Risk Information Services for Disaster Risk Management (DRM) in the Caribbean

Service Utility Document

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Authors: Stephen Grebby, Colm J Jordan and Tom Dijkstra
(British Geological Survey, Natural Environment Research Council).

British Geological Survey, Keyworth, Nottingham, UK, NG12 5GG,
www.bgs.ac.uk

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1 INTRODUCTION

1.1 Scope of the document

This document describes the assessment of the Earth Observation (EO) information products / services delivered by the British Geological Survey (BGS) via the framework of the European Space Agency (ESA) *eoworld2* initiative. The products / services were delivered to the Caribbean region and the World Bank (WB) primarily via the 'Caribbean Handbook on Risk Information Management' project (CHARIM) which is financed by the EU-funded ACP-EU Natural Disaster Risk Reduction Program, managed by the Global Facility for Disaster Reduction and Recovery, led by the WB team, and implemented with the University of Twente, ITC and the local users from various Government Ministries in the Caribbean region.

This document includes:

- descriptions of the EO products deliver under the three services;
- a summary of the results of the EO product assessment by the WB and local users;
- recommendations for future service improvement and relevance of services/EO information products within wider WB operations.

A note on copyright: there are a significant number of figures that were derived from satellite imagery within this report. For reference, the satellite image has been identified and the copyright attribution appears here:

Copyright notices for the satellite imagery used in the project are as follows:

- Products derived from Pleiades satellite imagery – includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved.
- Products derived from RapidEye satellite imagery – includes material © 2014 BlackBridge, all rights reserved.
- Products derived from ASTER satellite data – ASTER GDEM is a product of METI and NASA.
- Products derived from SPOT satellite data – includes material © CNES 2014, Distribution Astrium Services / SPOT Image S.A., France, all rights reserved.

1.2 Acronyms and abbreviations

AOI	Area of Interest
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer
BGS	British Geological Survey
CAPRA	Central American Probabilistic Risk Assessment
CHARIM	Caribbean Handbook on Risk Information Management
DEM	Digital Elevation Model
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FP	Final Products
FR	Final Report
GIS	Geographic Information System
GMES	Global Monitoring of Environment & Security
GPS	Global Positioning System
KO	Project kick-off
LiDAR	Light Detection And Ranging
MDB	Multi-Lateral Development Bank
MMU	Minimum Mapping Unit
NEMO	National Emergency Management Organisation
OD	Operational Documentation
PM	Progress meeting
SOW	Statement of Work
SRD	Service Readiness Document
SRR	Service Readiness Review
SRTM	Shuttle Radar Topography Mission
SUR	Service Utility Review
SUD	Service Utility Document
TPM	Third Party Mission
TTL	Task Team Leader
VP	Validation Protocol
WB	World Bank

2 SERVICE ASSESSMENT CONTEXT

2.1 EO Information Products Delivered

Numerous data layers were incorporated into 11 map-based EO information products that were delivered through the implementation of three Services for disaster risk management in the Caribbean region. These Services are summarised in Table 1. Services 1 and 2 deliver key information – including landslide inventories, land use/land cover maps, elevation data and information on rivers and streams – for input to landslide and flood hazard assessments undertaken within the WB-led CHARIM project (van Westen, 2014). Service 3 delivers elevation information for input to flood hazard assessments for Belize, also undertaken within the CHARIM project. More detailed descriptions of the Services and their associated EO information products are provided in the following sub-sections along with associated Service Readiness information published in Jordan & Grebby (2014) and Operational Documentation published in Jordan et al. (2015).

Table 1 Summary of the Services.

Service Number	Service Description	Service Coverage
1	Land use/land cover mapping	St. Lucia Grenada St. Vincent and the Grenadines
2	Hazard mapping to support landslide risk assessment	St. Lucia Grenada
3	Digital Elevation Model	Belize

2.1.1 Service 1: Land use/land cover mapping

The objective of Service 1 was to generate land use/land cover maps (including water features and road basic networks) for St. Lucia, Grenada, and St. Vincent and the Grenadines by exploiting recent high-resolution or very high-resolution optical satellite imagery. The mapping was undertaken using a combination of Pleiades (spatial resolution of 0.5 m panchromatic and 2 m multispectral) and RapidEye (5 m) satellite imagery, acquired from the relevant providers through the ESA Third Party Mission (TPM) scheme.

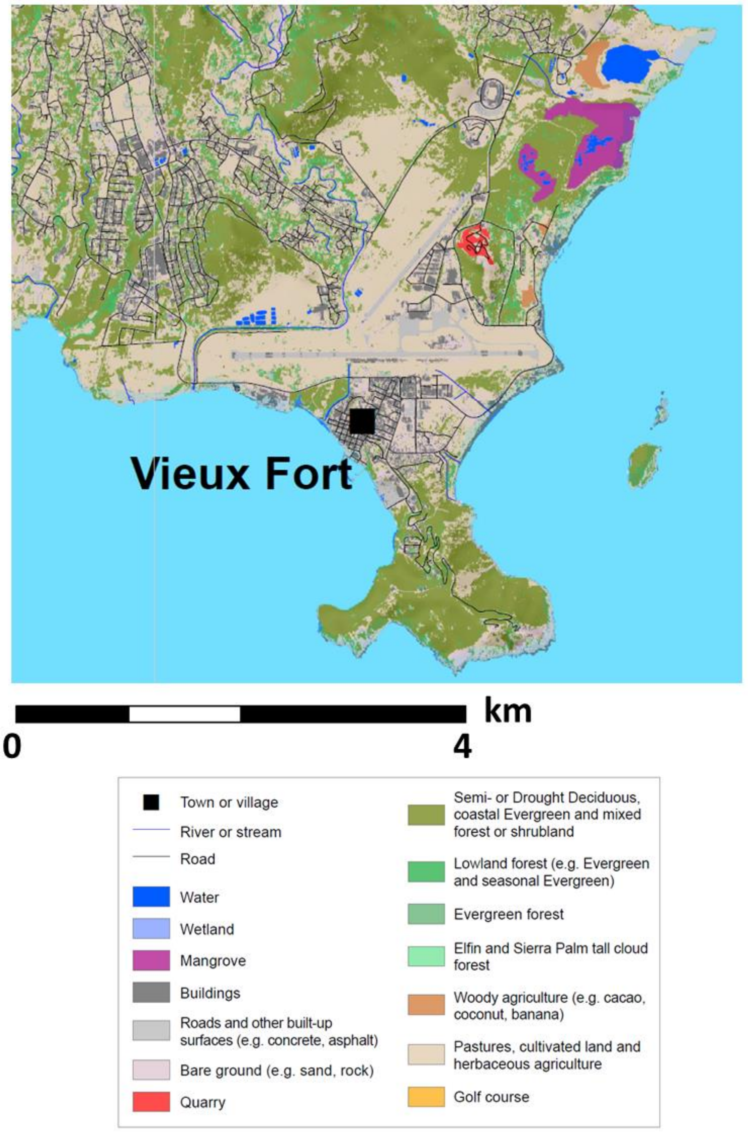
Service 1 demonstrates the ability to produce high-resolution land use/land cover maps remotely from EO data using a largely automated processing method. The primarily benefits of this approach are increased cost and time effectiveness in comparison to traditional field based mapping, and the ability to overcome terrain accessibility issues that commonly restrict field surveys in densely vegetated tropical environments and rugged terrain. The maps delivered by this Service provide a more contemporary snapshot of land cover/land use than the existing maps produced by The Nature Conservancy Mesoamerica and Caribbean Region project (Helmer et al., 2007; 2008), while also providing an order of magnitude increase in spatial resolution (2 m compared to 30 m). More detailed and recent land use/land cover information has been beneficial to the CHARIM project because it was used to better understand the factors controlling landslides and consequently improve the landslide susceptibility modelling. Beyond hazard risk, EO-derived land use/land cover information delivered by this Service has a wide spectrum of uses. For example, such information can be used for planning purposes, asset management and conservation. Given its semi-automated nature, the mapping approach implemented in this Service can be readily applied to monitor change over time.

Prior to delivery, the land use/land cover information products were quality checked and subject to an initial validation (Jordan et al., 2015). Quality checking generally comprised evaluating whether the products satisfied the specified user requirements with regards to the minimum coverage of the areas of interest (AOIs) and thematic accuracy. The thematic accuracy of the land use/land cover maps was determined using the conventional remote sensing approach of deriving confusion matrices (Congalton, 1991). Specifically, the land use/land cover class identities of a sample of validation pixels in the map were compare with their ‘true’ land use/land cover class to compute the overall accuracy (i.e., the percentage of validation pixels correctly classified). The thematic accuracies were then further corroborated with the aid of observations made in the field during a 10-day visit to the region in October 2014. This involved visiting numerous randomly selected locations on the ground to cross-check the actual land use/land cover type with that on the map.

Ahead of delivery, the land use/land cover data was released to the CHARIM project partners at ITC for initial validation. This initial validation involved evaluating the suitability of the define land use/land cover classes for hazard assessment and checking for significant misclassifications or artefacts in the maps.

The EO information products delivered through Service 1 are described in Figures 1-3.

<table>
<tr><th>Service and Product</th><th>Description</th></tr>
<tr><td rowspan="2">Service 1: Land use/land cover mapping

Land use/land cover map for St. Lucia</td><td>Map showing the spatial extent of the main land use/land cover types, as well as water bodies and the basic road network</td></tr>
<tr><th>Example</th></tr>
<tr><th>Metadata</th><td rowspan="7">
</td></tr>
<tr><td>• Spatial resolution:
2 m land use/land cover
1:10,000 roads & rivers
• Coordinate system: WGS84 UTM Zone 20N
• Thematic accuracy: 84.9%
• Time period: 2013-2014</td></tr>
<tr><th>Input data</th></tr>
<tr><td>Satellite imagery
• Pleiades panchromatic (0.5 m)
• Pleiades multispectral (2 m)
• RapidEye multispectral (5 m)

Ancillary data
• SRTM DEM (90 m)
• ASTER GDEM (30m)
• The Nature Conservancy's Mesoamerica and Caribbean Region Project land cover/land use maps (30 m)
• In-situ field observations</td></tr>
<tr><th>Methodology</th></tr>
<tr><td>• Automated image classification
• Visual image interpretation
• Rule-based post-processing refinement
• Map production
• Quality checking and validation</td></tr>
</table>

Figure 1. Land use/land cover map for St. Lucia (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

Service and Product	**Description**
Service 1: Land use/land cover mapping Land use/land cover map for Grenada	Map showing the spatial extent of the main land use/land cover types, as well as water bodies and the basic road network

Metadata

- Spatial resolution:
  2 m land use/land cover
  1:10,000 roads & rivers
- Coordinate system: WGS84 UTM Zone 20N
- Thematic accuracy: 84.8%
- Time period: 2011-2014

Input data

Satellite imagery
- Pleiades panchromatic (0.5 m)
- Pleiades multispectral (2 m)
- RapidEye multispectral (5 m)

Ancillary data
- SRTM DEM (90 m)
- ASTER GDEM (30m)
- The Nature Conservancy's Mesoamerica and Caribbean Region Project land cover/land use maps (30 m)
- In-situ field observations

Methodology

- Automated image classification
- Visual image interpretation
- Rule-based post-processing refinement
- Map production
- Quality checking and validation

