# The Role of Earth Observation for Managing Biodiversity and Disasters in Mesoamerica: Past, Present, and Future

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**Abstract** Mesoamerica is a term used sometimes in cultural context, but in this article we are using it to name the land bridge between North and South America, made up of the Southern Mexico States (Chiapas, Quintana Roo, Yucatán, Campeche y Tabasco), Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. With an area of approximately 755,000 square kilometers, it is one of the most heterogeneous regions of the world in terms of elevation, land forms, climate, natural ecosystems and human populations. In the general context given, the potential of Earth observation (EO) to assist the management of natural resources, biodiversity and disasters in the region is clear. In this chapter, we discuss the current state of EO applications and future perspectives related to land-use change, ecosystem dynamics and biodiversity and solid-earth hazards. We hope that this contribution can identify current and future challenges related to obtaining the biggest societal benefit of EO and suggest actions to take advantage of anticipated innovations and data availability.

## 1 Introduction

Mesoamerica is a term used sometimes in cultural context, but in this article we are using it to name the land bridge between North and South America, made up of the Southern Mexico States (Chiapas, Quintana Roo, Yucatán, Campeche y Tabasco),

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Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. With an area of approximately 755,000 $km^2$, it is one of the most heterogeneous regions of the world in terms of elevation, land forms, climate, natural ecosystems, and human populations.

With an estimated population of 58 million inhabitants by 2015, of which close to one third are under 15 years of age, the population is expected to grow to 69 million inhabitants by 2030 (Celade 2004, 2014; CONAPO 2014). Population growth dynamics vary from country to country with extremes in Guatemala, which is projected to have between 2015 and 2030 a 1.87 %/year increase in population and El Salvador that is projected to have 0.39 %/year increase for the same period. Ethnic diversity is another characteristic of human populations in Mesoamerica, with over 60 different ethnic/linguistic groups (Center for Support of Native Lands, National Geographic 2002). Around one third of the population lives with less than US$4/day and therefore they are considered poor, although the trend appears to be the reduction of this number (World Bank 2013).

The region has also been the scene of violent conflicts, including civil wars in Guatemala, El Salvador and Nicaragua that concluded by the end of the 1990s decade. More recently, and in connection with common crime, gangs, and organized crime, four of the eight countries in Mesoamerica (Honduras, El Salvador, Belize, and Guatemala) have been included in the top ten ranking of murder rates per 100,000/inhabitants (UNODC 2013). The aggregate effects of poverty and violence are the believed cause of massive migrations, highlighted recently by the crises of unaccompanied children migrating from Central America and Mexico into the U.S. (Pierce 2015).

Mesoamerica is one of the original proposed global biodiversity hotspots and contains 24,000 species of plants, 2859 species of vertebrates and is one of the leading regions of the world regarding the presence of endemic species (Myers et al. 2000). The northern part of the region is one of the eight centers of origin of domesticated plants, for world crops like maize, beans, peppers, tomato, cotton, and cacao (Vavilov and Freier 1951). Around 28 % of all the terrestrial area is under some kind of formal protection (UNEP-WCMC 2014) but there is concern regarding the limitations of the effectiveness of protected areas in conserving biodiversity, preventing deforestation and degradation(Blackman et al. 2015), which is often interpreted as the results of economical and social issues and the general scarcity of resources to manage and administer protected areas.

Deforestation is one of the biggest threats for biodiversity and protected areas in Mesoamerica. An estimated 5 million hectares of forest have been lost between 2000 and 2013 in the eight countries of the region (Hansen et al. 2013). Deforestation has been historically linked to the promotion of colonization by governments, spontaneous migration and more recently to the increasing importance of agro-industrial crops like oil palm (Rival and Levang 2015). Fire in the wild-lands is closely related to agricultural expansion because of the almost universal use of fire as a clearing tool and is the other big threat to biodiversity. Severe fire events occurred in 1998, 2003, and 2005 when hundreds of thousands of hectares of forests and savannas burned for several months and smoke of those burnings reached the U.S. (Wang et al. 2006).

Mesoamerica is also a region vulnerable to disasters that cause periodically important human and material losses. Statistics between 1990 and 2014 indicate that there have been 36 earthquakes, 104 floods, 17 landslides, 82 storms, and 21 volcanic events. These disasters have caused more than 28 thousand deaths, left homeless close to one million people and caused US$50 billion in damages (Guha-Sapir et al. 2009).

In the general context given, the potential of Earth Observation (EO) to assist the management of natural resources, biodiversity, and disasters in the region is clear. In this chapter, we discuss the current state of EO applications and future perspectives related to Land-use Change, Ecosystem Dynamics and Biodiversity, and Solid-Earth Hazards. We hope that this contribution can identify current and future challenges related to obtaining the biggest societal benefit of EO and suggest actions to take advantage of anticipated innovations and data availability.

# 2 Current State

## *2.1 Land-Use Change, Ecosystem Dynamics, and Biodiversity*

Wide availability and free access of remote sensing data along with advances in communications technology have made possible, relatively recently, an exponential growth of the use of EO data. The turning point in this growth of applications was probably the decision to make freely available all Landsat data in the U.S. Geological Survey (USGS) archive by 2008, when distribution went from a few thousand scenes by year to millions by year (Turner et al. 2015). Mesoamerica is no exception to that trend and increasingly more uses and applications are present in government, private, and academic contexts.

To characterize the recent progress and current state in the use of EO data in applications related to land use change, ecosystems, and biodiversity carried on in Mesoamerica we selected examples at national and regional scales. Information on 19 cases has been collected, 11 of them focused at the national level, and 8 are regional or multicountry level. A summary of these cases is presented in Table 1.

The earliest analysis included in Table 1 (Vreugdenhil et al. 2002) was the Map of Ecosystems of Central America and had the primary objective to describe the ecosystems to establish a baseline of biodiversity in the region and serve as a basis for biological monitoring programs. The map was also intended to be used as a reference in the design of the Mesoamerican Biological Corridor. The map was derived using visual interpretation of Landsat scenes with local experts in each country, helping to delineate ecosystems with a strong emphasis on field verification and ecosystem data collection. The map was perhaps the first time EO data was used at the regional scale, and still today is used even if the acquisition date of the Landsat scenes ranged between 1997 and 1999.

