its advantages and disadvantages, the main factors that influence the choice of a specific method are: time, credibility, flexibility, and cost.

Analyzing space-aided technologies, this paper in particular discusses how satellites, that have instruments to provide data supporting disaster risk management, are at the focus of the work. We will specify the type of data that can be used in situ and later during and after the post-processing stages. A discussion on the application of LIDAR sensing in DRM is also presented.

Ground-sensing discussions have been focused on techniques to acquire data and share the resulting information with public and governmental outreach. The legal aspects of acquisition, storage, and sharing of data are analyzed, and the key applicable legislation identified. Risk identification policies used by local governments of the prospective affected areas are very important for the project. Recommendations to those governments, particularly Belize, are made to address this aspect. In order to evaluate project feasibility, a cost–benefit analysis is performed through initial research, method proposal, and final evaluation.

The detailed development of all these major points is covered in the following sections.

3. Generating inputs for risk evaluation

The generation of valuable data for CAPRA is fundamental for risk assessment. As shown in Fig. 3, the project focused on three sources of this data—satellite technologies, airborne

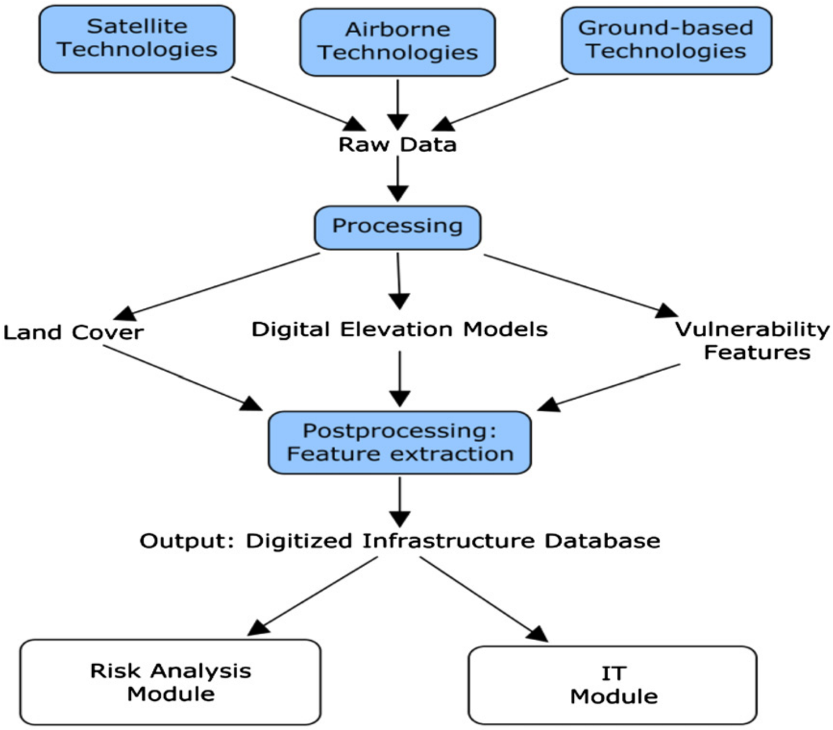

Fig. 3. Process schematics.

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technologies, and ground-based technologies. Each technology has its advantages and disadvantages and an approach that incorporates data from all three sources provides optimal performance. The project uses three different data generation methods. Digital elevation models provide image data on the height of both the terrain and buildings, and are key elements to effective vulnerability analysis. Feature extraction is a process by which simple unprocessed data from satellites is turned into meaningful vector images that can provide information on the asset type (i.e. wall material). Determining land cover and use is a final key component to assess risk potential to rural areas. The specific methods used to collect this data are detailed in the following section.

3.1. DEM generation

Digital elevation models (DEM) are an essential component of the proposed CAPRA 2.0 framework, since they enable accurate terrain analysis (useful in case of floods or landslides) and efficient infrastructure extraction. Our study concerned two types of digital models:

- Digital surface models (DSM) illustrate man-made infrastructure and is used for urban areas exposure and vulnerability analysis.
- Digital terrain models (DTM) illustrate Earth's surface and are used primarily for landslides and flood risk analysis.

Preliminary analysis has shown that digital models for populated areas (urban, rural riversides, and steep slope neighborhoods) require high horizontal resolution data (~1 m) and high vertical accuracy (~50 cm). Uninhabited areas (i.e. jungle) necessitate much less precise data (~30 m). In this context, the acquisition techniques for DEM generation were studied accordingly.

3.2. Acquisition techniques

LIDAR (light detection and ranging) uses light (ultraviolet, visible, or near-infrared) waves to estimate the distance to reflected objects. A LIDAR device can be installed on an airborne vehicle or car and maps the relevant areas according to two detection schemes: incoherent (based on round trip travel time) and coherent (based on analysis of phase shift and Doppler effect). LIDAR provides very high-resolution models (up to 15 cm of vertical accuracy) but it requires high acquisition times and costs.

Stereoscopic imaging uses binocular vision to produce overlapping photographs (two different angles) of an area [1] which, employing the parallax concept, can give a three dimensional model.

Interferometric synthetic aperture radar (InSAR) uses two or more synthetic aperture radar (SAR) images, from airborne or space sensors. These images can be used to determine elevation by analyzing differences in the phase of the waves returning to the instrument. The primary advantage of InSAR methods is that the elevation of each pixel is determined independently, unlike in stereoscopic DEM where individual pixels are binned into. However, InSAR is highly sensitive to sensor motion and speckle (granularity in the image).

The raw data acquired from the aperture has to be meticulously processed in order to eliminate geometrical distortions and measurement inaccuracies. For instance, due to aircraft positioning and attitude systems inaccuracies, the raw LIDAR dataset is "skewed", and bundle adjustment algorithms have to be used to address this problem. Both state-of-the art research and commercial solutions indicate that none of the aforementioned methods can be used in isolation. The most accurate and valuable models are generated through the combination of cartographic data, monoscopic images, low-resolution fluffy stereoscopic DEMs and the LIDAR data. This strategy allows for the most reliable automated feature extraction.