Example

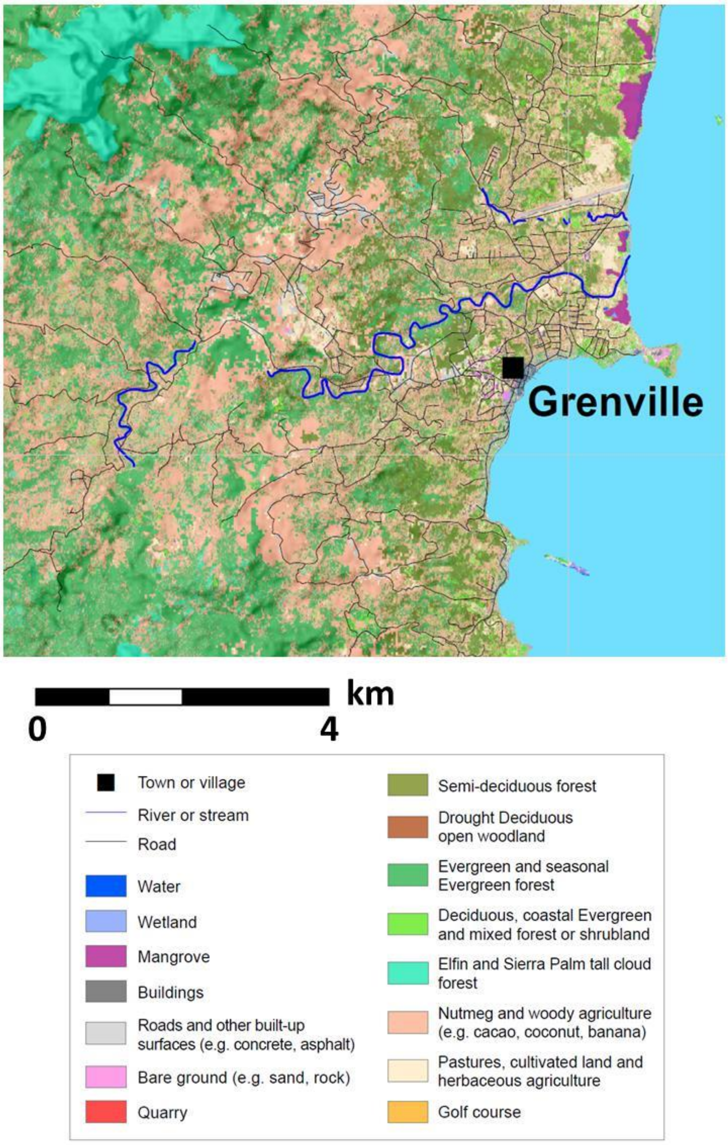
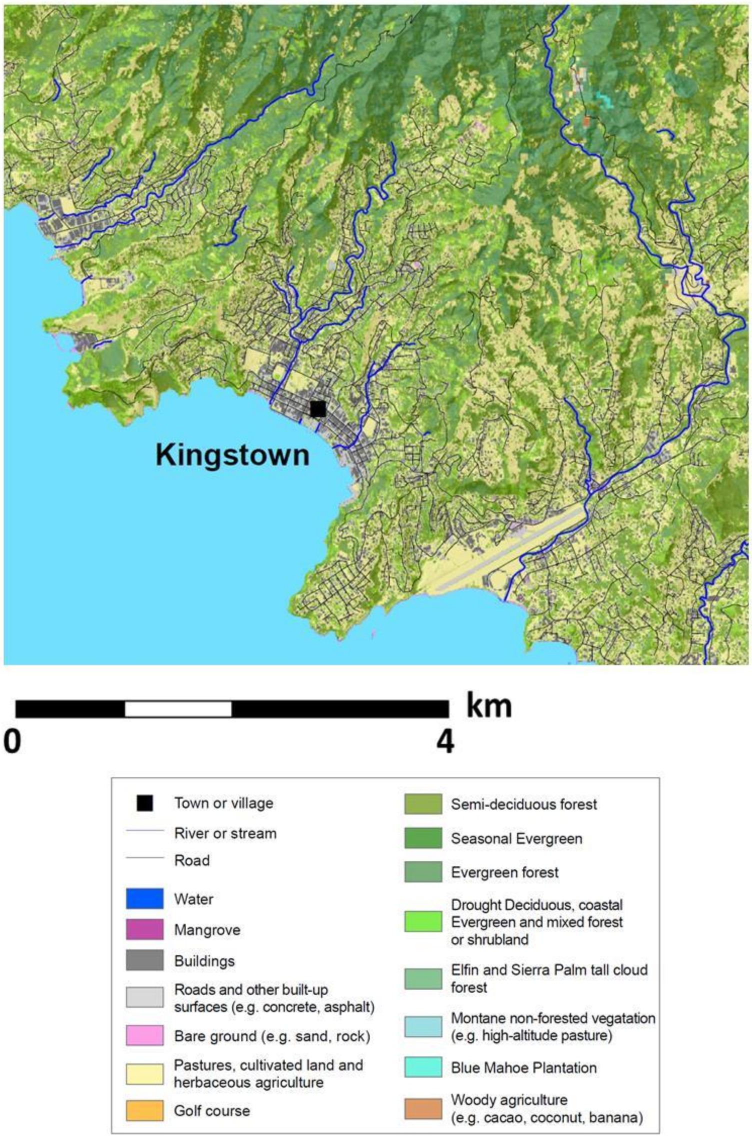


Figure 2. Land use/land cover map for Grenada (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

<table>
<tr><th>Service and Product</th><th>Description</th></tr>
<tr><td rowspan="2">Service 1: Land use/land cover mapping

Land use/land cover map for St. Vincent and the Grenadines</td><td>Map showing the spatial extent of the main land use/land cover types, as well as water bodies and the basic road network</td></tr>
<tr><td>Example</td></tr>
<tr><th>Metadata</th><td rowspan="7">
</td></tr>
<tr><td>• Spatial resolution:
2 m land use/land cover
1:10,000 roads & rivers
• Coordinate system: WGS84 UTM Zone 20N
• Thematic accuracy: 80.8%
• Time period: 2012-2014</td></tr>
<tr><th>Input data</th></tr>
<tr><td>Satellite imagery
• Pleiades panchromatic (0.5 m)
• Pleiades multispectral (2 m)

Ancillary data
• SRTM DEM (90 m)
• ASTER GDEM (30m)
• The Nature Conservancy's Mesoamerica and Caribbean Region Project land cover/land use maps (30 m)
• In-situ field observations</td></tr>
<tr><th>Methodology</th></tr>
<tr><td>• Automated image classification
• Visual image interpretation
• Rule-based post-processing refinement
• Map production
• Quality checking and validation</td></tr>
</table>

Figure 3. Land use/land cover map for St. Vincent and the Grenadines (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved. ASTER GDEM is a product of METI and NASA).

2.1.2 Service 2: Hazard mapping to support landslide risk assessment

The objective of Service 2 was to generate ground-truthed landslide inventories and digital elevation models (DEMs) for St. Lucia and Grenada. The landslide mapping was undertaken using a combination of multi-temporal, pan-sharpened Pleiades (spatial resolution of 0.5 m) and RapidEye (5 m) satellite imagery, acquired from the relevant providers through the ESA TPM scheme. The DEMs were generated using ASTER stereo satellite imagery (30 m) in conjunction with ancillary elevation data (e.g., airborne LiDAR, contour heights, SRTM DEM).

Service 2 demonstrates the ability to utilise very-high resolution, multi-temporal optical satellite imagery for landslide inventory mapping. Implementation of this Service has led to the delivery of annual landslide inventories for St. Lucia for the period 2010-2014 and a single inventory for Grenada (also covering the same period). Mapping landslides remotely from satellite imagery is again far more time and cost effective than traditional field-based mapping, and it provides a means of readily accessing the inhospitable terrain in which landslides typically occur. The very-high resolution Pleiades satellite imagery offers advantages over satellite imagery with a more moderate spatial resolution (e.g., Landsat) because it enables small landslides (<100 m^2) to be mapped in detail. Furthermore, the very-high resolution imagery provides sufficient detail to allow the generation of geomorphological maps that can be attributed with information such as the likely nature of deformation and a timeline of event progression. This Service also provides a practical means of monitoring landslide activity on an annual basis, which helps gain a better understanding of the landscape response to trigger events (e.g., hurricanes). Information on trigger event response, spatial distribution, magnitude-frequency, type of movement that can be obtained through this Service is very valuable for the development of landslide susceptibility maps and landslide risk assessments. Accordingly, the landslide inventories delivered in Service 2 comprised crucial information that was input to the landslide susceptibility modelling under the CHARIM project. Service 2 also delivered accurate national-scale 30 m DEMs generated from optical satellite imagery. This Service therefore demonstrates a cheaper, alternative approach to generating DEMs at this scale over large areas in comparison to ground-based GPS or airborne LiDAR surveys. The DEMs and derived information (e.g., slope, relief) are essential to both the landslide and flood risk assessments undertaken within the CHARIM project. The generation of 1 m DEMs was planned, but issues acquiring cloud-free Pleiades stereo satellite imagery during the Atlantic hurricane season meant that this could not be completed within the timeframe.

The landslide inventories were ground-truthed prior to delivery, by visiting the locations of potential landslides identified on the satellite imagery during a 10-day field trip to the region. Subsequently, the inventories were updated to remove any false positives that were confirmed during ground-truthing. The DEMs were validated by computing their vertical accuracies using GPS control points (St. Lucia) and high-resolution airborne LiDAR data (Grenada).

The EO information products delivered through Service 2 are described in Figures 4-9.

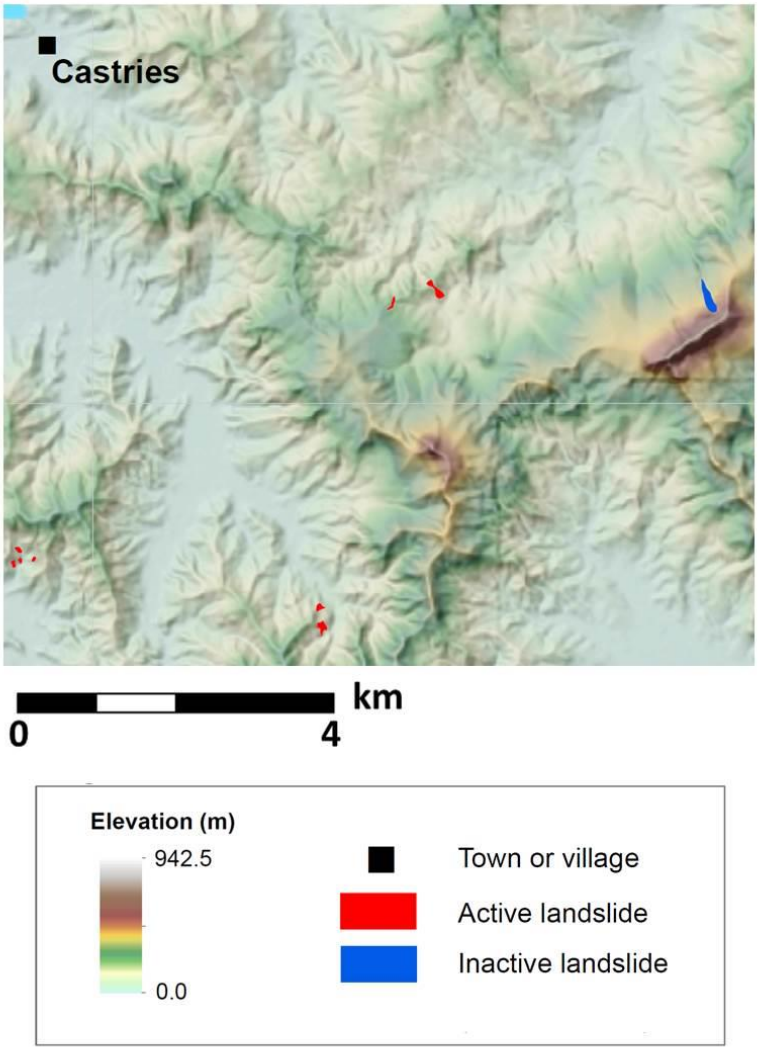
Service and Product	**Description**
Service 2: Hazard mapping to support landslide risk assessment Landslide inventory (2010) and digital elevation model for St. Lucia	Landslide inventory for 2010 and a national-scale 30 m digital elevation model (DEM). A total of 29 landslides were identified using the satellite imagery.
Metadata	**Example**
• Spatial resolution: 30 m digital elevation model 1:20,000 landslide inventory (50% at 1:10,000) • Coordinate system: WGS84 UTM Zone 20N (EGM96 geoid) • DEM accuracy (RMS): 1.4 m • Time period: 2010	
Input data	
Satellite imagery • Pleiades panchromatic (0.5 m) • Pleiades multispectral (2 m) • RapidEye multispectral (5 m) • ASTER stereo imagery (15 m) **Ancillary data** • ASTER GDEM (30 m) • Elevation contours • In-situ field observations • GPS data	
Methodology	
• Automated image classification of bare ground areas • Visual image interpretation of landslides • Photogrammetric processing of stereo imagery and calibration • Map production • Ground-truthing and validation	

Figure 4. The 2010 landslide inventory and national-scale DEM for St. Lucia (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