As expected, the most often used EO data comes from the Landsat Project (63 %), followed by the Moderate Resolution Imaging Spectroradiometer (MODIS)

**Table 1** Selected EO applications in Mesoamerica on land-use change, ecosystem dynamics, and biodiversity

| Description | Country coverage | Sensors | Acquisition date | Method | Institution | References |
|---|---|---|---|---|---|---|
| Map of the ecosystems of Central America | GT, BZ, HN, SV, NI, CR, PA | Landsat | 1997–1999 | Visual interpretation of remote sensing data, field verification | World Bank and the Comisión Centroamericana de Ambiente y Desarrollo (CCAD) | Vreugdenhil et al. (2002) |
| Changes in land cover and deforestation in Central America 1990–2008 | GT, BZ, HN, SV, NI, CR, PA | AVHRR, Landsat, MODIS, Spot Vegetation, MERIS, Alos Palsar | 1981–2010 | Data compilation, digital classification of remote sensing data, field verification | Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC) | Cherrington et al. (2011) |
| Ocean Algal bloom monitoring for Mesoamerica | MX, GT, BZ, HN, SV, NI, CR, PA | MODIS | 2005–present | SeaDAS (SeaWiFS Data Analysis System) image processing | Mesoamerican Regional Visualization and Monitoring System (SERVIR) | Graves et al. (2007) |
| Potential Impacts of climate change on Biodiversity in Central America, Mexico, Dominican Republic | MX, GT, BZ, HN, SV, NI, CR, PA, DO | Inputs related to landuse derived from Landsat | 1997–2005 | Data integration, climate change anomalies derivation | Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC) | Anderson et al. (2008) |
| Using EO data to improve REDD+ policy | MX, GT, BZ, HN, SV, NI, CR, PA, DO | Landsat, MODIS, SRTM, TRMM | 1995–present | Data integration, decision tools, digital classification of remote sensing data | Resources for the Future, Inc and Mesoamerican Regional Visualization and Monitoring System (SERVIR) | Blackman (2013) |

(continued)

**Table 1** (continued)

| Description | Country coverage | Sensors | Acquisition date | Method | Institution | References |
|---|---|---|---|---|---|---|
| Operational program for the detection of hot-spots using remote sensing techniques | MX, GT, BZ, HN, SV, NI, CR, PA | AVHRR, MODIS | 1998–present | AVHRR and MODIS fire detection algorithms adapted to the region | Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) | Flasse and Ceccato (1996) Giglio et al. (2003) Ressl et al. (2009) |
| MAD-MEX: Automatic Wall-to-Wall Land Cover Monitoring for the Mexican REDD-MRV Program Using All Landsat Data | MX | Landsat | 1993–2008 | Digital classification of remote sensing data | Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Comisión Nacional Forestal (CONAFOR), Instituto Nacional de Estadística y Geografía (INEGI) | Gebhardt et al. (2014) |
| A National, Detailed Map of Forest Aboveground Carbon Stocks in Mexico | MX | Landsat, Alos Palsar, SRTM | 2000–2008 | Modeling of the relationship between fused optical and SAR data and field above ground biomass measurements | Comisión Nacional Forestal (CONAFOR), Woods Hole Research Center (WHRC) | Cartus et al. (2014) |
| Mangroves of Mexico: extent, distribution, and monitoring | MX | Aerial photos, SPOT, Landsat | 1970–2010 | Visual interpretation of aerial photos, digital classification of remote sensing data | Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) | Rodríguez-Zúñiga et al. (2013) |
| A novel Satellite-based Ocean Monitoring System for Mexico | MX, GT, BZ, HN, SV, NI, CR, PA | MODIS | 2002–present | Algorithms to obtain surface temperature, and ocean color products, chlorophyll–a concentration, total suspended matter concentration, chlorophyll fluorescence and other variables | Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) | Cerdeira López (2011) |

(continued)

**Table 1** (continued)

| Description | Country coverage | Sensors | Acquisition date | Method | Institution | References |
|---|---|---|---|---|---|---|
| Dynamics of forest cover in Guatemala | GT | Landsat, Aster | 2000–2010 | Digital classification of remote sensing data | Instituto Nacional de Bosques (INAB), Consejo Nacional de Áreas Protegidas (CONAP), Universidad del Valle de Guatemala (UVG), Ministerio de Ambiente y Recursos Naturales (MARN), Universidad Rafael Landívar | INAB, CONAP, UVG, URL (2012) |
| Geospatial Information System for Fire Management (SIGMA-I) in Guatemala | GT | MODIS, Landsat, TRMM | 1998–2009 | Data compilation, digital classification of remote sensing data | Consejo Nacional de Áreas Protegidas (CONAP), Instituto Nacional de Bosques (INAB), Coordinadora Nacional para la Reducción de Desastres (CONRED), Ministerio de Ambiente y Recursos Naturales (MARN) | CONAP, INAB, CONRED, MARN (2010) |
| Forest cover and deforestation in Belize: 1980–2010 | BZ | Landsat | 1979–2010 | Digital classification of remote sensing data | Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC), Land Information Centre, Forest Department | Cherrington et al. (2010) |
| A MODIS generated land cover mapping of Honduras: a base-line layout to create a national monitoring center | HN | MODIS | 2009 | Digital classification of remote sensing data | University of Utah, Escuela Nacional de Ciencias Forestales | Rivera et al. (2011) |

(continued)

**Table 1** (continued)

| Description | Country coverage | Sensors | Acquisition date | Method | Institution | References |
|---|---|---|---|---|---|---|
| Application of low resolution satellite data for the detection and monitoring of fire in Nicaragua | NI | AVHRR | 1996–2003 | AVHRR and MODIS fire detection algorithms | Ministerio de Agricultura y Forestal, Ministerio de Ambiente y Recursos Naturales | Mejía et al. (2004) |
| Classification of coastal marine ecosystems in Costa Rica | CR | RapidEye, Worldview 2 | 2009–2011 | Digital classification of remote sensing data | Coastal Marine Biodiversity Project, Sistema Nacional de Áreas de Conservación, Deutsche Gesellschaft für Internationale Zusammenarbeit | BIOMARCC, SINAC, GIZ (2012) |
| Consistent historical time series of activity data from land use change in Costa Rica | CR | Landsat, RapidEye | 2000–2012 | Digital classification of remote sensing data | Agresta Sociedad Cooperativa, Digital Image Processing, Universidad de Costa Rica, Universidad Politécnica de Madrid | Agresta, Dimap, Universidad de Costa Rica, Universidad Politécnica de Madrid (2015) |
| High-fidelity national carbon mapping for resource management and REDD+ | PA | Landsat, MODIS, airborne LiDAR | 2008–2012 | Modeling of the relationship between LiDAR, field above ground biomass measurements and optical remote sensing data | Department of Global Ecology, Carnegie Institution for Science | Asner et al. (2013) |
| High resolution mapping of forest and forest types in Central America | GT, BZ, HN, SV, NI, CR, PA | Rapideye | 2011–2013 | Digital object oriented classification of remote sensing data | REDD-CCAD/GIZ Program and national counterpart agencies | Jimenez (2013) |