3.3. Feature extraction

Building features such as height and construction type are central to determining the strength and the resilience of buildings that are exposed to natural disasters. Given the potential scalability factor of the project, the research on feature extraction was mainly focused on automated methods, since diligent manual post-processing is known to be very costly.

3.4. Building geometrical characteristics

CAPRA's exposure and vulnerability analysis modules require precise information about the building height, area and roof type in order to estimate, for example, economical value or hurricane impact consequences. This knowledge should preferably be provided through reliable automated building feature extraction, which in turn necessitates high-quality DSMs.

Different research institutes around the world have developed ingenious extraction methods: Institut Geographique National (IGN) uses proprietary method Bati-3D® based on high precision aerial photogrammetry and is capable of providing 3D city models with up to 10 cm precision; UC Berkeley Visualization MURI merges aerial and car-based LIDAR data; ETH Zurich Institute for Geodesy and Photogrammetry combines aerial imagery and LIDAR.

Most of the aforementioned methods necessitate some kind of segmentation preprocessing. Pre-existing information about the buildings' position can be drawn from cadastral maps or road/street infrastructure. Lafarge et al. [2] use high-resolution 2D satellite imagery to propose a comprehensive approach in which building footprints are derived through the so-called marked point processes into rectangular layouts. This information allows 3D automated extraction algorithms to achieve ~80–90% reliability in densely populated areas. In order to obtain 100% detection rate, the remaining 10–20% of unrecognized structures have to be post-processed manually.

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3.5. Other feature extraction

Remote sensing can potentially offer the extraction of another type of information. For instance, spectral imaging (SI) utilizes sensors to analyze the reflectance of different wavelength bands in the visible and infrared (IR) spectrum in order to read the target specific signature (i.e. wall or roof type), and remotely identify the material. The two key properties for spectral imaging systems are the spatial and spectral resolution. However current operational sensors are limited in their ability to take advantage of both properties simultaneously. Identifying building roof materials requires both high spatial resolution (to distinguish between the relatively small features in an urban scene) and high spectral resolution (to separate materials with similar spectral signatures). Since today only few experimental (and technologically unreliable) hyper-spectral systems exist, this method shall be of less use for the CAPRA 2.0 model in the near future.

Another determining factor of building strength that could be extracted is the structure age. This parameter can be obtained from public records and comparison of temporal remote sensing pictures. By using high spatial resolution pictures (i.e. IKONOS) taken over time and relatively simple algorithms it is possible to compare the pictures to locate new building mass.

3.6. Land cover

Improving the exposure datasets for DRM requires detailed information about the land cover and its use. Regionally, major focus areas were cities, forests, and crops, and on the extraction of features (e.g., main rivers and transportation axes) from satellite images. At the urban scale, we evaluated the possibility to assess the main socio-economic resources of a city. This qassessment includes the identification of various types of elements including residential, commercial and industrial areas, transportation networks, vegetation, and green space.

The land cover recognition is based on the same principle as material based recognition described in the previous section, however requires much lower spatial and spectral resolutions. Optical space-borne sensors have traditionally been employed for these ends [3] because they offer multispectral imaging allowing for sufficient discrimination, are easier to process, and, finally, they provide sufficient spatial resolution. The use of space- or airborne radar for land cover analysis has also been studied [4]. The resulting remote sensing data is then examined and classified with the use of classical and machine learning algorithms [5].

Our study has been focused on the pertaining means towards road network identification, hydrological pattern identification, land cover discrimination, and urban land cover socio-economic discrimination. In addition, we have identified both existing commercial software solutions as well as research projects employing the aforementioned processing methods.

3.7. Recommendations

One of the main aims of the DREAM project was to provide CAPRA with thorough gap analysis and appropriate recommendations. In terms of generating inputs for the risk module through remote sensing, CAPRA do not possess any solution at present. Therefore a comprehensive strategy addressing technological challenges described in this section has to be drawn. We have focused on existing, ready-to-use and effective solutions, thus dismissing research concepts that are beyond the 5-year operational horizon.

The first recommendation consists of outsourcing to external companies providing a turnkey solution (urban feature extraction, land cover, DTMs, etc.). Survey results indicate that several companies are able to provide this kind of end-product: BATI-3D®, Satellite Imaging Corporation, and MJ Harden/GeoEye [6–8]. Some of them provide very high range solutions. BATI-3D® can deliver 3-D city models with up to 10 cm resolution in a completely automated fashion using imagery and LIDAR from an airplane flying over the targeted area in four directions. The resulting database of buildings (including roof shape and texture) is of very high quality. Still, the data acquisition is very time-consuming (2 h/km^2) rendering the solution relatively expensive. Other companies such as SIC or MJ Harden [9] have also resources and capabilities to deploy large scale data acquisition missions, and to provide appropriate inputs for the needs of the CAPRA program.

The second solution consists of developing a complete CAPRA in-house workflow support structure. This approach necessitates:

- Assuring raw data input from commercial satellites or aerial deployments (i.e., LIDAR, stereoscopy).
- Assuring access to the technology in the form of appropriate software solutions, allowing for DEM generation and management as well as building extraction and land cover analysis.
- Recruiting human resources, such as engineers and technicians capable of operating the aforementioned technologies.

For raw input data acquisition, data can be purchased from companies such as SpotImage or acquired from non-profit organizations and used directly for building age determination. LIDAR data can be obtained using a device developed by the Caribbean Community Climate Change Center (CCCCC). The digital models processing capability can be secured using dedicated software. Inpho GmbH proposes a complete set of DEM management software, with MATCH-T DSM capable of generating DSMs using stereoscopic coupled images; SCOP++ capable of managing and improving the quality of LIDAR based DEMs; and finally building generator capable of extracting building features at ~85% detection rate (personal communication from company representatives, August 16, 2009). Concerning land cover analysis, at the regional scale, it is recommended as a first step to use free-of-charge Landsat

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multispectral images. Many existing software solutions like Environment for Visualizing Images (ENVI) software [10], the Environmental Systems Research Institute (ESRI) environment [11] or the Earth Resources Data Analysis System (ERDAS) environment [12] allow for performing such land cover classifications. As a second step, if some areas are proven to be particularly risk-prone given the overall hazard, exposure, and vulnerability parameters, it is recommended to use higher spatial resolution images (SPOT) enabling more precise knowledge of river and road networks. The building urban use and socio-economic pattern assessment requires higher multispectral resolution images, such as QuickBird, GeoEye-1 or IKONOS. For automated extraction and classification methods it is recommended to use commercial software such as The Definiens eCognition software [13].