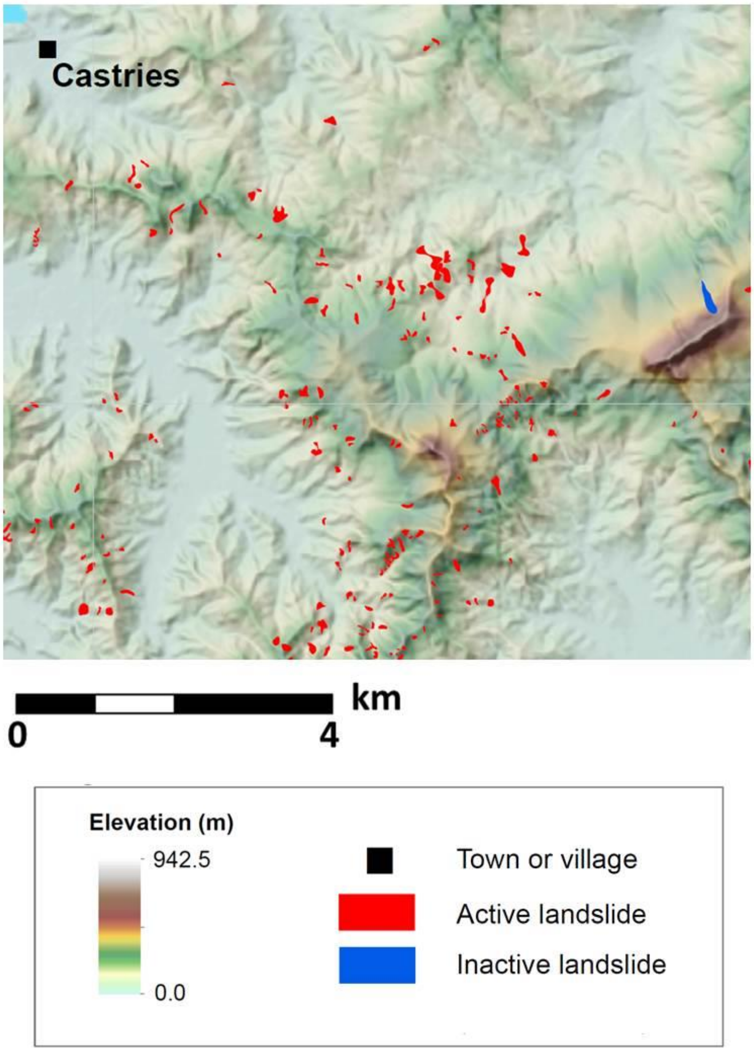
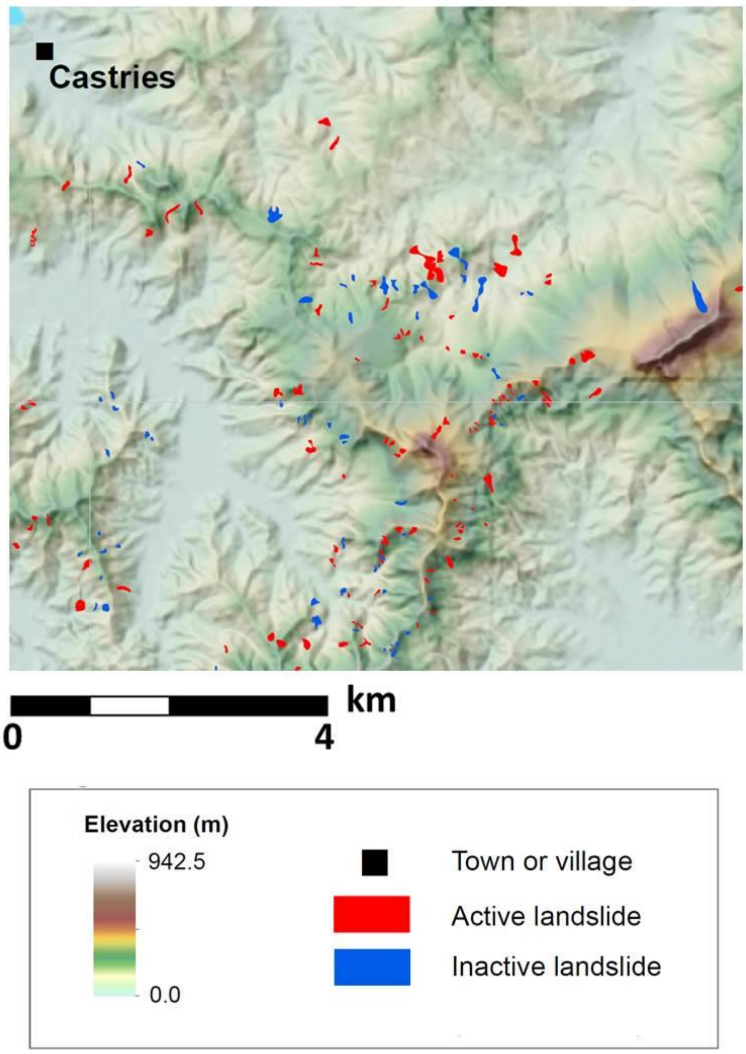
Service and Product	Description
Service 2: Hazard mapping to support landslide risk assessment Landslide inventory (2011) and digital elevation model for St. Lucia	Landslide inventory for 2011 and a national-scale 30 m digital elevation model (DEM). A total of 1028 landslides were identified using the satellite imagery.
Metadata	**Example**
• Spatial resolution: 30 m digital elevation model 1:20,000 landslide inventory (50% at 1:10,000) • Coordinate system: WGS84 UTM Zone 20N (EGM96 geoid) • DEM accuracy (RMS): 1.4 m • Time period: 2011 **Input data** **Satellite imagery** • Pleiades panchromatic (0.5 m) • Pleiades multispectral (2 m) • RapidEye multispectral (5 m) • ASTER stereo imagery (15 m) **Ancillary data** • ASTER GDEM (30 m) • Elevation contours • In-situ field observations • GPS data **Methodology** • Automated image classification of bare ground areas • Visual image interpretation of landslides • Photogrammetric processing of stereo imagery and calibration • Map production • Ground-truthing and validation	

Figure 5. The 2011 landslide inventory and national-scale DEM for St. Lucia (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

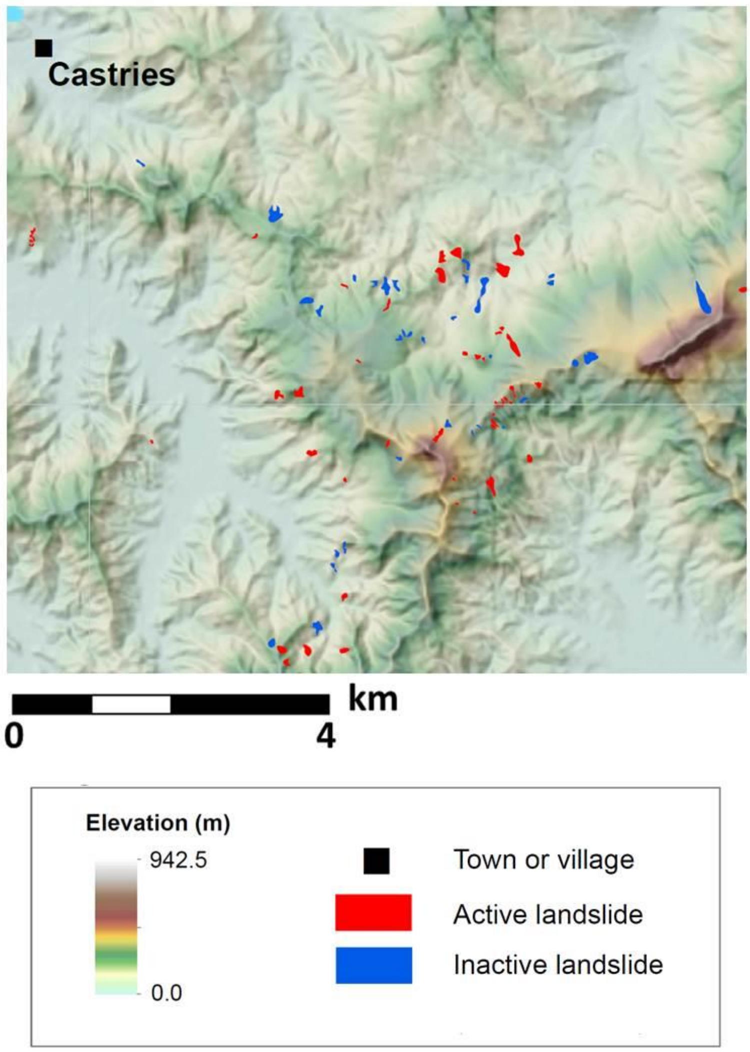
<table>
<tr><th>Service and Product</th><th>Description</th></tr>
<tr><td>Service 2: Hazard mapping to support landslide risk assessment

Landslide inventory (2012) and digital elevation model for St. Lucia</td><td>Landslide inventory for 2012 and a national-scale 30 m digital elevation model (DEM). A total of 793 landslides were identified using the satellite imagery.</td></tr>
<tr><th>Metadata</th><th>Example</th></tr>
<tr><td>• Spatial resolution:
30 m digital elevation model
1:20,000 landslide inventory
(50% at 1:10,000)
• Coordinate system: WGS84 UTM Zone 20N (EGM96 geoid)
• DEM accuracy (RMS): 1.4 m
• Time period: 2012</td><td rowspan="5">
</td></tr>
<tr><th>Input data</th></tr>
<tr><td>Satellite imagery
• Pleiades panchromatic (0.5 m)
• Pleiades multispectral (2 m)
• RapidEye multispectral (5 m)
• ASTER stereo imagery (15 m)

Ancillary data
• ASTER GDEM (30 m)
• Elevation contours
• In-situ field observations
• GPS data</td></tr>
<tr><th>Methodology</th></tr>
<tr><td>• Automated image classification of bare ground areas
• Visual image interpretation of landslides
• Photogrammetric processing of stereo imagery and calibration
• Map production
• Ground-truthing and validation</td></tr>
</table>

Figure 6. The 2012 landslide inventory and national-scale DEM for St. Lucia (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

<table>
<tr><th>Service and Product</th><th>Description</th></tr>
<tr><td>Service 2: Hazard mapping to support landslide risk assessment

Landslide inventory (2013) and digital elevation model for St. Lucia</td><td>Landslide inventory for 2013 and a national-scale 30 m digital elevation model (DEM). A total of 371 landslides were identified using the satellite imagery.</td></tr>
<tr><th>Metadata</th><th>Example</th></tr>
<tr><td>• Spatial resolution:
30 m digital elevation model
1:20,000 landslide inventory
(50% at 1:10,000)
• Coordinate system: WGS84 UTM Zone 20N (EGM96 geoid)
• DEM accuracy (RMS): 1.4 m
• Time period: 2013</td><td rowspan="5">
</td></tr>
<tr><th>Input data</th></tr>
<tr><td>Satellite imagery
• Pleiades panchromatic (0.5 m)
• Pleiades multispectral (2 m)
• RapidEye multispectral (5 m)
• ASTER stereo imagery (15 m)

Ancillary data
• ASTER GDEM (30 m)
• Elevation contours
• In-situ field observations
• GPS data</td></tr>
<tr><th>Methodology</th></tr>
<tr><td>• Automated image classification of bare ground areas
• Visual image interpretation of landslides
• Photogrammetric processing of stereo imagery and calibration
• Map production
• Ground-truthing and validation</td></tr>
</table>

Figure 7. The 2013 landslide inventory and national-scale DEM for St. Lucia (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

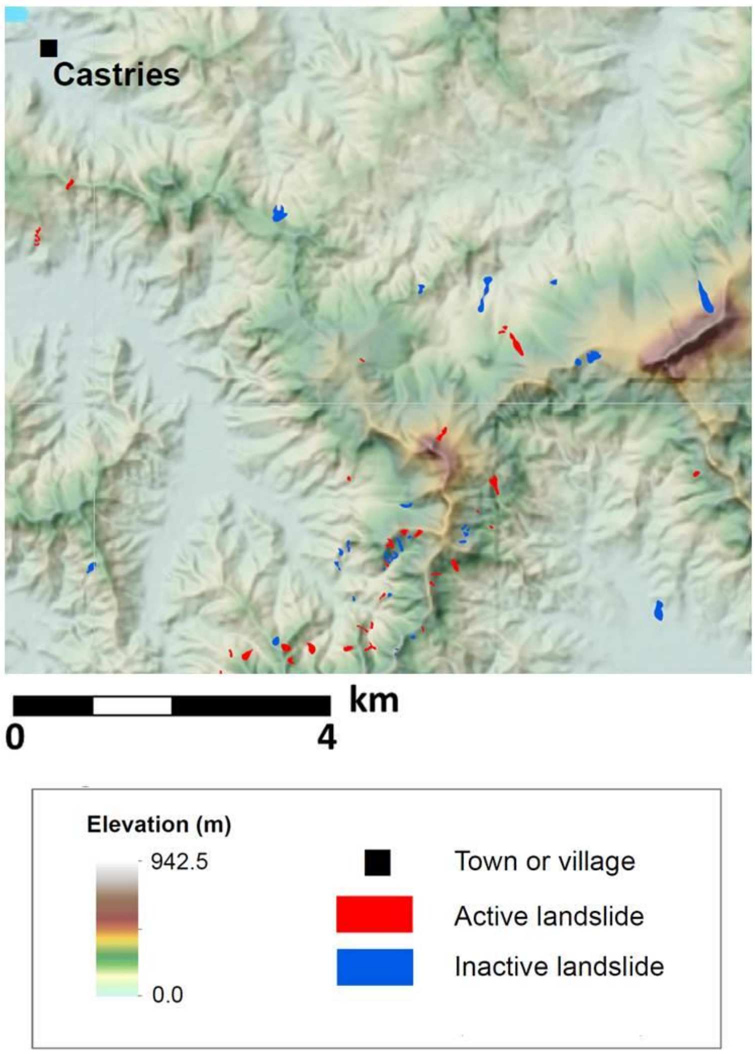
Service and Product	Description
Service 2: Hazard mapping to support landslide risk assessment Landslide inventory (2014) and digital elevation model for St. Lucia	Landslide inventory for 2014 and a national-scale 30 m digital elevation model (DEM). A total of 770 landslides were identified using the satellite imagery.
Metadata	**Example**
• Spatial resolution: 30 m digital elevation model 1:20,000 landslide inventory (50% at 1:10,000) • Coordinate system: WGS84 UTM Zone 20N (EGM96 geoid) • DEM accuracy (RMS): 1.4 m • Time period: 2014 **Input data** **Satellite imagery** • Pleiades panchromatic (0.5 m) • Pleiades multispectral (2 m) • RapidEye multispectral (5 m) • ASTER stereo imagery (15 m) **Ancillary data** • ASTER GDEM (30 m) • Elevation contours • In-situ field observations • GPS data **Methodology** • Automated image classification of bare ground areas • Visual image interpretation of landslides • Photogrammetric processing of stereo imagery and calibration • Map production • Ground-truthing and validation	