Country codes: MX = Mexico, GT = Guatemala, BZ = Belize, SV = El Salvador, HN = Honduras, NI = Nicaragua, CR = Costa Rica, PA = Panamá instrument (42 %), RapidEye and Advanced Very High Resolution Radiometer (AVHRR) (both with 16 %). Other data used included SPOT Vegetation, Medium Resolution Imaging Spectrometer (MERIS), Phased Array type L-band Synthetic Aperture Radar (PALSAR), Shuttle Radar Topography (SRTM), Tropical Rainfall Measuring Mission (TRMM), aerial photography, SPOT, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Worldview and Airborne Light detection and ranging (LiDAR). More than half of the applications (53 %) used multi-sensor, multi-resolution data, with two cases in which at least four sensors were integrated to obtain a final product (Cherrington et al. 2011; Blackman 2013).

The dominant application found was land use and land-use change mapping (53 %), often explicitly coupled with REDD+ support (42 %), followed by fire management mapping and support (21 %). Other applications included ecosystem mapping (16 %), biomass mapping (10 %), ocean monitoring (10 %) and only in one case (Anderson et al. 2008), biodiversity modeling was a primary objective of the application (4 %).

Applications working in an operational mode (21 %) include the production of fire monitoring outputs (Ressl et al. 2009), ocean monitoring (Graves et al. 2007; Cerdeira López 2011), and a REDD decision support system (Blackman 2013). Applications that do not produce outputs uninterruptedly, but that will likely do so periodically on an annual or multi-annual basis (37 %) are mostly related to REDD + support, fire management, mapping and land use and land-use change mapping (CONAP, INAB, CONRED, MARN 2010; Cherrington et al. 2010; INAB, CONAP, UVG, URL 2012; Rodríguez-Zúñiga et al. 2013; Jimenez 2013; Gebhardt et al. 2014 and Agresta, Dimap, Universidad de Costa Rica, Universidad Politécnica de Madrid 2015).

Government institutions participated in the majority of the applications (58 %), followed by regional or multilateral institutions (42 %) and academic institutions (26 %). CATHALAC, SERVIR and CONABIO were involved in almost half (47 %) of the applications and maintain all the ones considered operational.

With this general overview obtained from the selected applications reviewed, we can highlight several findings:

(a) Landsat and MODIS are the most used sensors in the region and are critical for several current and future applications, including those related to REDD+ and fire monitoring. It appears that the use of high resolution data, in particular RapidEye, is gaining traction in the region, in part because the need of more detailed products (for example to map forest degradation) and also because the REDD-CCAD/GIZ Program provided all the Central America countries with a wall to wall coverage year? Is notable the limited use of SAR data in a region even though there are zones (the Caribbean coasts of Honduras, Nicaragua, Costa Rica, and Panama) where cloud coverage makes the acquisition of useful optical data very difficult.
(b) With only one example of an application explicitly aimed to biodiversity issues, it appears to be necessary to promote a more active involvement of the conservation and protected area communities in the systematic use of EO data

in the region. Several frameworks that propose specific ways in which EO can help biodiversity and conservation have emerged recently (Secades et al. 2014; Rose et al. 2015; Skidmore et al. 2015) and they should be examined to give direction to regional and national efforts.

(c) REDD+ is an emerging driving factor in the development of EO applications. All or almost all the countries in Mesoamerica have joined the Forest Carbon Partnership Facility (FCPF) and the UN-REDD Program. That implies that, to go forward with REDD, there is an obligation to build robust and transparent national forest monitoring systems that will, at least, produce baseline and consistent frequent information related to land use, land-use change, forest biomass, and forest degradation. That represents clear opportunities to develop EO applications, that will need to persist in the long term, and that may have additional uses and benefit fields like ecosystem and biodiversity monitoring.

(d) The role of SERVIR and CATHALAC has been crucial in the advances in the region and both deserve the credit for substantial progress in the transfer of knowledge, the training of human resources in the region and the development of relevant applications. However, the dependence on projects with a limited life-span that, with a few exemptions, wrap up after the project has finished and the funding has depleted is an issue that has to be addressed. If long-term applications are necessary and desirable, a bigger share of the costs of implementation have to be absorbed by the local governments and other local stakeholders with a clear long-term vision. Public institutions involvement in the selected examples is relatively high, but, they often act as cooperation recipients, and that needs to transition to full adoption of applications, included the costs that may entail.

(e) Mexico is, clearly, the regional leader in terms of systematic use and high-level of sophistication of EO applications used in land-use monitoring, biodiversity, and ecosystems. The experience and capabilities of Mexican institutions are already being used to transfer technology and knowledge to the other countries in the region trough the *"South-South cooperation to exchange experiences and capacities on MRV systems and REDD+"* project (http://mrv.cnf.gob.mx/index.php/en/) and also through the provision of EO-derived data to users in the region (Ressl et al. 2009).

## *2.2 Solid-Earth Hazards, Resources, and Dynamics*

The unique location of Mesoamerica as an isthmus between North and South America and in the Inter-tropical Convergence Zone positions this region as one the most biodiverse territories on Earth. On the other hand, this unique location also makes the region more prone to a range of natural hazards, such as volcanic eruptions, earthquakes, hurricanes, heavy rains, floods, landslides, droughts, and storm surges, to mention some (REDLAC 2008). The high presence of hazards in combination with socioeconomical and political issues creates high vulnerability conditions for the population. More than half of the population in Central America and the Caribbean are at risk from multiple hazards (Dilley 2005).

This region has a high mortality risk from geophysical (earthquakes and volcanoes) and hydrological (floods, cyclone, and landslides) hazards (Dilley 2005). El Salvador, Costa Rica, Guatemala, Dominican Republic, Nicaragua, and Honduras rank among the top 15 countries at relatively high mortality risk from multiple hazards (Dilley 2005).

Further, according to the Climate Risk Index, the top ten countries more affected by disasters between 1997 and 2006 were led by Honduras and Nicaragua at a global level (Harmeling 2007; REDLAC 2008).