The last component of the CAPRA workflow support is the need for a dynamic team of engineers supporting efficient deployment and operations. This can be done either within the framework of CAPRA or by creating a small associated start-up structure. Finally, in the case of the second scenario, it is strongly recommended to engage in partnerships with leading laboratories working on DEM/building extraction issues, thus benefiting from state-of-the-art recommendations and at the same time from the prestige of working with a World Bank philanthropic program.

4. Risk identification, evaluation, and CAPRA approach

According to the general definition, we consider risk as the probability of hazardous events occurring, causing damage to people or objects. The purpose of risk analysis is to assess that level of risk in terms of human and economic losses when both these assets are exposed to a specific event of a specific intensity. Mathematically, we evaluate risk as a function of hazard, exposure and vulnerability to determine losses for a scenario:

$$\begin{aligned}&\mathrm{Risk}(\mathrm{Event},\ \mathrm{Intensity},\ \mathrm{Asset}) = f(\mathrm{Exposure}(\mathrm{Asset}),\\&\mathrm{Vulnerability}(\mathrm{Asset},\ \mathrm{Event},\ \mathrm{Intensity})\end{aligned} \tag{1}$$

A scenario is a single simulation of a hazardous event in a region for which the CAPRA-GIS is being used. After each simulated scenario the risk is generally measured in terms of the expected annual loss (EAL) and the probable maximum loss (PML). The terms that have been used in Eq. (1), and throughout this paper, are defined below.

4.1. Hazard

This parameter quantifies the intensity of a natural event at a specific location. Major natural events in Central America are hurricanes, earthquakes, floods, landslides, storm surges, and volcanoes [14].

4.2. Exposure

Exposure evaluates the social and/or economic value and represents the maximum possible loss during a hazardous event. This can be quantified in terms of the number of people affected (human exposure) and the monetary value (economic exposure) [15]. For Central America we focus on the exposure of buildings, people and critical infrastructures, including hospitals, water distribution network, relief centers, communication lines, and roads. As the region is developing, maintaining crucial infrastructures in times of disaster is key to quick, efficient, and successful recovery.

4.3. Vulnerability

This can be classified in physical, quantitative losses related to damage or interruption of services, and social/human vulnerability expressing the tendency of people to live in places of inherent risk [16]. Vulnerability data can be obtained using several methods and sources including: satellite imaging, user-generated data, LIDAR, and ground sensing.

CAPRA intends to provide a probabilistic approach for disaster risk mitigation to governments and other interested parties by offering the necessary tools, data and software infrastructure for disaster risk evaluation. The required inputs and factors that influence the computation of the risk figures are described below:

- Distribution of the population: This is an estimation using the volume of the buildings and the overall density of the population within the area.
- Distribution of building value over the country: This requires two different types of data that affects exposure. One is the occupancy of the building (affecting exposure) and the second is the economic value of the infrastructure.
- Vulnerability of each building: This defines a rough building classification based on the year of construction, roof shape, and the material type of the building.

Several limitations have been identified in CAPRA. These limitations are listed below, with suggestions for potential solutions:

1. *Limited accuracy of risk input data*: Fundamental drivers such as the occupancy/structural characteristics of the buildings and economic classes of infrastructures need to be implemented. We propose to increase the risk drivers' functionality, implementing a larger range of building classifications, such as public safety and government buildings, travel ways, emergency services, and disaster supply storage centers. For all of these we recommend the implementation of a wider range of at least five economic classes.
2. *Reliability of CAPRA input data*: As CAPRA inputs are supposed to define an accurate and reliable representation of the system under investigation, we suggest cross-checking processes with other external datasets with remote sensing analysis algorithms [17] in combination with geographic information systems applications.
3. *Lack of information and computation of the evolution of parameters with respect to time*: CAPRA uses only static parameters to simulate risks. The actual model does

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not take into account any evolution of the data with respect to time. Studies [18] have shown that the population distribution in the city can change throughout the day or the week. This information can be obtained via remote sensing and estimated in a variety of ways, such as changing traffic patterns, telephone and power usage, and building classifications.

4. *CAPRA-GIS user interface*: At present, only a limited number of users have the access or ability to use CAPRA. We recommend enhancing CAPRA's functionality by providing, in a self-explanatory manner, different modules for various occupational users that deal with disaster relief.
5. *Absence of long-term assessment*: CAPRA's outputs are limited to the number of deaths and the average cost of the physical losses immediately after a disaster occurs. CAPRA does not, however, assess long-term effects. We propose additional models for CAPRA to analyze the historical, social, and economic trends following a disaster [19]. These models could be very useful in estimating long-term effects following a disaster in the region, such as disease outbreaks and famine.
6. *Lack of flexibility*: CAPRA does not allow any flexibility with respect to input data format. This might present a technical limitation that hinders the use of the program. We propose a more flexible tool architecture allowing for a variety of data input formats. This structure should also allow for the use of user-generated datasets that may not match pre-existing formats.
7. *Limitation to Central America and relative language constraints*: The limitation of CAPRA to Central America represents a hurdle for any other country that would benefit from the program. Furthermore, the CAPRA Wiki is presently only available in Spanish, which creates an obstacle for non-Spanish speaking users. The CAPRA software and wiki should be provided in additional languages, most crucially English. This would allow the CAPRA software to be utilized across the globe.

5. Computer applications for DRM

Computer applications and IT infrastructure are essential for disaster risk management as they reduce the time necessary to gather, process, and present information to support human decision making. This section describes how to fill the gap in exposure information using ground-based computer applications. We propose both a web-based and a mobile-based application. For processing and storing large quantities of information, the uses of GRID and Cloud computing are evaluated. Recommendations and mock-ups for the usage of those technologies are provided.