Figure 8. The 2014 landslide inventory and national-scale DEM for St. Lucia (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

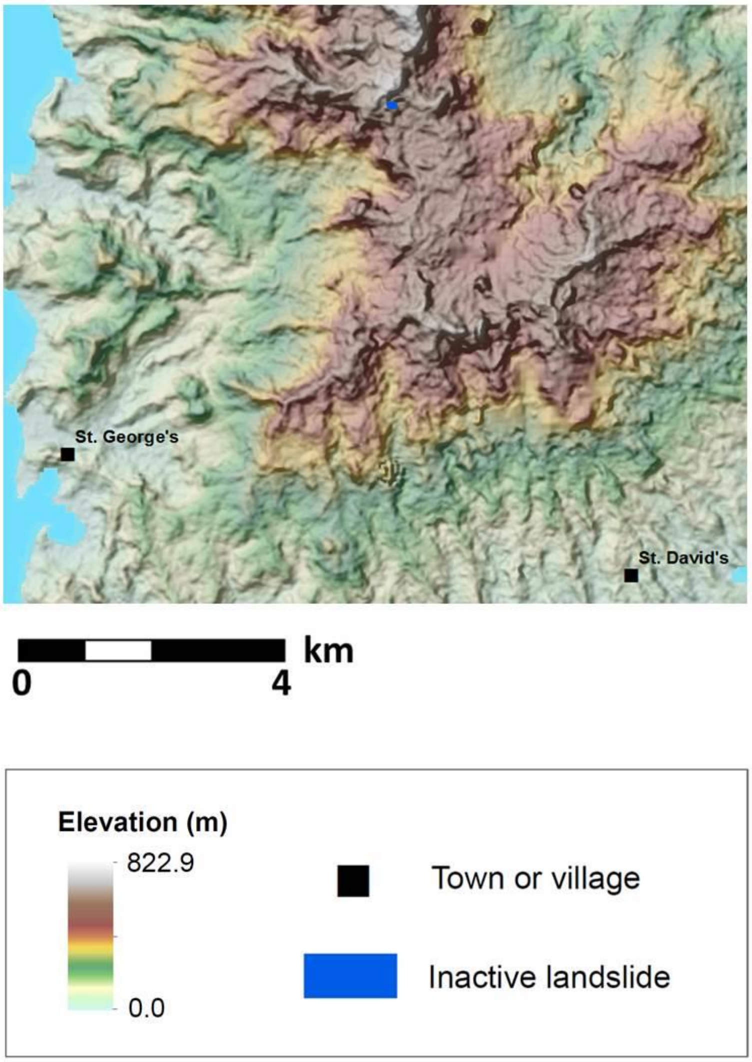
Service and Product	Description
Service 2: Hazard mapping to support landslide risk assessment Landslide inventory and digital elevation model for Grenada	Landslide inventory covering the period 2011-2014 and a national-scale 30 m digital elevation model (DEM). Only 1 inactive landslide was identified using the satellite imagery for this period.
Metadata	**Example**
• Spatial resolution: 30 m digital elevation model 1:20,000 landslide inventory • Coordinate system: WGS84 UTM Zone 20N (EGM96 geoid) • DEM accuracy (RMS): 4.9 m • Time period: 2011-2014	
Input data	
Satellite imagery • Pleiades panchromatic (0.5 m) • Pleiades multispectral (2 m) • RapidEye multispectral (5 m) • ASTER stereo imagery (15 m) **Ancillary data** • ASTER GDEM (30 m) • SRTM DEM (90 m) • Airborne LiDAR DEM (5 m) • In-situ field observations	
Methodology	
• Automated image classification of bare ground areas • Visual image interpretation of landslides • Photogrammetric processing of stereo imagery and calibration • Map production • Ground-truthing and validation	

Figure 9. Landslide inventory (2011-2014) and national-scale DEM for Grenada (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved and material © 2014 BlackBridge, all rights reserved. ASTER GDEM is a product of METI and NASA).

2.1.3 Service 3: Digital Elevation Model

The objective of Service 3 was to deliver a national-scale DEM for Belize and as a demonstration, a high-precision DEM (for an area 100 km^2) to support risk/hazard mapping. The national-scale 30 m DEM was generated using ASTER stereo imagery, while a higher resolution 20 m DEM covering 40% of the country was derived using SPOT-5 stereo satellite imagery. Pleaides tri-stereo (also refer to as triplet) satellite imagery, obtained through the ESA TPM scheme, was used to generate the high-precision 1 m DEM demonstration product.

This Service demonstrates the ability to generate both national and local-scale DEMs from optical satellite imagery with different spatial resolutions. In the absence of any other suitable elevation data, the 20 m and 30 m DEMs can be used as the basis for modelling flood risk at national-scale across Belize as part of the CHARIM project. Moreover, the precise DEM demonstration product derived from the very-high resolution Pleiades tri-stereo imagery can be used to more accurately model flood risk on a local-scale. With the ability to generate contemporary elevation data with a similar quality to airborne LiDAR, this approach represents a viable alternative to DEM production when airborne surveys are too costly or logistically challenging. Beyond flood risk modelling, high resolution DEMs such as this are important for infrastructure planning and resource management.

The DEMs delivered by this Service were quality checked for data gaps and artefacts, and rectified where necessary. In the absence of ancillary GPS or other control data, the national-scale 30 m DEM was validated using the higher resolution 20 m SPOT-derived DEM acquired from Airbus Defence & Space. The DEM was validated by computing the vertical accuracy using a subset of 32,000 randomly chosen elevation values from the 20 m DEM.

Due to issues acquiring cloud-free Pleiades tri-stereo satellite imagery during the Atlantic hurricane season, it was not possible to generate the 100 km^2 high precision DEM until relatively recently. For this reason – in addition to the lack of any suitable GPS or other control data – it has only been possible to undertake a preliminary validation of the high precision DEM to date. As for the national-scale DEM, this involved computing the vertical accuracy using 32,000 randomly chosen elevation values from the 20 m DEM.

The EO information products delivered through Service 2 are described in Figures 10-12.

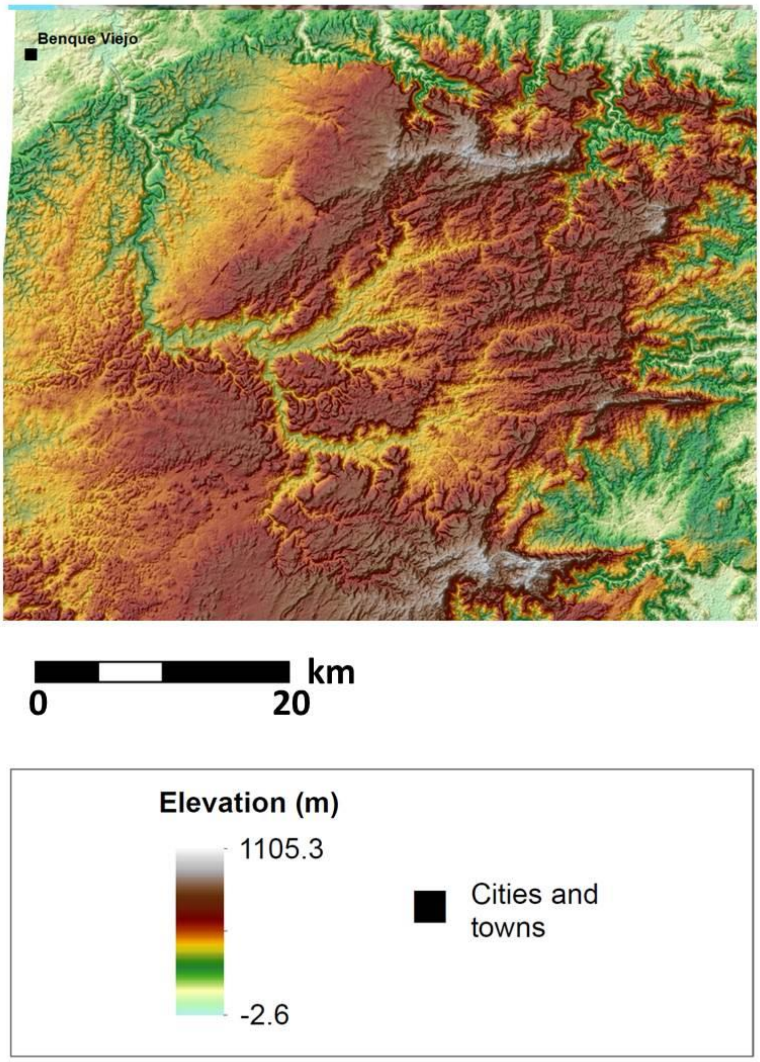
Service and Product	Description
Service 3: Digital elevation model National-scale digital elevation model for Belize	A 30 m digital elevation model generated for Belize using ASTER optical satellite imagery.
Metadata	**Example**
• Spatial resolution: 30 m • Coordinate system: WGS84 UTM Zone 16N (EGM96 geoid) • DEM accuracy (RMS): 9.8 m • Time period: 2000-2011	
Input data	
Satellite imagery • ASTER stereo imagery (15 m) **Ancillary data** • ASTER GDEM (30 m) • SPOT DEM (20 m)	
Methodology	
• Photogrammetric processing of stereo imagery • Vertical calibration with SPOT DEM • Map production • Quality checking and validation	

Figure 10. National-scale 30 m DEM for Belize (includes material © CNES 2014, Distribution Astrium Services / Spot Image S.A., France, all rights reserved. ASTER GDEM is a product of METI and NASA).

<table>
<tr><th>Service and Product</th><th>Description</th></tr>
<tr><td>Service 3: Digital elevation model

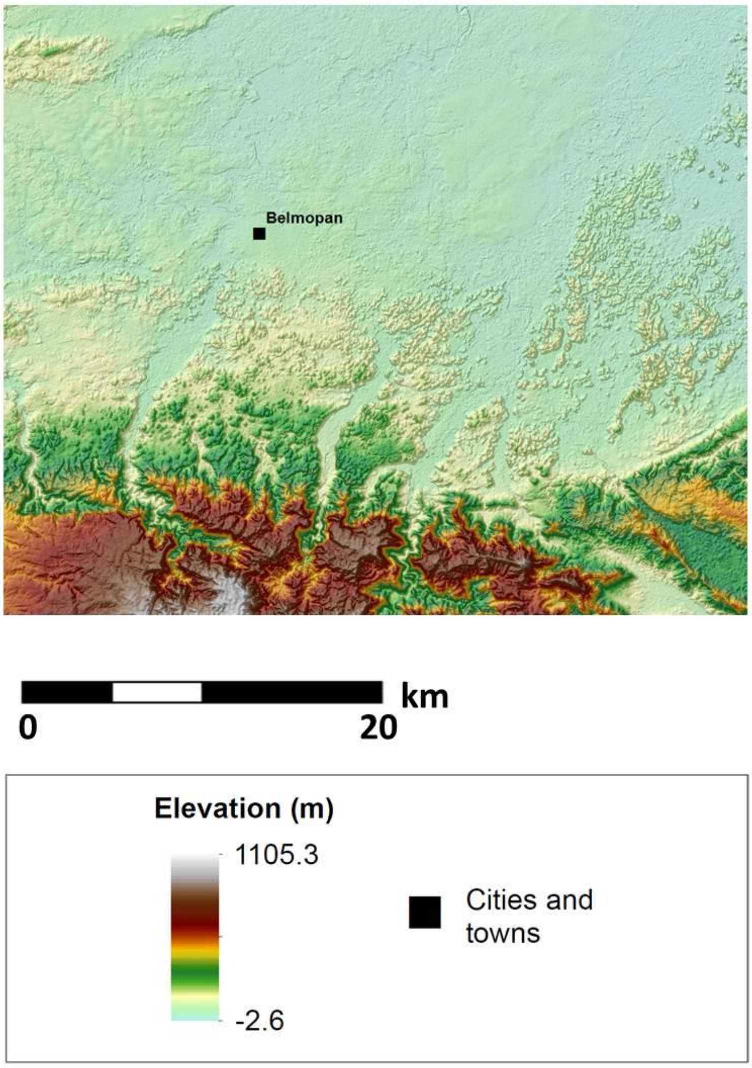
Digital elevation model for Belize</td><td>A 20 m digital elevation model (DEM) generated for Belize using SPOT-5 optical satellite imagery. This DEM provides approximately 40% coverage of Belize.</td></tr>
<tr><th>Metadata</th><th>Example</th></tr>
<tr><td>• Spatial resolution: 20 m
• Coordinate system: WGS84 UTM Zone 16N (EGM96 geoid)
• DEM accuracy (RMS): 7 m
• Time period: 2003-2006</td><td rowspan="5">
</td></tr>
<tr><th>Input data</th></tr>
<tr><td>Satellite imagery
• SPOT-5 stereo imagery (5 m)</td></tr>
<tr><th>Methodology</th></tr>
<tr><td>• Photogrammetric processing of stereo imagery
• Map production
• Quality checking and validation</td></tr>
</table>

Figure 11. The 20 m SPOT-derived DEM for a subset of Belize (includes material © CNES 2014, Distribution Astrium Services / Spot Image S.A., France, all rights reserved).