According to the EM-DAT International Disaster Database (Guha-Sapir et al. 2009) from 1960 to 2015 there have been 497 natural disasters in Mesoamerica and Dominican Republic that include drought, earthquake, extreme temperature, flood, landslide, mass movement (dry), storms, volcanic activity, and wildfire. Two hundred of these disasters occurred between 2001 and 2015. This means that about 40 % of the disasters reported in the past half century have occurred in the past 15 years. The accuracy of these disaster estimations may very depending upon the methodology used to collect the data, but it shows a general trend of disasters on the rise in Mesoamerica, which aligns with the global trend. Among the most frequent disasters in Mesoamerica and Dominican Republic are floods and storms accounting for 34 and 27 %, respectively, of the total disasters reported between 1960 and 2015 (Fig. 1). The third most frequent disaster in the region is earthquakes. Accounting for 13 %. In the 2001–2015 period, the trend of disaster affecting the region is the same.

The use of EO to provide actionable information in the case of disasters has been widely used in Mesoamerica and the Caribbean. There are several examples of the

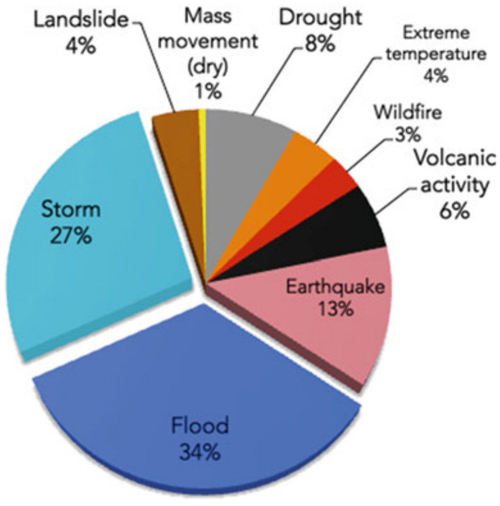


**Fig. 1** Types of natural disasters which affected Mesoamerica and Dominican Republic from 1960 to 2015. *Data source* EM-DAT The International Disaster Database (Guha-Sapir et al. 2009)

use of satellite remote sensing to assess the damages inflicted by disasters, to monitor weather events, and to provide valuable information for early warning (REDLAC 2008). This section will focus on examples in which EO data have been used primarily in post-disaster assessment, particularly for response and recovery purposes.

An example of the use of EO in disaster response is the International Charter Space and Major Disasters, (Charter for short). The Charter is "an international collaboration among EO mission owners/operators to provide space-based data and information in support of relief efforts during emergencies caused by major disasters" (Gevorgyan and Briggs 2014).

The Charter only supports the phase of immediate response to a disaster (Courteille 2015; Gevorgyan and Briggs 2014). It was created in 1999, after Hurricane Mitch had struck Mesoamerica, at the Third United Nations Conference on the Exploration and Peaceful Use of Outer Space (UNISPACE) in Vienna, where the European Space Agency (ESA) and the French space agency (CNES) proposed to supply satellite imagery to emergency responders (Rocchio 2014).

Since its activation in 2000 the Charter has covered more than 400 disasters in over 110 countries worldwide (Courteille 2015). The charter is now composed of 15 members from different space agencies and/or mission operators around the world. From the U.S., the National Oceanographic and Atmospheric Administration (NOAA), with its fleet of meteorological satellites, and the U.S. Geological Survey are authorized members of the Charter.

The Charter first provided satellite data to Mesoamerica in 2001 for an earthquake in El Salvador. Since then it has provided data for 27 different disasters covering Mesoamerica and the Hispaniola (Haiti and Dominican Republic). See Table 2.

The Charter has been activated mainly for hydrological-related disasters in Mesoamerica (Fig. 2). Hurricanes, tropical storms, heavy rains, and the resulting flooding and landslides account for more than 70 % of the major disasters in Mesoamerica and the Hispaniola that have triggered the Charter activation (Fig. 2).

Once the Charter has been activated, a project manager (PM) takes charge to quickly analyze the collected data and create value-added products for first responders (Rocchio 2014). Different types of satellite data are acquired through the Charter such as passive and active satellite remote sensing data, and from medium to high spatial resolution.

The Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC), in Panama, has acted as the project manager of 9 out of the 27 Charter activations in Mesoamerica and Hispaniola. Refer to Table 2. CATHALAC first hosted SERVIR in 2005. SERVIR links EO and geospatial technologies with developmental decision-making in SERVIR regions. Proven success of SERVIR in Mesoamerica has resulted in expansion to other regions. Currently SERVIR actively works in Eastern and Southern Africa, the Hindu Kush-Himalaya region, and the Lower Mekong region. CATHALAC—in the context of SERVIR and acting as the Mesoamerican hub- has served to connect the scientific, analytical, and decision-making needs of its users in the region. In Mesoamerica, SERVIR provided rapid response support during disasters by acquiring expedited satellite images, and

**Table 2** International charter space and major disaster activations for Central America and Hispaniola (2000–Oct 2015), organized by activation date

| No. | Call ID | Type of disaster | Country | Title | Date charter activation | Charter requestor | PM | Additional information |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Earthquake | SV | Earthquake and Landslide in El Salvador | 1/15/01 | French Civil Protection Agency | CNES | |
| 2 | 29 | Cyclone | MX | Hurricane in Yucatan, Mexico | 10/5/02 | National Forestry Agency of Mexico (CONAFOR) via the French Ministry of the Interior (COGIC) | ESA | Hurricane Isidore |
| 3 | 51 | Flood and landslide | DO | Flooding in the Dominican Republic | 11/27/03 | UNOOSA | UNOSAT | |
| 4 | 64 | Flood and landslide | HT and DO | Floods in Haiti and in the Dominican Republic | 5/26/04 | UNOOSA on behalf of UNOCHA /Red Cross | UNOSAT | |
| 5 | 72 | Cyclone | HT | Hurricane in Haiti | 9/21/04 | United Nations Office for Outer Space Affairs (UNOOSA) | CNES | Hurricane Jeanne |
| 6 | 106 | Cyclone | GT and SV | Hurricane, floods, landslides in Central America; Volcanic eruption in El Salvador | 10/5/05 | SIFEM-Argentina; UN-OCHA | Instituto Nacional del Agua | Hurricane Stan, Santa Ana volcano eruption |

(continued)