5.1. Mobile-based exposure data input

In developed countries the governments usually have detailed geospatial databases containing information on each building. Developing countries do not always possess this information. Manually collecting exposure data is a viable and accurate method that can be done efficiently using mobile devices.

The mobile-based application is targeted to governments and academic institutions as an on-field tool to gather data. Our example is based on the Apple iPhone®, for details of which see Fig. 4, although any type of handheld computer could be used instead. The iPhone® was chosen because it is a proven technology that is rapidly gaining popularity and shows great promise as a technology platform.

The application will allow the user to generate simple reports about individual buildings that include: the current position (provided by the phones built-in GPS), the number of floors, the building type (residential, office, store, etc.), and other optional parameters such as roof material, estimated construction year or a picture of the building (taken with the phone's camera). Reports are stored to make the information available to many users simultaneously and to accept contributions from many

Report #2

Basic information

Location

Type of building: Residential

No of floors: 5

Optional

Photo

Roof material

Build year: 1975-1979

People: 40-49

Fig. 4. User interface of the mobile-based application.

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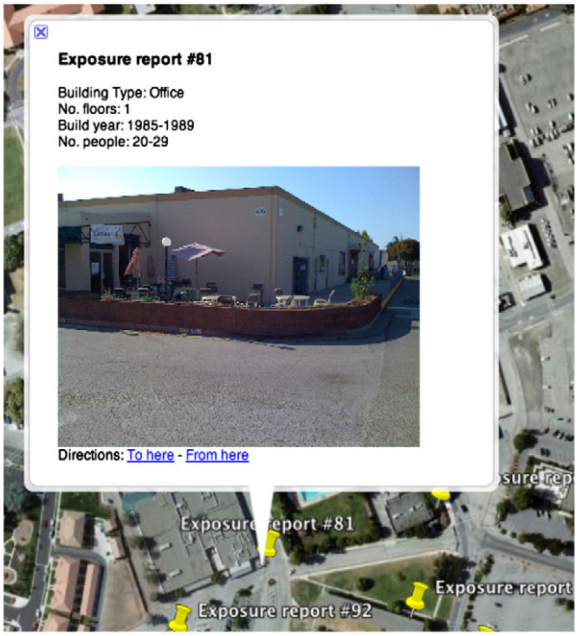
different sources. As depicted in Fig. 5, the content of the database is accessible via Google Earth.

5.2. *Web-based application*

We propose an intuitive and user-friendly web application called World disaster risk evaluation and management (DREAM), based on the World Wind (2006) tool [20].



Exposure report #81

Building Type: Office
No. floors: 1
Build year: 1985-1989
No. people: 20-29

Directions: To here - From here

Fig. 5. An example of exposure reports from iPhone on Google Earth.

This application is targeted to the general public, allowing anyone to view and contribute to exposure data. It allows the user to load and save exposure data, choose the type of hazard, and visualize the risk.

It will provide the capability to:

- add new buildings to the map by means of shapes that can be either polygons or spheres as seen in Fig. 6,
- load the hazard files relevant to that specific region from a dedicated database, and
- plot a selected region with its associated risk (after CAPRA computation).

GRID and Cloud computing are important technologies for the globalization of this application. GRID computing can be used for connecting resources such as maps, databases, satellite images, computational nodes and software. Cloud computing can be used to provide the capability of handling peak loads due to urgent requirements, and quick regeneration of the risk databases.

6. Business and development—DRM strategies

A cost–benefit analysis (CBA) on the various methods available to CAPRA for gathering DRM data is presented herein, as well as several procedures that will aid the organization to grow and expand beyond the scope and region of Central America. Recommendations towards building a sustainable CAPRA program and a list of potential collaborators are also included.

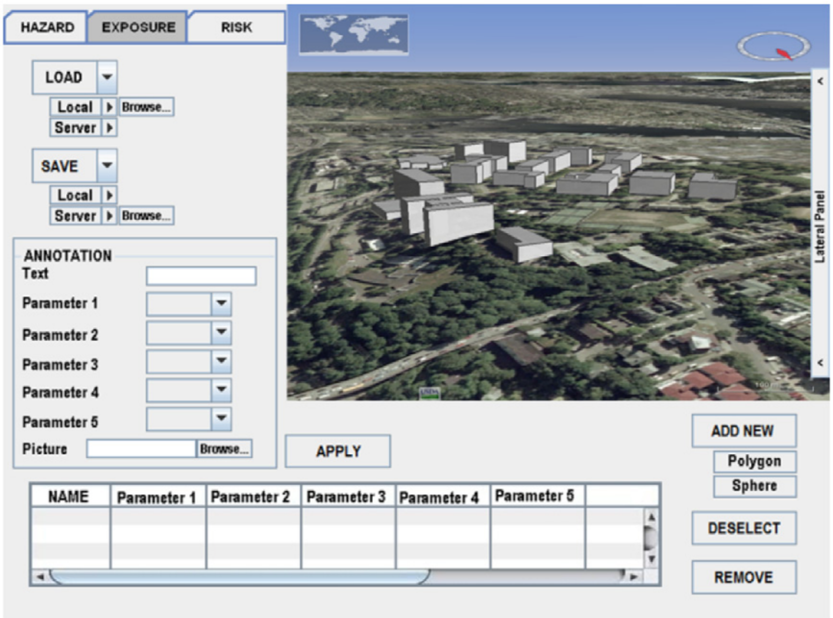


Fig. 6. Exposure definition interface at the DREAM World Wind application.

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6.1. Cost–benefit analysis

To use the CAPRA system for DRM in a new area, some parameters must be gathered utilizing space-borne, airborne and ground-based methods:

- Exposure (cost, population, contour).
- Vulnerability (height, floor/wall/roof material, age of buildings, soil type).
- Hazards (DEM/DSM, land cover).