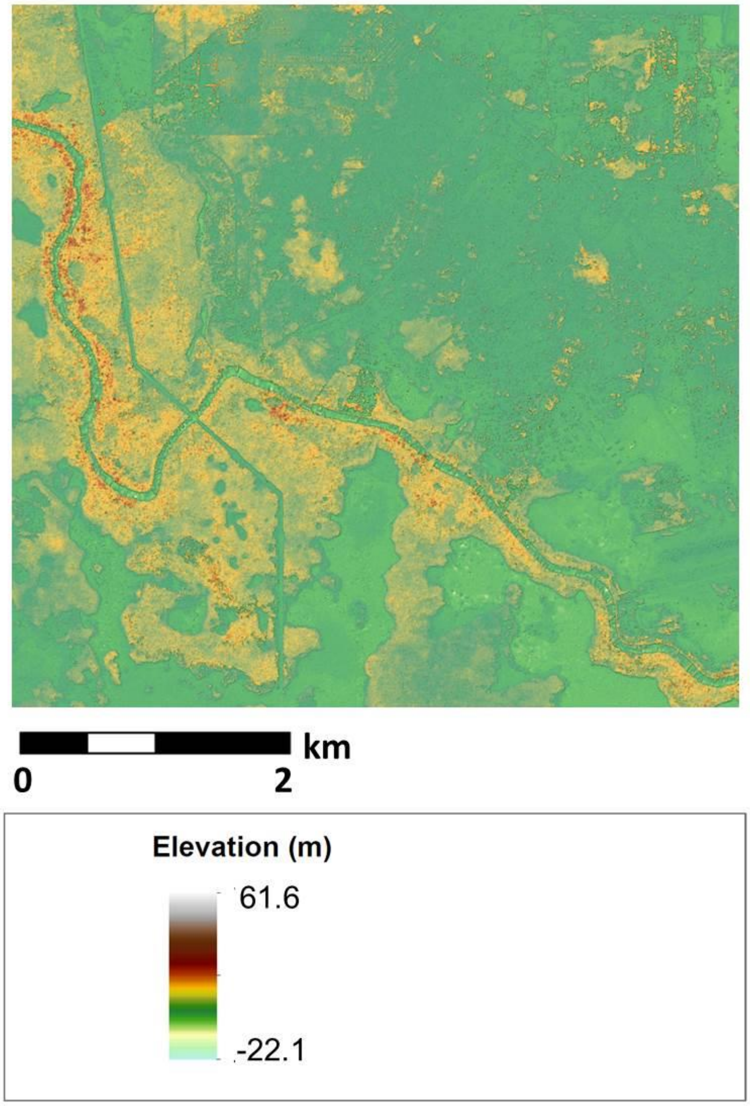
Service and Product	Description
Service 3: Digital elevation model Precise digital elevation model for Belize	A precise 1 m digital elevation model (DEM) generated using Pleiades tri-stereo optical satellite imagery. This DEM covers an area of 100 km^2 of Belize.
Metadata	**Example**
• Spatial resolution: 1 m • Coordinate system: WGS84 UTM Zone 16N (EGM96 geoid) • DEM accuracy (RMS): 4.1 m (preliminary estimate; true accuracy expected to be significantly better) • Time period: 2014	
Input data	
Satellite imagery • Pleiades tri-stereo satellite imagery (0.5 m)	
Methodology	
• Tasking of fresh tri-stereo imagery • Photogrammetric processing of tri-stereo imagery • Map production • Quality checking and initial validation	

Figure 12. The precise (1 m) DEM demonstration product for an area of Belize (includes material © CNES 2014, Distribution Airbus DS / SPOT Image S.A. France, all rights reserved).

2.2 Relevance to User Requirements

The EO products and Services delivered by this project address the issue of disaster risk management in the Caribbean region. Specifically, the Services deliver data products that are fundamental in helping to improve understanding of the risk posed by natural (geo-) hazards that frequently affect each country (Jordan et al., 2015) (Table 2). These data feed directly in to the WB-funded CHARIM project to enable flood and landslide hazard mapping to be undertaken. Dissemination of the Services via the CHARIM project will ultimately help to increase awareness of the capabilities of EO, and strengthen the capacity of regional and national governments to generate flood and landslide hazard information and subsequent application to disaster risk reduction.

Table 2 Hazard characteristics for the four countries (source: CDEMA, and Jordan et al., 2015, modified from van Westen, 2014).

	Belize	Saint Lucia	St. Vincent and the Grenadines	Grenada
Coastline	386 km	158 km	84 km	121 km
Terrain	Flat, swampy coastal plain; low mountains in south. Max. elevation 1,160 m	Volcanic and mountainous with some broad, fertile valleys. Max. elevation: 950 m	Volcanic, mountainous. Max. elevation: 1,234 m	Volcanic in origin with central mountains. Max elevation: 840 m
Natural hazards	Frequent, devastating hurricanes (June to November) and coastal flooding (especially in south).	Hurricanes and volcanic activity, debris flows, flash floods.	Hurricanes; Soufriere volcano on the island of Saint Vincent is a constant threat. Flash floods and landslides	Lies on edge of hurricane belt; hurricane season lasts from June to November. Flash floods and landslides.
Hazard characteristics	Hurricanes and tropical storms are the principal hazards, causing severe losses from wind damage and flooding due to storm surge and heavy rainfall. Hurricanes Keith (2000), and Iris (2001) caused some of the worst damage ever, reaching 45% (US$280 million) and 25% of GDP, respectively.	Saint Lucia's mountainous topography coupled with its volcanic geology means that it experiences landslides, particularly in the aftermath of heavy rains. Much of the island's housing is distributed along steep slopes and poorly engineered and constructed housing is particularly at risk. Additionally, the island periodically experiences earthquakes of generally lower magnitudes. Also storm surge and flash floods are among the other risks regularly faced by the island.	Landslides, particularly on the larger islands, are a significant hazard and the risk is increased during the seasonal rains. Coastal flooding is a major concern particularly relating to storm surge and high wave action. The Grenadines are more susceptible to drought. The active volcano La Soufriere, located on the north end of St. Vincent is another risk factor, posing threats from shallow earthquake and eruption events. Since 1900, St. Vincent has been hit by 8 named storms, the strongest being Hurricane Allen (Category 4), which passed between St. Lucia and St. Vincent in 1980. The 1939 eruption of the volcano Kick-'em-Jenny located some 100 km reports South of Grenada, generated a 2-meter high tsunami.	The country was heavily affected by Hurricane Ivan in 2004, and Hurricane Emily in 2005. There are two active volcanoes in Grenada, Mount St. Catherine in the centre of the island and the submarine volcano kick-'em-Jenny is located 8 km north of the island and has led to tsunami in the past. Flood risk in Grenada is largely associated with storm surge in low lying coastal areas. Flash flooding from mountain streams coupled with storm surge events are the primary causes of flood events and effects are generally limited to communities located in the coastal margins along stream passages. Landslides are a common event in Grenada, with much of the impact experienced along the roadway network.

The initial user requirements were determined by WB and the WB CHARIM project, and then used to define the Services in the SOW. In some cases, these initial requirements were been refined slightly following subsequent discussions with the WB team (i.e., the WB TTL and CHARIM project) and BGS-stakeholder discussions in workshops held in the Caribbean and in the Netherlands (Jordan et al., 2015). Overall, the Services are designed to support flood/landslide hazard mapping by providing essential data that is currently missing or inadequate due to limitations with the current practices. Specifically, the primary requirement is information on land cover/land use, water bodies (e.g., streams, rivers, lakes), landslides and elevation (i.e., DEMs). Acceptance of the Services by the users is therefore dependent on successfully demonstrating the capability to deliver EO products that provide information on these elements that is currently missing, or new information that represents a significant improvement over what already exists (e.g., in terms of accuracy, detail, time period). Further acceptance by the local users could also be dependent on them recognising the benefit of the EO products in applications beyond disaster risk management.

Service 1 provides comprehensive information on the main land use/land cover types, surface water bodies, basic road network and building footprints for St. Lucia, Grenada and St. Vincent and the Grenadines. Overall, the delivered EO products meet the requirements outlined in the SOW, and provide enhanced information that is considerably more detailed and up-to-date than already exists (Table 3). Although this can be implemented as an entirely stand-alone Service for land use/land cover mapping from optical satellite imagery, some aspects were augmented using ancillary baseline information (e.g., existing land use/land cover maps) in order to produce more accurate and consistent data for input to the risk assessment undertaken within the CHARIM project.

Service 2 delivered detailed landslides inventories and national-scale DEMs for St. Lucia and Grenada. The EO products fully meet the requirements, additionally providing yearly landslide inventories for St. Lucia. Although existing landslide inventories are available (see Table 3), the inventories delivered by Service 2 better capture the state of recent activity. Similarly, elevation data also exists, but is outdated, has a low spatial resolution or provides only partial coverage of the countries. Service 2 addresses this by generating DEMs with full coverage and the desired spatial resolution. The landslide inventory mapping aspect of this Service is stand-alone, as it was undertaken using information derived from the optical satellite imagery. However, as defined in the SOW, the mapping was ground-truthed using in-situ field observations. The generation of DEMs from optical satellite imagery can be implemented as a stand-alone process, but in this case was augmented with the existing elevation data to maximise the accuracy of the data for use in subsequent risk assessments.

Service 3 provides a national-scale DEM for Belize, in addition to a higher resolution regional DEM and a local-scale high-precision DEM. In contrast to Service 2, this Service is implemented as a stand-alone service for generating DEMs solely from optical satellite imagery. The resulting DEMs provide more accurate and higher resolution elevation information than currently available, therefore permitting enhanced flood risk modelling at national and local scale.

The EO information products delivered by the three Services are fundamental in assessing the flood and/or landslide risk in the four countries. However, these products must be used in conjunction with additional information (e.g., geology, soils, rainfall data) in order to robustly assess risk. Although beyond the scope of this project, optical satellite imagery and other types of EO data (e.g., radar) can be used to provide much of this additional information.

2.3 Current Practices

There is a range of skills and experience amongst the local users, ranging from little or no use of geospatial data, to complex use and understanding (e.g., research-driven activities at the University of West Indies). Table 3 lists the geospatial information currently being utilised by WB and local users through a variety of risk/hazard-related projects and initiatives in the Caribbean region. In general, flood and landslide hazard assessments to date have relied upon making the best use of any existing relevant geospatial data. However, much of this data is incomplete, generalised or somewhat outdated – with the historical data likely to have been produced through conventional means such as field surveys. Table 3 also highlights how the current project has utilised EO satellite data to help overcome limitations associated with the current practices and the availability of essential information.

In Grenada, risk mapping and GIS capability is managed predominantly by the Ministry for Agriculture, but progress is limited and digital data is relatively scarce. A vulnerability assessment of school buildings as shelters in the event of natural hazards has been completed (http://www.oas.org/CDMP/document/schools/vulnasst/gre.htm), but this did not consider landslides. Nonetheless, flooding due to torrential rain was considered, with the vulnerability assessment based on very generalised topographical and land use/land cover information gained through local field surveys. To date, a comprehensive multi-hazard map has not been prepared. The WB is implementing a Disaster Vulnerability Reduction Programme, in which Component 2 (Disaster and Climate Risk Reduction) focusses of new construction and rehabilitation of existing infrastructure in order to reduce their vulnerability to natural hazards and climate change. Included within the activities are consultancy services to undertake soil investigation mitigation measures for landslip sites in several sites. In 2006, a landslide hazard map was produced by the Caribbean Development Bank/Caribbean Disaster Emergency Response Agency. This involved producing a landslide inventory based on limited field work confined locations accessible from the road network. This inventory was used in conjunction with a DEM-derivatives derived from a contour map and low quality (i.e., outdated and generalised) soil and geology maps (see Table 3) to model landslide susceptibility. Recently, an enhanced airborne LiDAR DEM has become available, but this does not provide full national coverage. A national flood hazard assessment was also undertaken by the Caribbean Development Bank in 2006, but this did not involve rigorous hydrologic/hydraulic analysis and its reliability will be hindered by the use of outdated and generalised input data (e.g., land use/land cover, soil map) that was likely mapped through field surveys.

Table 3 Geospatial information sources currently used by WB teams and local users. The EO information delivered by the Services are highlighed in green (Jordan et al., 2015).