**Table 2** (continued)

| No. | Call ID | Type of disaster | Country | Title | Date charter activation | Charter requestor | PM | Additional information |
|---|---|---|---|---|---|---|---|---|
| 7 | 173 | Cyclone | MX | Hurricane in Mexico | 8/21/07 | USGS | CATHALAC | Hurricane Dean |
| 8 | 176 | Cyclone | NI and HN | Hurricane in Nicaragua | 9/4/07 | SIFEM | CATHALAC | Hurricane Felix |
| 9 | 183 | Cyclone | DO | Flooding and hurricane in the Dominican Republic | 10/30/07 | Public Safety Canada | CATHALAC | Tropical storm Noel |
| 10 | 184 | Flood and landslide | MX | Flooding in Mexico | 11/2/07 | SIFEM for the National Center for Disaster Prevention of Mexico | CATHALAC | |
| 11 | 220 | Cyclone | HT | Hurricanes in Haiti | 8/30/08 | USGS on behalf of Haiti | Office of U.S. Foreign Disaster Assistance; CNES | Hurricane Hanna, Hurricane Ike, Hurricane Gustav |
| 12 | 229 | Flood and landslide | HN | Flood in Honduras | 10/27/08 | UNITAR/UNOSAT on behalf of UN OCHA | ESA | |
| 13 | 237 | Earthquake | CR | Earthquake and landslide in Costa Rica | 1/9/09 | SIFEM (Sistema Federal de Emergencias) | CONAE | Turrialba Volcano eruption |
| 14 | 278 | Cyclone | SV | Flood and ocean storm in El Salvador | 11/10/09 | UNITAR/UNOSAT on behalf of UN OCHA; USGS on behalf of Centro de Gobierno, El Salvador | CATHALAC | Hurricane Ida |

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**Table 2** (continued)

| No. | Call ID | Type of disaster | Country | Title | Date charter activation | Charter requestor | PM | Additional information |
|---|---|---|---|---|---|---|---|---|
| 15 | 287 | Earthquake | HT | Earthquake in Haiti | 1/13/10 | French Civil Protection, UNOOSA on behalf of UN Peacekeeping Mission in Haiti (MINUSTAH), Public Safety of Canada, American Earthquake Hazards Programme of USGS | CNES in collaboration with the SAFER project in the framework of the GMES initiative. | |
| 16 | 312 | Cyclone | GT | Ocean Storm in Guatemala | 5/30/10 | USGS on behalf of CONRED | CATHALAC | Tropical storm Agatha |
| 17 | 329 | Cyclone | MX | Hurricane Karl, Mexico | 9/22/10 | USGS on behalf of Mexico National Center for Disaster Protection | USGS | |
| 18 | 342 | Cyclone | HT | Ocean Storm in Haiti | 11/5/10 | Public Safety Canada | CSA | Tropical storm Tomas |
| 19 | 348 | Flood and landslide | PA | Flood in Panama | 12/9/10 | USGS on behalf of SINAPROC/Panama | CATHALAC | |
| 20 | 378 | Cyclone | Central America, SV | Flood in El Salvador | 10/19/11 | UNITAR/UNOSAT on behalf of UN OCHA | UNITAR/UNOSAT on behalf of UN OCHA | Tropical depression |
| 21 | 396 | Volcanic eruption | GT | Eruption of lava from Fuego volcano in Guatemala | 5/21/12 | SIFEM on behalf of SECONRED | CONAE | |
| 22 | 418 | Cyclone | HT | Hurricane Sandy in Haiti | 10/29/12 | UNITAR/UNOSAT on behalf of UNOCHA | SERTIT | Hurricane Sandy |

(continued)

**Table 2** (continued)

| No. | Call ID | Type of disaster | Country | Title | Date charter activation | Charter requestor | PM | Additional information |
|---|---|---|---|---|---|---|---|---|
| 23 | 420 | Earthquake | GT | Earthquake Guatemala | 11/8/12 | SIFEM on behalf of SE-CONRED | CONRED | |
| 24 | 496 | Fire | DO | Fire in La Vega, Dominican Republic | 7/30/14 | USGS on behalf of Centro de Operaciones de Emergencias of the Dominican Republic (COE) | DLR | |
| 25 | 501 | Flood and landslide | PA | Flood and landslide in the Republic of Panama | 8/18/14 | USGS on behalf of SINAPROC /Chiriqui Province /Municipality of Tierra Alta | CATHALAC | |
| 26 | 525 | Volcanic eruption | CR | Turrialba Volcano in Costa Rica | 3/14/15 | USGS | OFDA-USGS Volcano Disaster Assistance Program | |
| 27 | 545 | Flood and landslide | GT | Landslide in Guatemala | 10/7/15 | USGS on behalf of National Emergency Operations Center of Guatemala | CATHALAC | |

*Source* compilation of data from: https://www.disasterscharter.org/ Visited on October 2015. PM = Project managers
Call ID = Charter ID # per disaster. *CONAE* Comision Nacional de Actividades Espaciales de Argentina; *CONRED* National Coordination for Disaster Reduction of Guatemala, *CSA* Canadian Space Agency; *DLR* German Aerospace Center; *OFDA* Office of US. Foreign Disaster Assistance; *SERTIT* Service Regional de Traitement d'Image et de Teledetection; *SIFEM* Sistema Federal de Emergencias; *SINAPROC* Sistema Nacional de Proteccion Civil de Panama; *UNITAR* United Nations Institute for Training and Research; *UN OCHA* United Nations Office for the Coordination of Humanitarian Affairs; *UNOSAT* Operational Satellite Applications Programme

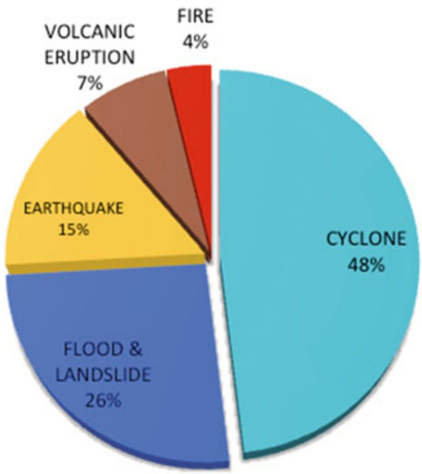


**Fig. 2** Charter Activations by Disaster Type in Central America, South of Mexico, and Hispaniola from January 2001 to October 2015. *Source* compilation of data from: https://www.disasterscharter.org/, Visited on October 2015. *Note Cyclone disasters include hurricanes, tropical storms, and tropical depressions*

creating and sharing value-added products with end users (Flores et al. 2012). While it is no longer an active SERVIR hub, CATHALAC continues to meet the needs of its network of users by applying space data to disaster response support.

Flores et al. (2012) describes the type of EO data and information used in SERVIR-Mesoamerica from 2004 to 2011 to create value added products provided for monitoring, response, recovery and general disaster awareness.