There are three categories for collecting GIS data:

- Space (electro-optical, SAR, and hyper-spectral satellites).
- Air (LIDAR, electro-optical, SAR and hyper-spectral payloads).
- Ground (governmental census, web-based and cellular applications, and commercial data).

The CBA considers gathering DRM GIS data over an area of 1 km^2, taking into account four criteria to compare the data:

- Time (between the request, and receipt of data by a customer).
- Cost (required for data acquisition).
- Credibility (level at which we can trust the reliability of the data).
- Flexibility (to gather new data from specific area).

Each one of the above parameters is assigned a value and is mapped to the gathering methods:

- Building heights and DEM for the hazard models can be supplied by DEM/DSM (governmental, commercial, or by generating new products), LIDAR or extracted from an existing governmental census.
- Building contours can be extracted from accurate governmental cadastral data and maps or from EO images.
- Wall and roof materials can be surveyed or extracted from an existing governmental census. Rough data can be evaluated from SAR imagery or from hyper-spectral sensors.
- Soil composites can be monitored by multispectral imagery.
- Cost and age of buildings and size of population cannot be determined by air- or space-borne systems. A cost of a building can be roughly estimated by dividing the city into socio-economic areas and assigning different parameters to each area. The age of a building may be estimated by temporal analysis of imagery of the area of interest. The size of population may be evaluated by calculation of the building height and area, and the socio-economic factor.

The most significant conclusions of the CBA conducted take into account the four different methods mentioned before, as follows:

- From air and space-borne data gathering, there is little difference between different sensors.
- The cost of space-borne sensors is lower than that of their airborne counterparts.
- Using pre-existing data (census data) is the most efficient method.
- There are three main time scales for gathering information: (a) short (up to several months)—imagery data; (b) moderate (up to a year)—gathering in-situ information; (c) long (years)—community contributions.
- SAR sensors are useful for measuring height of buildings and identification of structure materials or metallic infrastructure, and can be used at any time (night time or through clouds). They are more beneficial than the EO sensors used for generating DSM of urban areas.
- EO satellites with moderate resolution (2.5–10 m) are cost beneficial for mapping large (rural) areas, generating DEM and identification of soil composites and land cover multispectral imagery.

6.2. DRM strategy

Considering the time scales previously mentioned, it is recommended to CAPRA to gather required DRM data items in three phases for better management of the project:

- *First phase (rapid)*: Most of data (80%) gathered in a short time (20%) [21]. For data items which do not have a direct measurement method (such as building age or value) generalization is done according to the surrounding area of the building. Satellites and airborne sensors must be used in order to gather data from large areas within a short time, and combined with existing commercial and governmental data. The use of aerial imaging will be more effective for highly clouded areas.
- *Second phase (accurate)*: Enhancing the data density (20%) during a long period of time (80%). In situ measurements conducted by trained reviewers within the same urban areas identified in the 1st phase will increase the accuracy of the building value, building age, and population size parameters.
- *Third phase*: Ongoing passive enhancement of the data. Community (general public) generated data may be added to the database using web-based and cellular applications. Before use, data will be checked for credibility.

6.3. Strategic plan towards sustainability

DRM data is generated and utilized by commercial entities such as insurance companies to gauge and price potential markets across the globe. To become commercially sustainable, CAPRA must generate a strategic plan to utilize this demand, and the first step is to establish relationships and agreements with the geospatial imaging companies to donate/sell imagery for DRM use at a

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specific rate to the World Bank. DRM products are of interest to commercial entities as well as third-world governments. Insurances companies are not prevalent in developing countries, concentrating their activities in large markets with high populations or GDPs. If CAPRA offers reliable DRM data for these areas at a specific fee, many insurance companies could use the data to expand their markets. As shown in Fig. 7, the money earned through sales of data to insurance companies and other commercial entities can be then reinvested in either purchasing more datasets for use by CAPRA, or in providing the CAPRA software and datasets to developing countries at a subsidized rate.

For future expansion into other developing countries, CAPRA would benefit from adopting a divisional organization structure.

6.4. List of potential collaborators

Contact was established with a number of satellite imaging companies and other organizations that expressed interest in assisting the CAPRA project (see Table 1). It is recommended that the World Bank pursue further contact with these organizations as they have been identified as relevant to the scope of this project.

6.5. Final section comments

To grow and become sustainable, CAPRA must generate and follow a long-term strategic plan, such as the one offered above. CAPRA should do this by establishing professional relationships with other DRM related organizations worldwide, such as UN SPIDER. Furthermore, CAPRA should develop business relationships and agreements with satellite operators, geospatial software companies and other businesses which could donate and/or sell imagery and DRM related software. Another huge market CAPRA should enter is the insurance and broker market, where DRM assessments can be sold for a high price.

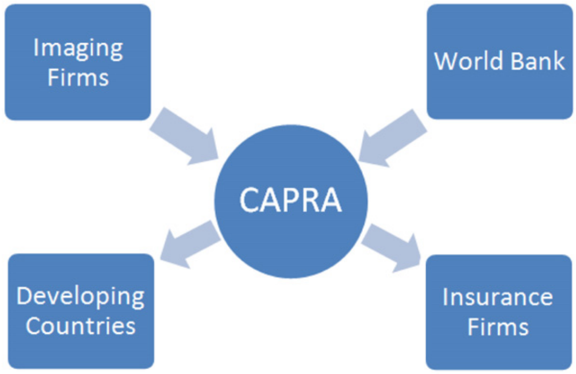

Fig. 7. Flow of cash and information.

The World Bank may use different methods for gathering information as input to the CAPRA software. These methods were processed with a cost–benefit analysis and prioritized to give an optimal strategy for information gathering.

Our final analysis shows large advantages in using census data (if it exists for the region in question) as a basic source for inputs to CAPRA. Additionally, and in areas with no census, a combination of high-resolution EO and SAR imaging is important for modeling areas of interest. These resources can also be used in deriving data such as building heights, building materials, roof contours, the number of residents and building cost. LIDAR technology was found to be too costly and hyper-spectral technology was found to be not mature enough.