Geospatial information	Grenada	St Vincent and the Grenadines	Saint Lucia	Belize
DEM	10m raster DEM (source unknown) and partial LiDAR coverage	5m raster DEM (higher parts are not covered). There are LiDAR data, but the format is incorrect so they cannot be analysed	50m raster maps and contours with 2.5m intervals	ASTER (30m) and SRTM (90m). Higher resolution DEM urgently required for flood risk modelling.
	30m DEM, full coverage		**30m DEM, full coverage**	**National DEM at 30m, 40% of territory at 20m and 100km^2 at 1m**
Land use/land cover	USDA 30m raster map from Landsat data from ca. 2000.	Polygon map exists with 11 land use classes (ca. 2000)	1:50,000 raster maps. Vegetation information is in vector format	Not applicable
	Derived from 2m satellite data	**Derived from 2m satellite data**	**Derived from 2m satellite data**	
Landslide inventory and hazard map	1988: OAS study for selected towns. 2006: CDB/CDERA limited landslide inventory, not available digitally	Landslide footprints are available from 1987, but there is no detailed information.	Inventory for 1987 (USDA) and 2006 (CDB/CDERA). 2010 inventory produced from satellite imagery	Not applicable
	Landslide inventory at 1:20,000		**Landslide inventory at 1:20,000 with key areas (< 50%) at 1:10,000**	
Elements-at-risk	Non-attributed building footprints	Not available	Building footprints available for country - occupancy/ structural type unavailable	Not available
	Building footprints captured on 2m land use/land cover map	**Building footprints captured on 2m land use/land cover map**	**Building footprints captured on 2m land use/land cover map**	
Geological map	A very general one is available, made by USGS	A very general one is available, made by USGS	Vector map is available	Not applicable
Soil map	A 1959 soils report exists, but map not available	General soil map from USAID from 1990	Vector map is available	General map has been scanned by ITC
Discharge data	Continuous stream flow data do not exist	None available	None available	None available
Geotechnical data	None available to date	None available	None available	Not applicable
Rainfall data	50 stations, non-continuous data available from Land Use Division, Ministry of Agriculture, Lands, Forestry & Fisheries	None obtained thus far, but rainfall stations do exist	Hourly rainfall data for 24 stations	Missing
Socio-economic data	Missing	Missing	Missing	Missing

In Saint Vincent and the Grenadines, progress in preparation of hazard maps is also limited. To date, risk mapping has largely focussed on volcanic risks and some coastal vulnerability analyses. A landslide inventory and susceptibility map exists (produced in 1987), but this was based on generalised and somewhat outdated input data (e.g., geology, elevation, land use/land cover) and therefore will not accurately reflect the current state. Similarly, past flood hazard assessments have been hindered by coarse DEMs derived from contour maps. In recent years higher resolution elevation data (e.g., airborne LiDAR) has become available from an unknown source, although the data is currently in a format that is usable. Basic GIS-ready maps of roads, contours, rivers, coastlines, agricultural & urban land use have been prepared – primarily available through the Ministry of Planning and the National Emergency Management Organisation (NEMO). The WB is implementing a Regional Disaster Vulnerability Reduction Programme. Components include identification and creation of required baseline data for hazard assessment; development of institutional systems for the collection, sharing and management of geospatial data among national agencies and with regional institutions; training and education in applications integrating geospatial data systems, hazard and risk assessment to support decision making within various sectors and mainstream the use of these tools as a standard practice in development planning.

In Saint Lucia, landslide inventories were produced in 1987 and 2006 through field reconnaissance. However, fieldwork was confined to areas accessible from the roadside and so the inventories do not provide an accurate reflection of the spatial distribution of landslide activity. Subsequently, the Caribbean Development Bank/Caribbean Disaster Emergency Response Agency produced a landslide susceptibility map from the 2006 inventory, but this was again based on low quality (i.e., outdated and generalised) soil and geology maps and elevation data. A 2010 landslide inventory is available, although this appears to have been generated through automated classification of bare ground on satellite imagery. Accordingly, the inventory contains many false-positive landslides owing to a lack of expert knowledge and interpretation. A landslide hazard map was produced in 2012, but this predominantly relates to debris flows and there is also some concern about the source and integrity of much of the input data. A national flood hazard assessment was also undertaken by the Caribbean Development Bank in 2006, but this did not involve rigorous hydrologic/hydraulic analysis and its accuracy will be hampered by outdated and generalised input data. The WB is implementing a Disaster Vulnerability Reduction Programme. Component 2 (Technical Assistance, Regional Collaboration Platforms for Hazard and Risk Evaluation, Geospatial Data Management, and Applications for Improved Decision-Making) would finance: a series of capacity-building, knowledge-building and technical assistance interventions at the national and regional levels to support disaster risk management and climate change adaptation. There are specific areas that have been identified and proposed as high priorities for intervention. At the national level, activities would include, inter alia: i) enhancement of national hydro-meteorological monitoring networks; ii) development of an integrated watershed management plan for flood mitigation; iii) technical assistance for the establishment of maintenance monitoring systems for bridges and public buildings that would integrate natural hazards and extreme events considerations; iv) establishment of geo-spatial data sharing and management platform and related training activities; and v) climate change adaptation public education and awareness campaigns. The GeoNode platform for Saint Lucia is accessible here: http://sling.gosl.gov.lc.

In Belize, a multi-hazard risk study was undertaken in 1999 for several districts as part of a support activity for NEMO. This study focusses on landslides, volcanic and storm hazards amongst others. This assessment appears to have been based largely on historical data, local reports of the occurrence of such events and basic GIS data. Although a nationwide flood hazard map based on hydrological modelling does not appear to exist, several local- or regional studies have focussed on the susceptibility of the road network flood and coastal flooding. Nevertheless, flood hazard mapping in Belize is hindered by the absence of a detailed and accurate DEM. Previous studies were restricted to using a coarse DEM generated from a 1:50,000-scale contour map with 20 m contour intervals. Belize is participating in the Central American Probabilistic Risk Assessment (CAPRA) platform, but the initiative remains modest in Belize.

2.4 Scope of Assessment

Successful acceptance of the Services/EO information products by WB and the local users was assessed with respect to the four attributes of a sustainable service, i.e., whether they are useful, available, reliable and affordable. These success criteria are summarised below and in Appendix A. The goal was to obtain factual information (and quantitative information where possible) relating to each of these attributes.

- **Useful:** This attribute determines whether the EO Services/information products can be used to improve the user's operations (with a measurable benefit). Generally, this is assessed by considering aspects such as whether the Services provide information that is better that what already exists, new information that did not previously exist, and does this permit new analysis and work that was not previously possible. It is also important to consider whether the new information is easy to use/understand and is fit for the intended purpose, and what additional EO-based information the users would like to have access to in the future.

- **Available:** Overall, this attribute assesses the spatial and temporal coverage provided by the EO Services/products. It determines whether the EO information products can be generated in a reasonable amount of time and made available to users as and when required, and whether the data provides sufficient coverage of the areas of interest. The compatibility of the data with historical information also needs considering, as does the ability of the Service to continue producing consistent information in the future. The Service Provider (BGS) is better placed than the users to assess most aspects of this particular attribute.

- **Reliable:** This assesses whether the EO products meet the requirements and/or expectations of the users. It involves determining the level of confidence that the users have in the information products with respect to the approach used to generate them, their accuracy, quality and validation process.

- **Affordable:** This attribute involves comparing the performance, content and quality of the EO products with existing information from conventional sources to determine whether the additional benefits offered by the Services justify the costs. It also asks users to consider whether the procurement of EO-based information products could help to reduce their overall expenditure on projects.

2.5 World Bank Team Roles

The Service assessment was undertaken by the WB team (Fernand Ramirez (TTL), and Dr Melanie Kappes) in connection to the EU-funded CHARIM project together with the University of Twente ITC, The Netherlands and the local users. The CHARIM project was the primary user of the Services and EO information products delivered by this project. The WB TTL provided approval for the EO information products to be delivered to the various users. Contact between BGS and the Caribbean stakeholders (via CHARIM workshops and training courses) further helped to ensure that the Services were fit-for-purpose in the view of the end-users. The WB TTL and the CHARIM project team were the primary conduits for the Services and also acted as independent assessors for the suitability of the delivered EO products for input to flood and landslide hazard mapping. This comprised assessing whether the products meet the requirements as defined in the SOW, particularly with respect to spatial and temporal coverage, thematic accuracy and information content (e.g., preferred land use/land cover classes, landslide attributes). Close contact with the CHARIM team has been maintained throughout the project to help ensure that the EO Services satisfied the requirements and to try to incorporate any necessary refinements to the specification following subsequent discussions and feedback.

It was agreed at the outset of the eoworld2 project that direct contact between BGS and the local users would be limited, and primarily directed via the WB and ITC, in order to avoid confusion with the ongoing CHARIM project. However, dedicated Service Readiness Review and Service Utility Review meetings with the local users planned for Washington DC did not take place and were subsumed into a workshop in the Caribbean. The reduced contacts made it a challenge to fully understand the needs and expectations of the Services, and for the local users to undertake a thorough assessment of the delivered EO information products. BGS participated in a CHARIM workshop in the Caribbean in September 2014, which provided a brief opportunity to present some preliminary EO products to the CHARIM project team local users and subsequently gain feedback relating to their requirements of the products. In March 2015, BGS also participated in the CHARIM training workshop at ITC (in The Netherlands) on ‘The use of geo-data for landslide and flood hazard and risk assessment'. This presented the primary opportunity to provide the local users with hands-on training of working with the EO products and to have them assessed with respect to their requirements and the criteria outlined in the previous sub-section. The training was delivered as a combination of lectures – highlighting how the products were made and validated – and practical sessions that enabled the participants to evaluate the data and compare it with any existing data. The local users that attended the CHARIM workshop in the Netherlands from the relevant countries are listed in Table 4.

Table 4 Participants of the CHARIM workshop and EO product assessment.

Country	Name	Affiliation
Belize	Mrs. Gina Young	Ministry of Natural Resources and Agriculture
Belize	Mr. Irving Thimbriel	Ministry of Works and Transport
Grenada	Mr. Fabian Purcell	Ministry of Communication, Works, Physical Development, Public Utilities, ICT and Community Development
Grenada	Mr. Jason Williams	Ministry of Communication, Works, Physical Development, Public Utilities, ICT and Community Development
St. Lucia	Mrs. Karen Augustin	Ministry of Physical Development, Housing and Urban Renewal
St. Lucia	Mrs. Renate McKie	Ministry of Infrastructure, Port Services and Transport
St. Lucia	Mr. Mervin Engeliste	Watershed Management Authority
St. Vincent and the Grenadines	Mr. Desmond Shallow	Ministry of Housing, Informal Human Settlements, Lands & Surveys and Physical Planning
St. Vincent and the Grenadines	Mr. Andy Baptiste	Ministry of Transport, Works, Urban Development and Local Government

3 EO INFORMATION SERVICES ASSESSMENT

3.1 Methods

The EO service/information products were subjected to a three-stage assessment which incorporates the feedback received throughout from the WB TTL and the CHARIM project, in addition to that of the local users obtained during the initial contact at the CHARIM workshop in the Caribbean (September 2014) and the subsequent training workshop in the Netherlands (March 2015). As outlined above, one of the main phases of the assessment took place during the workshop at ITC, where the EO products were evaluated in some detail by the local users. As part of the evaluation, the users were provided with a form to capture their feedback (see Appendix B). The form was designed to gain feedback relating to the four assessment attributes above, with a particular emphasis on identifying the benefits of each of the EO Services and information products over current practices, their perceived limitations and any additional information products that may be of particular use in the future. The main outcomes of the assessment are summarised below.

3.2 Service Utility

3.2.1 Service 1: Land use/land cover mapping

Overall, the assessment for the Service 1 land use/land cover information products resulted in positive feedback, with all users agreeing that the new products provide better information than the existing land use/land cover maps. Specifically, the new products were perceived to provide much more detail than the existing maps in terms of spatial resolution, while also providing an updated representation of the current land use/land cover:

- *“The new land use/land cover maps are more precise and accurate where the old one is general” – Grenada.*
- *“The map quality is an improvement to the previous one (higher resolution)…more classes of land cover identified” – St. Vincent and the Grenadines.*
- *“Generally seems to be good and properly represented…there is no new information, but it shows an updated land cover map” – St. Lucia.*

With some minor refinement, the land use/land cover maps were used to successfully support the landslide and flood risk mapping within the CHARIM project (e.g. http://www.charim.net/sites/default/files/handbook/maps/SAINT_LUCIA/FINAL_LANDSLIDE_SAINT_LUCIA.pdf). Moreover, many of the local users recognised that the timely delivery of information through the Service could enable them to undertake new work that was not previously possible based on current practices and information:

- *“The land cover maps for Grenada, Saint Lucia and Saint Vincent are very important datasets for us, and they will certainly contribute a lot to improving the quality of the landslide and flood maps for these islands” – CHARIM project team.*

- *“This will result in on time delivery of maps which can assist in decision making and planning. When a map is done using other methods it sometimes takes too long to materialise and sometimes the land cover may have changed before even producing a map” – St. Lucia.*

- *“Can help with development decision making and help in preserving of watersheds” – Grenada.*

- *“The map can be useful in monitoring changes in forest cover…gives a good idea as to where development is taking place” – St. Vincent and the Grenadines.*

The majority of users stated that more detailed information on the land use/land cover types would be beneficial:

- *“Some of the types in the legend should be separated” – Grenada.*

- *“It will be nice if the cultivated land class could be further split into other uses” – St. Vincent and the Grenadines.*

- *“Classes for new land use/land cover maps need to be separated to be used for informing decisions for watershed management” – Grenada.*

The land use/land cover classes used in the mapping were selected to ensure full compatibility with the existing maps. In the future these classes could be easily refined with input from the users to further enhance the information content of the maps.