Table 3 lists the EO-derived measurements and/or products used by SERVIR-Mesoamerica from 2004 to 2011 to generate added-value products for a variety of disasters.

Then, Table 4 lists the respective satellite sensors from which the derived EO measurement and/or product were generated, respectively.

Some Level 3 satellite-derived products such as land cover, and model products such as gridded population distribution were used to link the physical hazard (cyclone, heavy rain, flood, landslide, etc.) with the human or ecological factor at risk (Flores et al. 2012).

The majority of the satellite sensors used by SERVIR-Mesoamerica to provide added value products were from passive remote sensors that collect electromagnetic energy reflected or emitted by Earth's surface. Using this type of sensors proves difficult when estimating flooded areas during heavy rain and high cloud coverage conditions. Active remote sensors, such as C-band SAR and L-band SAR on board of Radarsat 1 and 2 and ALOS, respectively, were used heavily in cases with high cloud coverage particularly to map flooded areas during disasters. Hyper spectral satellite remote sensing was used primarily for water quality assessment during cases of algal blooms and was also used for monitoring volcano activity.

Some of the satellite data used by SERVIR-Mesoamerica to address disasters was acquired through the Charter, but not all. SERVIR-Mesoamerica also provided value-added products to smaller disaster events that did not trigger the Charter activation.

**Table 3** EO-derived measurement and/or product used by SERVIR-Mesoamerica from 2004 to 2011 to analyze different type of disasters

| Disaster type | Earth observation derived measurement and/or product | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Elevation data | Rainfall | Multispectral VNIR reflectance /radiance | Hyperspectral VNIR reflectance /radiance | Fire and thermal anomalies | Burned area | Surface temperature | Land cover | Relative Humidity | Synthetic Aperture Radar (SAR) images | SRTM-water body | Gridded population distribution | Near-real time cloud movement |
| Flood | ✓ | | ✓ | | | | | | | ✓ | ✓ | ✓ | |
| Tropical cyclone/heavy rain | | | | | | | | | | | | ✓ | ✓ |
| Landslide | ✓ | ✓ | ✓ | | | | | ✓ | | | | ✓ | |
| Volcanic eruption | ✓ | | ✓ | ✓ | ✓ | | ✓ | | | | | | |
| Earthquake | ✓ | ✓ | ✓ | | | | | ✓ | | | | | |
| Fire | | | | | ✓ | ✓ | | ✓ | | | | | |
| Drought | | ✓ | | | | | ✓ | ✓ | ✓ | | | | |
| Algal bloom | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | | | |

*Source* Summarized from (Flores et al. 2012)

**Table 4** List of satellite sensors used to generate each derived measurement and/or product by SERVIR-Mesoamerica from 2004 to 2011

| EO-derived measurement and/or product | Sensor, satellite |
|---|---|
| Elevation data | SRTM<br>ASTER, Terra |
| Rainfall | Imager, GOES series<br>MVIRI, Meteosat-7/5<br>VISSR, GMS<br>TMI, TRMM<br>SSM/I, DMSP series<br>AMSR-E, Aqua<br>AMSU-B, NOAA series |
| Multispectral VNIR reflectance/radiance | AVHRR, POES series<br>MODIS, Aqua/Terra<br>ASTER, Terra<br>ALI, EO-1<br>Landsat series<br>SPOT<br>GeoEye-1<br>Ikonos<br>QuickBird<br>Worldview-1 & 2<br>Formosat-2 |
| Hyperspectral VNIR reflectance/radiance | Hyperion, EO-1 |
| Fire and thermal anomalies | MODIS, Aqua/Terra |
| Burned area | MODIS, Aqua/Terra |
| Surface temperature | Landsat Thermal Infrared (TIR) |
| Land cover, tree cover maps | MODIS, Aqua/Terra<br>MERIS, Envisat<br>Landsat series<br>ASTER, Terra<br>SPOT<br>L-Band SAR (PALSAR), ALOS |
| Relative Humidity | AIRS and AMSU, Aqua |
| Synthetic Aperture Radar (SAR) images | C-band SAR, Radarsat-1 & Radarsat-2<br>C-band SAR, ERS-2<br>L-Band SAR (PALSAR), ALOS |
| SRTM-water body | SRTM |
| Gridded population distribution | DMS series |
| Near real-time cloud movement | Imager, GOES series |

*Source* Summarized from (Flores et al. 2012)
*ASTER* Advanced Spaceborne Thermal Emission and Reflection Radiometer, *AVHRR* Advanced Very High Resolution Radiometer; *GMS* Geostationary Meteorological Satellite; *GOES* Geostationary Operational Environmental Satellite; *MERIS* Medium Resolution Imaging Spectrometer; *MVRI* Meteosat Visible Infra red Imager; *TRMM* Tropical Rainfall Measuring Mission; *PALSAR* Phased Array type L-band Synthetic Aperture Radar; *POES* Polar Operational Environmental Satellite; *SSM/I* Special Sensor Microwave Imager; *VISSR* Visible/Infra Spin Scan-Radiometer

SERVIR started in Mesoamerica when Landsat data was still not freely available, however, through SERVIR the region started getting access to such datasets and used for environmental monitoring and disaster response. As SERVIR-Mesoamerica started building up during its 5 years it also increased the generation of valued-added products for disasters to attend user needs in the region.

Today disaster response agencies across the region are heavily using EO data to address disaster response. As example national disaster institutions in Mesoamerica have become more involved in the Charter process to obtain satellite data, such is the case of SINAPROC in Panama, and CONRED in Guatemala. This last one has even acted as a project manager of the Charter.

# 3 Future Prospects

## *3.1 Land-Use Change, Ecosystem Dynamics, and Biodiversity*

Despite the challenges, the future looks promising for EO in Mesoamerica. Access to free and open data is growing at a very fast pace. Beyond Landsat we can already use data of the Sentinel constellation that may solve problems related to cloud coverage (Sentinel-1) and provide a new and valuable resource for middle resolution optical data (Sentinel-2). Already free, or being put to public access are historical data of SPOT and ALOS PALSAR providing an additional opportunity to add more layers of EO data. Data continuity for middle resolution data appears to be solved in the mid-term, with for example, plans to build, and launch Landsat 9 underway.

We think that REDD+, fire and climate change monitoring are going to be pivotal for EO applications in the near future in Mesoamerica. REDD+ processes have started in all the countries in the region, and a great part of the success of the mechanism relies on the premise of being able to monitor forests continuously and with a level of detail that will need to resolve at a highest resolution possible deforestation and degradation of forests.