7. Policy and law

7.1. Policy and legal considerations

The CAPRA initiative is both interdisciplinary and international—it targets governments and international organizations, uses remote sensing technology, depends on widespread data sharing, and will consist of contributions from people all over the world. This raises a myriad of policy and legal aspects that must be considered before further development of CAPRA occurs.

7.2. Remote sensing legal framework

The legal framework for remote sensing is based on three main components:

- UN principles of remote sensing
- National law
- International policy

Although the UN principles themselves are not legally binding [22], in most cases, the resolutions are taken from aspects of existing treaty law or customary international law and are binding [23]. With the rapid evolution of the space industry the UN principles have quickly become outdated, as they do not dictate any precedent for commercial remote sensing and the high-resolution data

Table 1
List of potential collaborators.

Established contacts	Initiated contacts	Contacts for future collaboration
GeoEye	SPOT Image	Academic institutions
	MJ Harden	Finance organizations (banks, insurance, brokers, and mortgage companies)
ImageSat International	INPHO (DEM software)	
	Galen University	National organizations
Digital Globe	Google Earth	International organizations
	IDB, SES	Extra-regional DRM organizations

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available today. To compensate for this shortcoming, many countries have adopted new national, legal, and policy measures to regulate remote sensing activities. National laws and policies determine the extent to which the government of a sensing state will make available the data/imagery pertaining to other countries. For example, the USA's *Land Remote Sensing Act* of 1992 and *Presidential Decision Directive* of 1994 relaxed the restrictions on the sale of US imagery to foreign bodies [24]. Canada and India have similar policies and the availability of satellite data for inclusion within the CAPRA system will be strongly dependent on the national data laws of the country that owns the imagery of interest. Thus, for legal reasons, it can beneficial to obtain imagery instead from private, commercial data sources.

7.3. CAPRA ownership and distribution

Ownership is a key legal issue. The CAPRA architecture has been developed to be "modular, extensible, and open source, which allows it to be modified, improved and expanded" [25]. Citizens of disaster-prone countries play a vital part in reducing the impact of disasters. The use of a system such as creative commons (CC) might allow broader use of copyright material while maintaining the integrity of satellite imagery provided by commercial or governmental sources.

There are several benefits to this approach, such as allowing a custom-tailored usage of CAPRA by governments and organizations. Also, by broadening data access the cost of data collection, maintenance, and updates decreases [26].

7.4. International Charter for space and disasters

The Charter supports relief efforts in the event of a major disaster. It provides priority acquisition of data and archived image retrieval at no cost to assist disaster response. In the DRM cycle it is only applied during response to a disaster. It has been established that applying DRM techniques against hazards affecting certain countries can result in substantial reduction in human and monetary losses. In accordance with cost–benefit analysis recommendations, the focus of the Charter's efforts should be shifted from response to mitigation. One idea would be to add pre- and post-disaster scenarios to the Charter. An amended Charter would allow countries to access EO data at no cost or at reduced cost for mitigation activities against hazards. This would be of particular benefit to developing countries, allowing them to plan for disasters.

7.5. Existing DRM policies in Central American countries

There are several DRM organizations active in Central America, such as:

- Center of Coordination for the Prevention of Natural Disasters in Central America (CEPREDENAC).
- The European Community Humanitarian Office (ECHO).
- Caribbean Disaster Emergency Response Agency (CDERA).
- Caribbean Community Climate Change Center (CCCCC).

The country at the focus of this report, Belize, has established organizations and initiatives to deal with hazard mitigation such as the National Emergency Management Organization (NEMO) that was established in response to the devastation left by Hurricane Mitch in 1998. NEMO's charge is to preserve life and property and to mitigate the impacts of an event on the country and its people. Additionally, Belize passed the Disaster Preparedness and Response Act of 2000 and drafted a National Hazard Mitigation Policy in 2003.

7.6. National usage of CAPRA

As the World Meteorological Organization is a good example of the sharing of data, their current operational framework might serve as a suitable model for national usage of CAPRA:

- All requests for data should be submitted to a CAPRA data management office.
- After approval the request should be forwarded to the data provider to secure appropriate inputs for the CAPRA software.
- Governmental agencies should submit a copy of their final research or output to CAPRA.
- Research and projects resulting from CAPRA software outputs should be carried out in collaboration with the data provider.

7.7. Final section comments

The legal issues pertaining to CAPRA and its use range far and wide, and it is beyond the scope of this paper to address all that might be encountered. There are varying levels of DRM policy in Central America, but the region appears capable of integrating output from CAPRA into their national strategies recommendations

It is necessary to clearly ascertain the legal status of the CAPRA systems and any legal implications of its use before progressing to further development stages. Advocating a national policy model for data sharing such as that of the World Meteorological Organization will allow countries to make best use of CAPRA.

8. Dream outreach

This section addresses how space agencies, space industry, and universities can be empowered and enabled to support CAPRA and, more generally, DRM efforts. However, we also wish to underline the importance of raising public awareness of disaster mitigation. It is fundamental to inform the population of the direct benefit of investing in risk management, and to educate them in

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procedures that mitigate not only economic loss but also, more important, human suffering.

8.1. New methods of obtaining exposure data

Getting high resolution Earth observation data is critical for a DRM process chain and can represent a reliable source of information for a DRM initiative. Earth observation data is available through governmental and non-governmental sources.

In most circumstances, military data is off-limits for any use by other countries and is deemed critical for national security. Moreover, key providers for commercial Earth observation (e.g., GeoEye and Digital Globe) are strongly dependent on the US government licensing the data to certain countries. It is expected that soon China, India, Russia, and Brazil will be entering the commercial marketplace for Earth observation satellite imagery. This will increase the number of reliable sources for imagery which can have a positive impact on an initiative like CAPRA. Beyond the commercial sources mentioned above, SpotImage and ImageSat International are good examples of commercial sources of Earth observation data that have been utilized for this project.