3.2.2 Service 2: Hazard mapping to support landslide risk assessment

The landslide inventories delivered by Service 2 were primarily of interest to the CHARIM project because these were essential inputs to the landslide risk mapping. The St. Lucia inventory delivered by this Service was particularly useful because it provided the most comprehensive and up-to-date representation of recent landslide activity:

- *“The landslide inventory map for Saint Lucia is a very important dataset for us, and it will certainly contribute a lot to improving the quality of the landslide map for the island” – CHARIM project team.*

Relatively little feedback on the national-scale DEMs was received from the local users, possibly due to unfamiliarity in working with elevation data or the similarity in spatial resolution between the delivered DEMs and those that already exist. Nevertheless, one local user expressed some degree of satisfaction with the DEMs, but suggested that a higher resolution product would be more desirable:

- *“The DEM was more or less OK. A higher resolution DEM will be appreciated though” – Grenada.*

Although the DEMs delivered by the Service met the specifications outlined in the SOW, the intention was to produce 10 m DEMs for St. Lucia and Grenada. Unfortunately, this was not possible due to the inability to acquire suitable cloud-free imagery during the project timeframe because of the hurricane season. Nevertheless, this Service has successfully demonstrated that it is possible to produce DEMs from stereo optical satellite imagery, irrespective of the resolution.

3.2.3 Service 3: Digital Elevation Model

Based on the feedback received, the 20 m DEM delivered for part of Belize under this Service was deemed to provide information that is significantly better than the existing data, in terms of both spatial resolution and accuracy:

- *“The 20m map is better than we currently have, which is a 30m” – Belize.*

The precise 1 m DEM demonstration was considered to be the most useful by the users because it would enable much more accurate flood risk mapping than currently possible using the existing 30 m DEM:

- *“The maps are useful, especially the 1m, this is really what we need” – Belize.*

3.3 Service Availability

3.3.1 Service 1: Land use/land cover mapping

The land use/land cover maps for the islands were generated using a combination of automated image classification and visual interpretation. As a result, each map was produced in approximately three days, which is significantly quicker than possible through conventional field-based mapping. The ability of the Service to produce land use/land cover maps in a timely manner and the benefits offered by this were recognised by local users:

- *“I believe that the land cover maps generated through satellite takes so little time as doing it on site. This will result in on-time delivery of maps which can assist in decision making and planning” – St. Lucia.*

The land use/land cover classes are based on those in the existing maps, ensuring that compatibility is maintained. The methodology used the generate the maps is predominantly objective, meaning that it can be employed to produce consistent land use/land cover maps both in to the future, as well as from archived satellite imagery. The ability to produce consistent land use/land cover maps makes this Service particularly advantageous to the local users going forward:

- *"Images on a 2-year interval from 2000 to future years would be appreciated" – St. Lucia.*

The maps produced under this Service provide an order of magnitude increase in spatial resolution in comparison to the existing 30 m land use/land cover maps. As highlighted above, all users commented that the new 2 m maps would enable them to undertake new work that was not previously possible using the existing data. Nevertheless, one local user did believe that higher resolution information would be more advantageous for monitoring purposes:

- *"A 2 m resolution is good, but for on the ground monitoring a 1 m or 50 cm resolution would be better" – St. Lucia.*

The maps were produced at a 2 m resolution because this is the native resolution of the multispectral bands on which land use/land cover discrimination is dependent. Nevertheless, it is possible to perform pan-sharpening using the panchromatic band to increase the spatial resolution of the multispectral imagery to 50 cm. However, this could potentially pose technical challenges for processing the imagery for relatively large areas because the file size will increase dramatically.

3.3.2 Service 2: Hazard mapping to support landslide risk assessment

The landslide inventories were initially produced from the very-high resolution RapidEye and Pleaides satellite imagery before being validated in the field. This combined approach to mapping was used to generate comprehensive landslide inventories in a more time-efficient manner than possible through field mapping alone. For St. Lucia, the multi-temporal approach employed also demonstrates the ability to produce consistent landslide information both historical imagery and imagery acquired in the future. In this particular case, the multi-temporal mapping approach made it possible to monitor the activity of individual landslides throughout the 5-year period. This approach can also be used to continue to monitor landslide activity into the future.

Only one landslide was identified for Grenada during the 4-year period covered by the satellite imagery. This lack of information on previous landslide activity therefore made it difficult for the CHARIM project to model the future hazard. However, this was not an issue with the mapping approach employed in this Service, but rather the restriction on the time period for the mapping that was defined in the SOW (i.e., using imagery no older than 2010). To gain a better understanding of the previous landslide activity, the CHARIM team acquired archived imagery that pre-dated 2010 and used the same methodology to derive a landslide inventory.

The DEMs for St. Lucia and Grenada appeared to be of lower importance to the users. Nonetheless, one local user did express an interest in having access to a higher resolution DEM for Grenada. As discussed above (sub-section 3.2.2), the acquisition of fresh stereo imagery was tasked, which would have enabled the generation of 1-m DEMs for St. Lucia and Grenada. However, all attempts to acquire suitable imagery within the timeframe of the project were hampered by the persistent cloud cover during the Atlantic hurricane season. Despite this, the Service demonstrated the ability to generate DEMs from optical stereo satellite imagery for the entire area of interest in a timely manner. Moreover, the largely automated nature of the processing means that consistent elevation information can be generated from both archived and future stereo imagery, if required.

3.3.3 Service 3: Digital Elevation Model

This Service demonstrates the ability to generate DEMs for Belize from stereo and tri-stereo imagery a several types of satellite imagery with different spatial resolutions (30 m, 20m, and 1 m). Again, owing to the largely automated technique used to generate the DEMs, consistent elevation data can be rapidly derived from both future and historical imagery. As in Service 2, the main constraint affecting the ability to produce the DEMs in this Service is the successful acquisition of stereo or tri-stereo imagery with acceptable levels of cloud cover.

The 1 m and 20 m DEMs were both deemed to represent a significant enhancement over the existing 30 m DEM. Although the 1 m DEM demonstration met the 100 km^2 coverage specified in the SOW, the local users thought it was preferable to have national-scale coverage at this level of detail and quality. Whilst this is possible, it would require additional imagery and more processing time. Furthermore, one of the local users considered bathymetric data for the wetland areas to also be important for assessing flood risk:

- *"The limitation is the ability to effectively resolve the areas covered by water; most of the areas of work are in such areas" – Belize.*

Although not within the remit of this project, it is technically possible to extract bathymetric data from high-resolution optical satellite imagery in relatively shallow water. This is one aspect of the Service that could potentially be upgraded in the future.

3.4 Service Reliability

3.4.1 Service 1: Land use/land cover mapping

The land use/land cover maps were validated using a combination conventional confusion matrices and limited field verification. Information about this validation procedure was provided to the users. This was sufficient information for most users to accept the EO products with a high level of confidence, although others felt that it would be necessary for them to conduct their own ground-truthing before they could incorporate the products into their work activities:

- *"I believe that the BGS has the ability to provide maps for the region in a timely manner and is also accurate" – St. Lucia.*
- *"It makes a great base map for further ground work/field verification" – St. Vincent and the Grenadines.*
- *"Some more ground work can be done to verify information on the ground" – Grenada.*
- *"Ground truthing to verify represented information on the maps would allow for monitoring of development and growth" – St. Lucia.*
- *"The accuracy will help in certain developments" – Grenada.*

The main issue associated with this Service was the incompleteness of the rivers and roads layers across the entire area of interest:

- *"For some instances the roads and rivers seem to disappear" – St. Lucia.*
- *"Rivers and streams in some areas appear to be incomplete" – Grenada.*

This is due to a combination of cloud cover in the imagery and obscuring by dense vegetation. Although the issue with cloud cover can be overcome by acquiring imagery at a different time of year, the problem with vegetation obscuring roads and rivers is a problem that persists in tropical settings. The use of airborne LiDAR to generate 'bare-earth' to create digital terrain models is the only effective way of overcoming the obscuring effects of vegetation. Furthermore, existing road / river network maps could be used as a baseline, and updated using satellite imagery. This is an exercise that the Planning / Surveying Ministries could undertake.

Some minor land use/land cover misclassifications were noted by the CHARIM team. This specifically related to misclassification between some vegetation types, and between some buildings, bare ground and roads. This is due to similarities in their spectral characteristics in the imagery at visible to near-infrared wavelengths detected by the sensors. The target thematic accuracies specified in the SOW were achieved, but such classification confusion can be reduced through manual refinement or the use of satellite imagery with more spectral wavebands. Although for current satellite sensor technology, it should be noted that imagery with additional spectral information generally has a lower spatial resolution.

3.4.2 Service 2: Hazard mapping to support landslide risk assessment

The landslide inventories initially produced from very-high resolution satellite imagery were subsequently validated on the ground and updated appropriately. The vast majority of the mapped landslides visited in the field were verified, thus providing an extra level of confidence in the EO products. The use of multi-temporal imagery ensured full spatial and temporal coverage for the entire areas of interest, with the remote sensing approach enabling mapping of areas that were inaccessible on the ground (Jordan et al., 2015). No issues regarding the landslide inventories for St. Lucia were raised, and these were used successfully by the CHARIM team for hazard mapping. The only issue for Grenada was the lack of landslide activity during the time period specified in the SOW. With hindsight, the specification needed adjusting to incorporate imagery that was acquired prior to 2010, when a climate event caused significant landsliding on the island.

Little feedback on the reliability of the DEMs was received, but discussions with the local users revealed that they were generally satisfied with the quality DEMs and the validation procedure. The only specific comment was that higher resolution DEMs would be preferable.

3.4.3 Service 3: Digital Elevation Model

Due to a lack of accurate elevation data (e.g., GPS), the DEMs for Belize were subjected to a preliminary validation procedure. Understandably, this has implications for the level of user confidence in the EO products:

- *“The maps are useful…but verification needs to be done first” – Belize.*

Nonetheless, the potential of this approach to generating DEMs that are comparable to other state-of-the-art techniques in terms of accuracy and detailed is clearly recognised:

- *“We have been asking for LiDAR, but for some projects these maps that you produce can substitute for the accuracy needed” – Belize.*

3.5 Service Affordability

3.5.1 Service 1: Land use/land cover mapping

The existing land use/land cover maps for the countries were produced from freely-available Landsat satellite imagery acquired ca. 2000. Although free, the data have only a moderate spatial resolution of 30 m. In contrast, the new land cover maps were predominantly generated from very-high resolution Pleiades satellite imagery, which provides an order of magnitude increase in the spatial resolution (2 m) of the resulting maps. Access to the Pleiades satellite imagery was provided through the ESA TPM scheme, but commercially such imagery typically costs upwards of €17 per km^2. Taking into account the overwhelmingly positive feedback from users, it is apparent that the enhanced information content, quality and subsequent benefits of the new maps fully justify the costs. Moreover, land use/land cover mapping using EO data is generally more time and cost efficient than conventional field-based mapping. This was recognised by one local user:

- *"EO products will enable me to reduce the overall expenditure of data collection" – Grenada.*

3.5.2 Service 2: Hazard mapping to support landslide risk assessment

Landslide inventory mapping was based largely on the visual interpretation of multi-temporal Pleaides and RapidEye satellite imagery. This imagery enabled the extent of landslides to be mapped in detail and their failure mechanisms to be determined across the entirety of the St. Lucia and Grenada areas of interest. In this project the imagery was obtained free-of-charge through the ESA TPM scheme, but the commercial cost of such imagery is typically €17 per km^2 and €0.95 per km^2, respectively. The cost benefit of the Service is fully justified just on the basis that it can be utilised to produce national-scale landslide inventory maps more efficiently than possible using conventional field mapping techniques. Moreover, previous attempts to produce landslide inventories have focussed only on field mapping in areas accessible from the roadside, whereas this EO-based Service provides a means of overcoming accessibility issue to generate more comprehensive inventories. Furthermore, EO data provides the user with the opportunity to undertake historical mapping from archived data and extend this into the future for long term monitoring activities. It should also be noted that the same Pleiades data used for land use/land cover mapping in Service 1 was also used to generate the landslide inventories. The ability to utilise the imagery for multiple applications only acts to further justify the costs.

The national-scale DEMs for St. Lucia and Grenada were generated using ASTER stereo satellite imagery with a spatial resolution of 30 m and vertical accuracies (RMS) better than 5 m. Although elevation data with a higher spatial resolution and accuracy can be acquired through traditional ground-based GPS surveys, this approach is extremely inefficient when covering large areas. Airborne LiDAR can provide accurate and high resolution elevation data, although surveys have to be commissioned and can therefore be very costly. At a cost of approximately $60US for a scene covering 3600 km^2, ASTER satellite imagery proves a cost effective means of generating a DEM for applications such as national-scale landslide and flood hazard mapping. If temporal coverage of the DEM is not an issue, then the 30 m ASTER Global DEM, generated using imagery acquired in 2000–2011, is available free of charge. As was initially planned for this project, optical stereo imagery acquired by the Pleiades satellites can be used to generate DEMs with a much higher spatial resolution (ca. 1 m) and vertical accuracy. Such imagery can be acquired for a cost in the region of €29 per km^2, and would enable the landslide and flood risk to be mapped more accurately.

3.5.3 Service 3: Digital Elevation Model

Although offering a slightly enhanced spatial resolution and vertical accuracy over the 30 m ASTER-derived DEM for Belize, the 20 m DEM generated from SPOT satellite imagery is more expensive at a cost in the region of €2 per km^2. Accordingly, in the absence of a DEM produced through traditional means, the use of stereo satellite imagery is the most cost effective method of producing a DEM of Belize for national-scale flood risk mapping purposes.