Fire, closely related to REDD+, because is a cause of forest degradation, is an increasing problem in the region and also a phenomenon of interest that can be monitored using EO. We will need to be able to go from just monitoring fire, to actually helping to modify significantly its management with early alert systems tied to regulations on the use of fire as an agricultural tool, for example.

REDD+ and fire applications have the potential to be designed in such a way, that products and outputs can be used in other fields, including biodiversity, ecosystem monitoring, climate change, water management, and agriculture. Because of that, communication and collaboration between remote sensing scientists, conservation practitioners and natural resource managers is fundamental.

### 3.2 Solid-Earth Hazards, Resources, and Dynamics

The current disaster trend indicates that disasters are increasing at the local and global scale (Guha-Sapir et al. 2009).[1] This is particularly dangerous for regions like Mesoamerica that have a high mortality risk from geophysical and hydrological hazards (Dilley 2005). The use of EO data has proven useful for disaster response and recovery and given the increasing positive trend of events it is expected that the role of EO in disaster management will intensify in years to come.

The current availability of new satellite data such as the Visible Infrared Imaging Radiometer Suite VIIRS on board of Suomi National Polar-orbiting Partnership (NPP), and Landsat 8 will allow continuity of products already used in Mesoamerica for disaster monitoring and response, such as the case of MODIS products used for fire monitoring, burned areas, and land cover to mention some. In addition, new missions such as the Soil Moisture Active Passive (SMAP) will generate new understanding of weather and climate patterns.

A pressing need of the technical community using satellite data for disaster assessment, particularly for response and recovery is the access to radar data to map floods under high cloud cover. The majority of the disasters in this region are related to hydrological hazards Figs. 1 and 2, which trigger other set of hazardous events, such as floods and landslides.

The new C-band SAR sensor, Sentinel 1 from the new European EO Programme, Copernicus, will be instrumental in providing information during high cloud coverage. The advantage of Sentinel 1 when compared to other radar data is that is freely available. This will open its use and application not only for disaster-related analyses but also for other applications.

NASA and Indian Space Research Organization (ISRO) SAR Mission (NISAR) also promises to become a source of valuable data for disaster risk management with the potential ability to measure deformation before and after geophysical hazard events.

## 4 Conclusion and Way Forward

There is no doubt about the fact that EO holds an immense potential in applications related to land use, ecosystems, biodiversity, and disaster risk management. We think that is also true that this potential has not been fully used in Mesoamerica (and elsewhere in the tropics). There are several challenges to improve on that:

[1]Disaster trends. Interactive graphs that show various trends and relationships within the EM-DAT data. EM-DAT: The OFDA/CRED International Disaster Database—http://www.emdat.be/disaster_trends/index.html.

(a) Governments in the region that, in most cases, are the potential users with the power to modify policies and effectively generate change, invest very little in agencies in charge of natural resources, ecosystems, and biodiversity management. Therefore, these agencies often lack the resources to maintain technical units in charge of applications of EO.
(b) EO data is often presented in formats that are not legible enough for the audiences that can influence and make decisions, including the general public. The message that EO delivers has to be clear and understandable to all.
(c) There is often a disconnection between user needs and products. We have to examine carefully if the processes we use to choose what to do is backed by enough feedback from the people and entities that will actually use EO products to make decisions.
(d) It is critical to understand that one of the main values of EO data relies on systematic, long-term observations that actually lead to information on changes and trends. Applications that emphasize research and demonstration obviously are critical for the development of EO, but the ones that can be used operationally and with a clear, practical purpose are those that function and provide societal benefits over a long time.
(e) We have to aim, when possible, at the use of EO application products to support compliance, regulations, and law enforcement. Doing that will represent a technical and perhaps legal challenge, but it would be a significant contribution to governance and environmental justice.
(f) At regional and local scale the use of EO data should be appropriately integrated into the operational processes of disaster risk management agencies to support all the phases of disaster risk management. The generation of geospatial-baseline information primarily in urban areas is critical to properly assess pre and post-event damage needed for immediate response and recovery. Such baseline information becomes more critical in this region that is undergoing population growth and is prone to natural hazards including earthquakes.

## References

Agresta, DIMAP, Universidad de Costa Rica, and Universidad Politécnica de Madrid (2015). *Índice de cobertura como base para la estimación de la degradación y aumento de existencias de carbono*, Agresta, Dimap, Universidad de Costa Rica, Universidad Politécnica de Madrid, Costa Rica.

Anderson, E., Cherrington, E., Flores, A., Pérez, J., Carrillo, R., & Sempris, E. (2008). *Potential impacts of climate change on biodiversity in Central America, Mexico, Dominican Republic*. Panamá: Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC).

Asner, G. P., et al. (2013). High-fidelity national carbon mapping for resource management and REDD+. *Carbon Balance and Management, 8*(1), 7. doi:10.1186/1750-0680-8-7.

BIOMARCC, SINAC, & GIZ (2012). *Clasificación sistemas marino costeros costa Pacífica de Costa Rica*. Costa Rica: BIOMARCC, SINAC, GIZ

Blackman, A. (2013). Evaluating forest conservation policies in developing countries using remote sensing data: An introduction and practical guide. *Forest Policy and Economics, 34*, 1–16. doi:10.1016/j.forpol.2013.04.006.

Blackman, A., Pfaff, A., & Robalino, J. (2015). Paper park performance: Mexico's natural protected areas in the 1990s. *Global Environmental Change, 31*, 50–61. doi:10.1016/j.gloenvcha.2014.12.004.

Cartus, O., Kellndorfer, J., Walker, W., Franco, C., Bishop, J., Santos, L., & Fuentes, J. (2014). A national detailed map of forest aboveground carbon stocks in Mexico. *Remote Sensing, 6*(6), 5559–5588. doi:10.3390/rs6065559.

CELADE. (2004). *America Latina y el Caribe: Estimaciones y proyecciones de población 1950–2050*. Chile: CEPAL.

CELADE (2014). *Estimaciones y proyecciones de población a largo plazo* 1950–2100

Center for the Support of Native Lands, and National Geographic (2002). *Indigenous peoples and natural ecosystems in Central America and Southern Mexico.*

Cerdeira-Estrada, S., & López-Saldaña, G. (2011). Nuevo Sistema Satelital de Monitoreo Oceánico para México. *Ciencias marinas, 37*(2), 237–247.