We proposed two new ideas for getting exposure data. First, students of the University of Belize in cooperation with existing DRM-focused institutions, such as the Hazard Center of University of Colorado, US, can use mobile phone handheld devices like the iPhone® to provide data about buildings that would be used to develop an accurate exposure model of their country. Secondly, high resolution satellite imaging capabilities owned by an NGO or IGO, such as the United Nations or the World Bank, can improve accessibility to useful satellite imagery by developing nations. One recommendation is that such an organization could buy a near end-of-life satellite at a reduced cost. The organization could operate it for humanitarian purposes such as risk assessment in the last year or two of its technical lifetime.

8.2. Outreach in the space industry

During the 1990s Central America played a pioneering role in efforts to reduce the effects of natural disasters and made major progress in both conceptual and practical terms. An important development in this process was the recognition of the role of the local and community level for DRM and the resulting involvement of local organizations in developing DRM strategies. In this point of view, for DRM to be most effective, it is important that all relevant national and regional bodies be involved in national mitigation processes.

There are a number of existing DRM programs connected to space activities that have been created by different organizations such as NASA SERVIR, GMES RESPOND, DMCii, and UN SPIDER. However there have been limited past attempts to promote CAPRA within the space industry. On the one hand, the World Bank is a globally influential organization and has a lot of experience in financially supporting the sustainable development of developing countries for many years. On the other hand, the World Bank lacks the intimate knowledge of the space industry that is required to garner its support. At present, the space industry focuses primarily on disaster response and lacks awareness of the presence of initiatives such as CAPRA. We would like to suggest cooperation between CAPRA and the space industry. The technical support of the space industry is, in our opinion, vital for the development of CAPRA. The cooperation will lead to better DRM, allowing CAPRA to expand on a global scale.

Fig. 8. ‘DREAM Aware’ endorsement.

We suggest that outreach of CAPRA to members of the space industry could be facilitated by the establishment of an ‘endorsement’ awarded in recognition of a certain level of activity or proficiency in the field of DRM. CAPRA would award this endorsement, named ‘DREAM Aware’ for the purposes of this project, to bodies within the space industry that become partners and provide data to aid in DRM projects. For example, as seen in Fig. 8, the donation of imagery by GeoEye and SPOT Image would merit the award of the ‘DREAM Aware’ status.

A scheme such as this offers benefits to both the space industry and CAPRA. Gaining the endorsement of CAPRA indicates a high level of experience of, and participation in, DRM activities. Publicity within general populations is also achieved through this scheme. Of course extensive further investigation is required to determine the feasibility of this suggested scheme and it is one of the key recommendations of this section that CAPRA researches how effective the ‘DREAM Aware’ endorsement might be.

9. Applying CAPRA 2.0 on Belize

Belize is located on the eastern coast of Central America and has a total population of 330,000, growing 3% annually. The total area is 22,966 km^2 out of which 22,806 km^2 is mostly flat and swampy, and the other 160 km^2 is water area, mainly rivers and lakes [27]. The coastline borders the Caribbean Sea, and contains the Belize Barrier Reef, the second largest reef in the world. Throughout its history Belize has been mainly affected by hurricanes and tropical storms [28]. Population and infrastructure growth in the past thirty years, concentrated on the coasts and in flood plains, have

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greatly increased the damage potential from floods and hurricanes. Between 1998 and 2008 floods and hurricanes affected the economic and business development in Belize, costing more than USD 660 million.

9.1. *Rationale for choosing Belize*

Belize is an excellent case study for disaster risk management for a few major reasons. With a small area and population, Belize serves as a good test platform to implement DRM strategies. Belize serves as a bridge between Central America and the Caribbean, and lessons learned in Belize can be applied to both regions. As an English speaking country, an international team can more effectively communicate with local policy makers. Local policy makers have expressed interest in funding DRM missions to save money and lives in the long term. Finally, hurricanes have impacted up to 19% of Belize's GDP, and so managing disaster risk can have a tremendous impact. In particular, Belize City, the largest city in Belize, is a good case study of an urban area where many lives can be improved for a relatively low investment of satellite and LIDAR imaging and where statistical and structural analyses can be conducted.

9.2. *Historical background*

In late 1998 the government of Belize began a new program of public expenditure [29], pushing the annual growth to a record high 13.03% in 1999. However, in the following years disasters took a heavy toll and generated widespread losses amounting to 19% of the GDP in 2000 and 18% of the GDP in 2001. The detriment to economic growth generated widespread political instability and social unrest in 2003 and 2005. These storms also caused incalculable social and economic damage due to a decrease in national morale and loss of opportunities. Hence, hurricanes adversely impact Belize in several qualitative ways that cannot be measured by economic or human losses.

9.3. *Disaster response vs. management*

To stop losses, Belize has created an organization for disaster risk management called National Emergency Management Organization (NEMO) [30]. Unfortunately, due to lack of funding [31], current NEMO projects focus primarily on emergency response [32]. However, disaster mitigation saves more money and lives than disaster response alone. According to the World Meteorological Organization and the United Nations (UN) International Strategy for Disaster Reduction, "*The disaster mitigation and preparedness programs in Andhra Pradesh, India, yielded a benefit-to-cost ratio of* 13:3" and "*China spent USD* 3.15 *billion on flood control between* 1960 *and* 2000 *and is estimated to have averted losses of some USD* 12 *billion*" [33].

9.4. *Funding*

In this particular case study the DREAM team examined several possible monetary sources for DRM projects in Belize. We examined programs sponsored by the Inter American Development Bank (IDB), Caribbean Development Bank (CDB) and the Caribbean Catastrophe Risk Insurance Facility (CCRIF). Of these three, the strongest opportunity for the Belize government to obtain funding for DRM is from the IDB in the form of development projects. During the implementation of the CAPRA initiative both in Belize and in Central America in general, IDB development loans should be sought. This investment would potentially save billions of dollars during the next Belizean disaster.