The precise 1 m DEM for 100 km^2 of Belize provides a demonstration of the full potential in using optical satellite to generate accurate and high-resolution DEMs. In this case, the DEM was generated using state-of-the-art Pleiades tri-stereo satellite imagery. Again, the imagery was acquired free of charge through the ESA TPM scheme. Commercially, this type of imagery costs in the region of €50 per km^2. Whilst this is quite costly, the feedback from the users suggested that a DEM of this quality and accuracy is urgently required for accurate flood risk mapping in Belize because it far exceeds that of the existing DEM. Based on this alone, the cost associated with this Service appears fully justified with respect to the potential benefits and opportunities it can bring. The 1 m DEM delivered by the Service is comparable to the resolution and accuracy achievable using airborne LiDAR. In generally, the generation of DEMs from tri-stereo optical imagery is probably more cost effective than airborne LiDAR for mapping areas up to 200 km^2.

3.6 Overall Appraisal

Overall, the results of the assessment provide clear evidence of acceptance of the Service and EO information products by the users. The ability to utilise EO data to produce land use/land cover maps that are considerably more detailed than the existing data was greatly appreciated by all users:

- *“The use of satellite data for generating land cover maps is pretty accurate as it relates to what is really on the ground. Hence I support the use of satellite imagery to generate land cover maps”* – St. Lucia.

The users also recognised the benefit of using EO data to map land use/land cover and landslides efficiently, thus enabling them to reduce their overall expenditure on data collection in comparison to traditional fieldwork. Another major strength of the EO approach is the ability to produce consistent land use/land cover data in a timely manner, which would provide local users with the means to undertake various monitoring activities that are not possible or viable using current practices. This is permitted by the development and application of largely automated and objective processing techniques in the Service. Use of EO data was also deemed to be particularly advantageous in helping to generate more comprehensive landslide inventory maps, thus overcoming the accessibility issues that limit traditional field-based mapping approaches. The ability to generate DEMs from the optical imagery was perceived to be another major strength of the Services. This was particularly true for the precise 1 m DEM for Belize, with one local user adamantly stating that data of that quality was what they urgently required to enable accurate flood risk mapping.

A major limitation of the EO Services was the dependency on cloud free imagery. Many users commented on the incompleteness of the rivers and roads layers owing to clouds and associated shadows in the imagery. Cloud cover is arguably one of the main restrictions on the use of EO data in tropical environments such as the Caribbean region, largely because of the Atlantic hurricane season. The probability of acquiring useable cloud-free imagery can be maximised by increasing the time duration of the acquisition window or to avoid tasking during known climatic events.

Although information on the validation of the EO products using conventional procedures was provided, it is apparent that some local users preferred the opportunity to undertake their own field validation. This may be partly due to the relative unfamiliarity of these users with EO-based products and conventional validation procedures. Although not possible in this project, more interaction with the local users prior to and during the assessment phase would have helped to improve the level of confidence these user have in the reliability of the EO products. Despite this, all users were able to recognise the substantial benefits provided by the use of EO data in their activities.

4 EO SERVICE SUSTAINABILITY

4.1 EO Service Recommendations

Following the user assessment, it is recommended that future implementation of Service 1 should involve some refinement of the land use/land cover classes, with input from the local users. The required classes would undoubtedly vary between applications, but it should be possible to define a common set of classes to meet the overall needs of the range of users. Additionally, it might also have been useful to demonstrate to the users the capacity of Service 1 to generate land use/land cover maps that can be used for monitoring purposes.

One of the main recommendations for Service 2 is the extension of the time period covered by the landslide mapping inventories. Only one landslide was identified for Grenada during the specified period in the SOW, which made it difficult to accurately represent previous landslide activity in the hazard modelling. A further recommendation is to always seek to utilise the available satellite imagery with the highest spatial resolution. Although the RapidEye imagery has a relatively high spatial resolution (5 m), the pan-sharpened Pleiades imagery (0.5 m) provides an order of magnitude increase in the amount of detail that can be resolved. Consequently, the Pleiades satellite imagery provided a step-change in the capability to map landslides in this complex terrain, by enabling smaller occurrences to be detected and the style of landslide activity (e.g., rotational, translational, complex) to be determined. Ultimately, having access to very-high resolution satellite imagery acquired prior to 2010 would have aided the generation of a more comprehensive inventory, and subsequently helped to gain a better understanding of the controls on landslide activity.

Services 2 and 3 could be improved by providing national-scale DEMs that represent a significant increase in spatial resolution over the existing data. The specification of 30 m national-scale DEM would probably need increasing to at least 10 m to enable more accurate landslide and flood risk modelling undertaken by the CHARIM project. This project aimed to address this for St. Lucia and Grenada by delivering 1 m DEMs derived from Pleiades stereo satellite imagery. However, this was not possible within the timeframe of the project because of difficulty in acquiring usable cloud-free imagery. For Service 3, one user recommended that the precise 1 m DEM would be extremely useful for the whole of Belize. Moreover, based on user feedback, Service 3 could also be updated to assess the ability extract shallow bathymetric data from very high resolution optical satellite imagery.

Access to relatively cloud-free imagery has been one of the primary constraints on this project, hampering both the land use/land cover mapping and DEM generation aspects of the Services. One general improvement for the future would be to adjust the timing of the project to ensure that the tasking of new satellite imagery does not coincide with the hurricane season. This would help to significantly improve the chances of acquiring imagery with acceptable levels of cloud cover.

The three Services have been designed primarily to meet the needs and requirements of the CHARIM project. For this reason, contact with the local users has been restricted. Accordingly, it has been somewhat challenging to gain a better understand of needs and expectations of local users in order to help ensure that the delivered EO products are also fit for their purposes. More dedicated interaction with the entire range of users would help to address this, while also allowing a more rigorous assessment of the Services to be undertaken.

4.2 Relevance to Wider Bank Operations

This project demonstrates the ability to utilise EO data to provide risk information services for disaster risk management. Specifically, the Services have provided fundamental geospatial information directly for input to the landslide and flood risk mapping that has been undertaken for the Caribbean region by the WB CHARIM project. Nevertheless, the type of EO-derived land cover/land use maps, landslide inventories and DEMs delivered by Services 1, 2 and 3 are also relevant for other WB disaster risk-related projects, such the sub-Saharan African landslide risk project that has recently commenced, and the WB Regional Disaster Vulnerability Reduction project. In fact, information on land use/land cover and DEMs should be considered a mandatory requirement of any hazard mapping project, whether that be related to the disaster risk or the risk posed by climate change. The generation of landslide inventory maps using EO data, as demonstrated in Service 2, is especially useful in rugged or mountainous terrain as this approach helps to overcome accessibility issues that limit traditional field surveys. Recently, BGS has employed this approach for mapping co-seismic and monsoon-induced landslides in Nepal following the 25 April 2015 earthquake (e.g. http://www.bgs.ac.uk/research/earthHazards/epom/Nepalearthquakeresponse.html).

Service 1 has the capability to generate temporal land use/land cover information which would be of considerable benefit to other WB Urban Development, Forestry, and Coastal/Ocean monitoring projects being undertaken as part of the eoworld2 initiative. Specifically, the approach used in Service 1 could be used to support ongoing WB forestry, biodiversity and conservation projects in South America, Africa and Indonesia. Moreover, the combination of land use/land cover, river/stream information and DEMs would be applicable to watershed management projects in areas such as Nigeria and India, and sustainable land and water management projects in Ghana and Mauritania. The EO data and techniques utilised in Service 1 can also be modified to contribute information in support of projects concerning food security. For example, such approaches can be used to provide information on agricultural productivity in areas with harsher climatic conditions, in particular Africa and the Middle East.

Service 3 demonstrates the ability to generate accurate and high-resolution DEMs from very high resolution optical satellite imagery. Accordingly, such an approach provides a valuable cost-effective alternative for acquiring elevation data in parts of the world where airborne LiDAR surveys are not feasible due to financial or political constraints. However, if terrain elevation information is required, then airborne LiDAR is perhaps more suitable in areas with dense forest, such as the Caribbean, South America, Indonesia and forested regions of Africa.

4.3 Conclusions

This project successfully demonstrates how information derived from EO data can contribute directly to flood and landslide disaster risk management in the Caribbean by providing fundamental geospatial information on land use/land cover, landslides and DEMs. The users appreciated the ability to produce this information from EO data with a higher degree of detail and accuracy than already available, in a more time- and cost-effective manner. Another major strength of the EO approach is the ability to produce consistent information, both historical and in the future (as soon as imagery is acquired). This provides users with the means to undertake various monitoring activities that are not possible or viable using current practices. The main limitations of the EO approaches in the Services were perceived to be the cloud cover and the validation of the EO products. Cloud cover and associated shadows in the imagery made it challenging to achieve complete coverage of the areas of interest during the hurricane season. Although unavoidable here, this issue can be mitigated in the future by either extending the tasking window or planning the acquisition of new imagery around the hurricane season. All the EO products delivered by the Services were validation using conventional practices where possible. However, some users felt that it was necessary to further validate the products through their own additional ground-truthing. This may be partly due to the relative unfamiliarity of these users to EO based products and conventional validation procedures. Accordingly, in future additional interaction with the local users may be required to increase their level of confidence in the reliability of the EO products. Nonetheless, in summary, all users expressed acceptance of the Services, with the delivered EO products appearing to either meet or exceed their expectations.

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APENDIX A: GUIDELINE QUESTIONS FOR EO INFORMATION PRODUCT / SERVICE ASSESSMENT

(NOTE: It is well-known that it will be difficult to get factual (and even more difficult to get quantitative) feedback from the Users. This is especially the case with the World Bank TTLs, as many of them will have never previously worked with EO-based digital information before).

Do not get 'yes/no' answers to the questions below, but dig further to get to the underlying facts.

Useful

- Did the EO based products provide information that already exists in the information/working processes of the project?
- Did the EO based products provide information that you did not previously have?
- Would you describe the EO products as being fit for the purpose of how you planned to use them?
- What problems did you have in trying to use the EO based information?
- Can you draw conclusions from the EO based products that can be directly input into your activity on this project?
- Did the EO based products provide a structure to better understand or utilise the information you already have?
- Were EO based products generated in shorter time scales than alternative sources of information and does this represent a significant advantage for your projects?
- Does the information from the EO based products enable you to undertake new analysis, monitoring or other management tasks that were previously not possible or viable?
- The products generated were a subset of the originally requested information – what additional parameters derived from satellite Earth Observation would you be interested in having access to?
- How would you describe the benefits of this type of information within your project-based work?

Available

- Were the products generated in a reasonable amount of time?
- Were there technical problems and constraints that prevented requested information being generated?

- Will consistent or similar products continue to be available for all of your areas of interest?
- Is sufficient historic information available over all areas of interest at an appropriate scale or resolution?

Reliable

- Did the information provided from the EO based products meet your expectations?
- Was the information generated for all areas of interest and all time periods of interest at an acceptable level of quality and performance (e.g., timeliness, accuracy)?
- Was validation information provided and if so, did this address the concerns you may have with respect to using the information provided?
- Are there best practices, standardised working practices or defined standards applicable for the collection and analysis of geo-information with respect to your projects and has the EO based information been generated in a manner consistent and compliant with these?

Affordable

- How does the information content, quality and performance compare with alternative sources of information that you have used?
- How do the ROM costs for EO product generation compare with available budgets for data collection and analysis?
- Would the procurement of EO based products enable you to reduce the overall expenditure on data collection and analysis? If not, does inclusion of EO based products reduce uncertainty and lack of information in a manner that contributes to a tangible reduction of overall project risk?

APPENDIX B: EO PRODUCT ASSESSMENT FEEDBACK FORM

EO Product Feedback Form

A product review comprises an important aspect of this European Space Agency and World Bank initiative. As end-users, your feedback is crucial in helping to establish whether the Earth Observation (EO) based products that have been generated (i.e., land use/land cover maps, digital elevation models, landslide inventory) meet your needs and requirements. Feedback such as this is extremely important in helping us to ensure that any future products can be of maximum benefit to end-users.

Accordingly, we would be most grateful if you could please some spend time evaluating the products and capturing your thoughts in the table below. We'd very much like to know what specific things you like about the products, what you don't like (and why), and any suggestions on how to improve the products.

Some things to consider are:

- Do the EO based products provide information that you did not previously have?
- If not, how does the information content, quality and performance compare with alternative sources of information that you have used?
- Will the information from the EO based products enable you to undertake new analysis, monitoring or other management tasks that were previously not possible or viable?
- Are the EO based products available in suitable formats (e.g., paper maps, digital maps, ArcGIS files)?
- Do you think that the procurement of EO based products would enable you to reduce the overall expenditure on data collection and analysis? If not, does inclusion of EO based products reduce uncertainty and lack of information in a manner that contributes to a reduction of overall project risk?
- Has the EO based information been generated in a manner consistent or compliant with you working practises and standards?
- Has validation information provided and if so, does this address the concerns you may have with respect to using the information provided?

Name:...

Product title	Comments