Cherrington, E., Ek, E., Cho, P., Howell, B., Hernández, B., Anderson, E., Flores, A., García, B., Sempris, E., & Irwin D. (2010). *Forest cover and deforestation in Belize: 1980–2010*. Panamá: Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC)

Cherrington, E., Hernández, B., García, B., Oyuela, M. & Clemente, A. (2011). *Changes in land cover and deforestation in Central America 1990–2008*. Panamá: Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC).

CONAP, INAB, CONRED, & MARN (n.d.). *Sistema de Información Geoespacial para Manejo de Incendios en la República de Guatemala (SIGMA-I)*. Guatemala: CONAP, INAB, CONRED, MARN.

CONAPO (2014). Dinámica demográfica 1990–2010 y proyecciones de población 2010–2030

Courteille, J. -C. (2015). *International Charter "Space and Major Disasters" space-based information in support of relief efforts after major disasters*

Dilley, M. (2005). *Natural disaster hotspots: A global risk analysis*, disaster risk management (series no. 5). Washington, DC: World Bank.

Flasse, S., Ceccato, P. (1996). A contextual algorithm for AVHRR fire detection. *International Journal of Remote Sensing, 17*(2), 419–424.

Flores, A., Anderson, E., Irwin, D., & Cherrington, E. (2012). *Contributions of servir in promoting the use of space data in climate change and disaster management*. Naples, Italy: International Astronautical Federation.

Gebhardt, S., et al. (2014). MAD-MEX: Automatic wall-to-wall land cover monitoring for the Mexican REDD-MRV program using all landsat data. *Remote Sensing, 6*(5), 3923–3943. doi:10.3390/rs6053923.

Gevorgyan, Y., & Briggs S. (2014). International charter "Space and major disasters".

Giglio, L., Descloitres, J., Justice, C. O., & Kaufman, Y. J. (2003). An enhanced contextual fire detection algorithm for MODIS. *Remote Sensing of Environment, 87*(2–3), 273–282. doi:10.1016/S0034-4257(03)00184-6.

Graves, S., Yubin He M., & Hardin D. (2007). *SERVIR at the age of four: The development of an environmental monitoring and visualization system for Mesoamerica*. University of Maryland University College.

Grupo Regional Interagencial de Riesgo, Emergencia y Desastres de America Latina y el Caribe (REDLAC) (2008). *Diez años después del huracán Mitch: panorama de la tendencia de la gestión del riesgo de desastre en Centroamérica.*

Guha-Sapir, D., Below, R. & Hoyois, P. (2009). EM-DAT:International disaster database—www.emdat.be, http://www.emdat.be/advanced_search/index.html (Retrived from 2 November 2015)

Hansen, M. C., et al. (2013). High-resolution global maps of 21st-century forest cover change. *Science, 342*(6160), 850–853. doi:10.1126/science.1244693.

Harmeling, S. (2007). *Global climate risk index 2008.* Bonn, Berlin: Germanwatch.

INAB, CONAP, UVG, & URL (2012). *Mapa de Cobertura Forestal de Guatemala 2010 y Dinámica de la Cobertura Forestal 2005–2010*. Guatemala: INAB, CONAP, UVG, URL.

Jimenez, A. (2013). Metodología para el mapeo de tipos de bosques en el contexto de la cuantificación de la biomasa y el carbono forestal.

Mejía, S., Valerio, L., & Coronado, C. (2004). *Aplication of low resolution satellite data for the detection and monitoring of fire in Nicaragua* (pp. 413–417). Istanbul, Turkey: ISPRS.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*(6772), 853–858. doi:10.1038/35002501.

Pierce, S. (2015). *Unaccompanied Child Migrants in U.S. Communities, Immigration Court and Schools*. Washington, DC: Migration Policy Institute.

Ressl, R., Lopez, G., Cruz, I., Colditz, R. R., Schmidt, M., Ressl, S., & Jiménez, R. (2009). Operational active fire mapping and burnt area identification applicable to Mexican Nature Protection Areas using MODIS and NOAA-AVHRR direct readout data. *Remote Sensing of Environment, 113*(6), 1113–1126. doi:10.1016/j.rse.2008.10.016.

Rival, A., & Levang, P. (2015). The oil palm (Elaeis guineensis): Research challenges beyond controversies. *Palms, 59*(1), 33–49.

Rivera, S., Lowry, J. L., Sánchez, A. J. H., Ramsey, R. D., Lezama, R., & Velázquez, M. (2011). A MODIS generated land cover mapping of Honduras: a base-line layout to create a national monitoring center. *Revista de teledetección: Revista de la Asociación Española de Teledetección, 35*, 94–108.

Rocchio, L. E. P. (2014). *Mapping disaster: A global community helps from space landsat science*

Rodríguez, M., et al. (2013). *Manglares de México: extensión, distribución y monitoreo*. México: CONABIO.

Rose, R. A., et al. (2015). Ten ways remote sensing can contribute to conservation: Conservation remote sensing questions. *Conservation Biology, 29*(2), 350–359. doi:10.1111/cobi.12397.

Secades, C., O´Connor, B., Brown, C., & Walpole M. (2014). *Earth observation for biodiversity monitoring: A review of current approaches and future opportunities for tracking progress towards the Aichi Biodiversity Targets*. Montréal, Canada: Technical Series, Secretariat of the Convention on Biological Diversity.

Skidmore, A. K., et al. (2015). Environmental science: Agree on biodiversity metrics to track from space. *Nature, 523*(7561), 403–405. doi:10.1038/523403a.

Turner, W., et al. (2015). Free and open-access satellite data are key to biodiversity conservation. *Biological Conservation, 182*, 173–176. doi:10.1016/j.biocon.2014.11.048.

UNEP-WCMC (2014). World database on protected areas (WDPA).

UNODC. (2013). *Global study on homicide*. Vienna, Austria: UNODC.

VAVILOV, N. I., & FREIER, F. (1951). *Studies on the origin of cultivated plants.*

Vreugdenhil, D., Meerman, J., Meyrat, A., Gomez, L. D., & Graham, D. (2002). *Map of the ecosystems of Central America : Main report*. Washington, DC.: World Bank.

Wang, J., Christopher, S. A., Nair, U. S., Reid, J. S., Prins, E. M., Szykman, J., & Hand, J. L. (2006). Mesoscale modeling of Central American smoke transport to the United States: 1. “Top-down” assessment of emission strength and diurnal variation impacts. *Journal of Geophysical Research*, *111*(D5). doi:10.1029/2005JD006416.

World Bank. (2013). *Shifting gears to accelerate shared prosperity in Latin America and the Caribbean*. Washington, DC: World Bank.