9.5. *Remote sensing*

Belize, extending over an area of 22,966 km^2, can be covered using three Landsat images. The price for these three LANDSAT 7 ETM+ images, with a 30 m resolution, would be USD 393 [34], Additionally, Landsat orthorectified image archives offer free-of-charge products, and can be used for retrieving particular images concerning the Belize region. For retrieving a DEM of the countryside areas, ASTER provides a 30 m resolution free-of-charge. For generating the DSMs, one alternative to using optical images and stereoscopy, could be the use of LIDAR instruments being developed by the Caribbean Community Climate Change Center (CCCCC) in Belize. These LIDARs are expected to be of similar resolution as the NASA Experimental Advanced Airborne Research LIDAR. The 300 m swath width and 240 m instrument altitude allows for a coverage area of 43 km^2 per hour, with a nominal ranging accuracy of 3–5 cm and a nominal horizontal positioning accuracy of less than 1 m. To map the whole Belize area using LIDAR, this will require about 534 h and hence take several months until project completion. For mapping Belize City itself, this process should only take a few hours.

9.6. *Risk analysis*

Bearing the above considerations in mind, it is crucial to the societal and economic future of Belize that the country take precautions to help manage future disaster risk before disasters occur, as well as to establish infrastructures capable of mitigating effects of disasters as they occur. Comprehensive data is a crucial element to knowing where risks are and how to best manage them. Datasets that will be especially useful to Belize are population distribution maps, socio-economic zones, building construction indices, locations of key infrastructures like hospitals, roads, fire departments and relief centers, and hydrology maps. All of the above should be obtained using a combination of satellite imaging, obtainable through partnerships with NASA and other public entities, user-generated content, obtainable through mobile and open-source web services, and LIDAR, which may be costly, but can provide very accurate

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data. All the added data sources will help with establishing a historical registry supporting future disaster risk management.

9.7. Information technology implementations

After analysis of the Belize scenario and DRM requirements, the following points are highlighted for a prospective Belize DRM:

- Database updates using iPhone® applications can be performed by providing iPhone® sets to students in collaboration with local universities.
- The application being developed by the DREAM project team using World Wind will be available under open source license for the people/students of Belize to develop new applications to achieve the goals of CAPRA.
- The information and technology infrastructure available in Belize is suitable for generating the risk database. Further requirements like computing resources and disk storage space can be made accessible over the Internet by using the proposed GRID and cloud computing technologies.
- The crowd-sourcing concept will be used to train Belizean people to identify buildings and infrastructures on the satellite images to contribute to the CAPRA database.

9.8. Public policy

Belize has only recently begun to routinely engage in disaster mitigation (rather than just response) and as such the Government of Belize has implemented several major DRM policy decisions. The Government's National Hazard Mitigation Policy is realized by the Belize National Hazard Mitigation Plan, a document that provides a wide-ranging framework aimed at reducing the human and financial cost of disasters. If CAPRA is to move beyond being simply a software-based initiative, there must be clear organization between CAPRA, the World Bank, developing countries, imaging firms, and other interested countries.

9.9. Future of CAPRA in Belize

We envision a scenario where CAPRA evolves into a facilitating organization. CAPRA would establish the relationships and agreements with the geospatial imaging companies to donate/sell imagery for DRM use at a specific rate. Countries interested in improving their DRM would come to CAPRA, who would provide the imagery and DRM programs to the country. The imagery and program would be provided either free (paid by the World Bank or some sponsors program) or heavily subsidized by the commercial areas of CAPRA. To be truly sustainable this plan needs to bring in capital outside of donations and the World Bank coffers. Insurance companies spend billions of dollars globally assessing risk from a variety of sources. However this risk analysis is primarily concentrated in 'large markets' with high populations or GDPs. Due to this, insurance is not very prevalent in developing countries. If CAPRA can offer reliable DRM data for these areas at a specific fee, many insurance companies could use the data to expand their markets. This is potentially a large untapped business opportunity for insurance companies, and one for which they would be willing to pay. The money earned through sales of data to insurance companies and other commercial entities can be then reinvested in either purchasing more datasets for CAPRA's use, or in providing the CAPRA program and datasets to developing countries at a subsidized rate.

9.10. Final section comments

By combining the CAPRA initiative with large partnerships with imaging firms and resale of data to insurance agencies, the World Bank will create a sustainable program for DRM unparalleled in the world. The recommendations made in this project have wide-reaching applications also for other developing countries in the world.

10. Conclusion and recommendations

CAPRA is a rapidly developing tool and possible areas of improvement in its data-gathering capabilities have been identified in this paper. The DREAM project focused on identifying space-aided, airborne, and ground-based methods for this purpose. A three-stage strategy was proposed for gathering information based on satellite imagery, ground surveys, and community participation. Using the staged strategy, the lessons learned in Central America for the CAPRA toolset can be scaled and applied globally.

Methods of outreach to both the space community and the general public were suggested, resulting in the development of a prototype iPhone® application for gathering CAPRA input data. A significant result for the DREAM project was that the industry outreach work resulted in GeoEye, ImageSat International, and Spot-Image providing CAPRA with satellite imagery of Belize.

Due to the widespread applications of this project, future work should include expansion of the CAPRA initiative to regions beyond Belize. This expansion would benefit from a divisional organization structure where the information technology and human resources departments, for example, are integrated across all the regions covered by CAPRA. By focusing on user-generated, open-source, and future-conscious methods massive global change can be effected.

CAPRA and the World Bank should maintain the contacts established with satellite operators (GeoEye, ImageSat International, SPOT image) and work towards creating long-term partnerships with these companies. Contact with other DRM related organizations and companies identified in this report are also recommended. This will provide more sources of data for the CAPRA software. We also recommend the establishment of a historical imagery database in order to build a data 'reference library' for future CAPRA activities.

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In terms of the CAPRA technology, the use of service-oriented architecture for CAPRA should be evaluated to provide inter-operability and improve accessibility. It was determined that the architecture of the CAPRA software is lacking in structure, largely due to the lack of thorough system engineering. Another issue is the limited technical documentation of the software itself. It is recommended that an external consulting service be recruited to review current CAPRA systems engineering process and existing products.

In conclusion, space-aided, airborne, and ground-based technologies and recommendations have an immense potential to contribute to the World Bank's CAPRA tool and the DREAM project has identified some of the key areas in which this is possible. With the inclusion of these technologies the CAPRA initiative may continue to improve its efforts to mitigate the adverse effects of disasters in Central America.

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