# NALCMS

## The North American Land Change Monitoring System

A trinational collaboration of more than 21 million square kilometers

CEC

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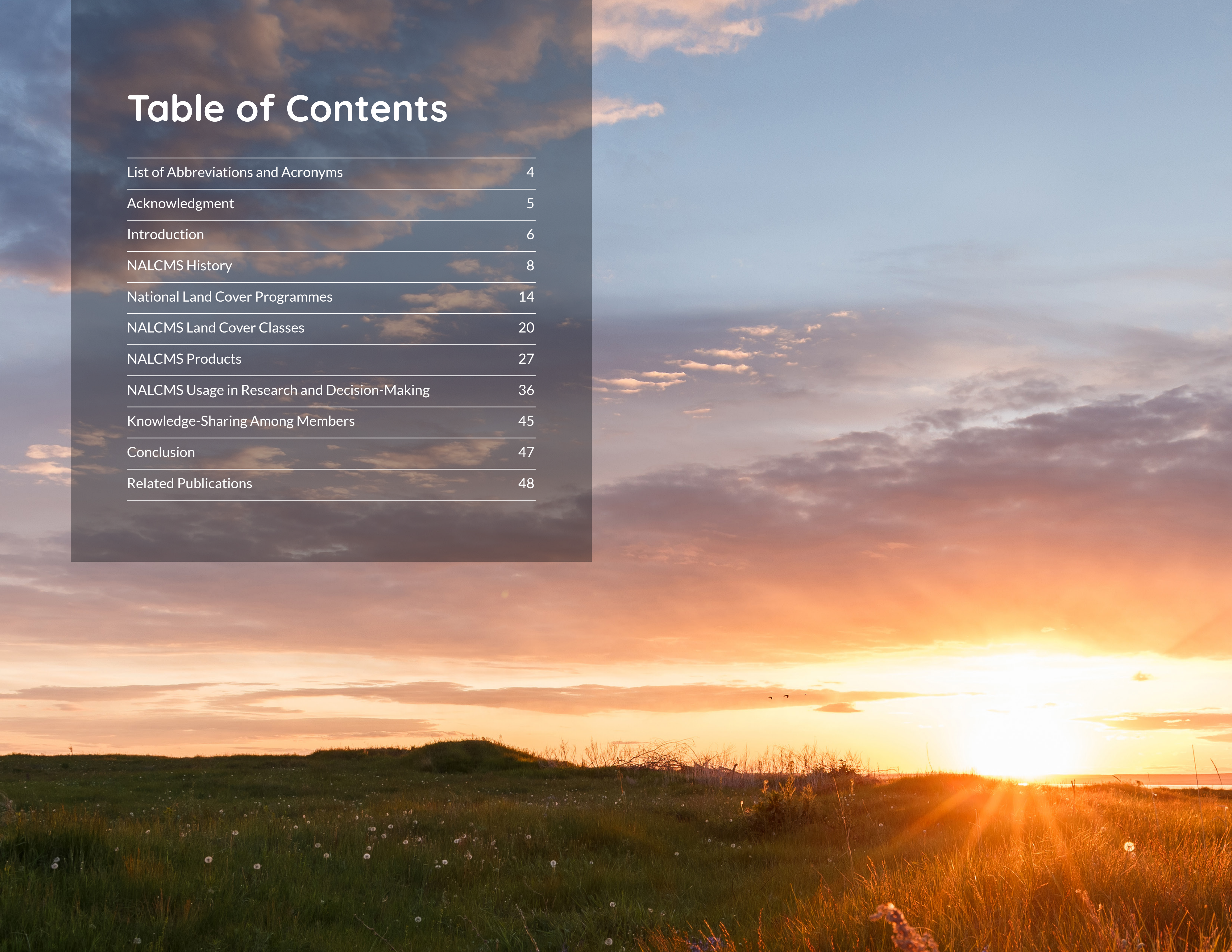

# List of Abbreviations and Acronyms

| | |
|---|---|
| **AGU** | American Geophysical Union |
| **CCMEO** | Canada Centre for Mapping and Earth Observation |
| **CCRS** | Canada Centre for Remote Sensing |
| **CEC** | Commission for Environmental Cooperation |
| **CONABIO** | *Comisión Nacional para el Conocimiento y Uso de la Biodiversidad* (National Commission for the Knowledge and Use of Biodiversity) |
| **CONAFOR** | *Comisión Nacional Forestal* (National Forestry Commission) |
| **CONUS** | Conterminous United States |
| **EROS** | Earth Resources Observation and Science (Center) |
| **ETM+** | Enhanced Thematic Mapper Plus |
| **GIS** | Geographic Information System |
| **INEGI** | *Instituto Nacional de Estadística y Geografía* (National Institute of Statistics and Geography) |
| **LCCS** | Land Cover Classification System |
| **LCMAP** | Land Change Monitoring, Assessment, and Projection |
| **MAD-MEX** | Monitoring Activity Data for the Mexican REDD+ program |
| **MIICA** | Multi-Index Integrated Change Analysis |
| **MMU** | Minimum Mapping Unit |
| **MODIS** | Moderate Resolution Imaging Spectroradiometer |
| **MRLC** | Multi-Resolution Land Characteristics Consortium |
| **NALCMS** | North American Land Change Monitoring System |
| **NLCD** | National Land Cover Database |
| **NRCan** | Natural Resources Canada |
| **SAMOF** | *Sistema Satelital de Monitoreo Forestal* (Satellite system for forest monitoring) |
| **TM** | Thematic Mapper |
| **UN-GGIM** | United Nations initiative on Global Geospatial Information Management |
| **USGS** | United States Geological Survey |

# Acknowledgment

The success of the North American Land Change Monitoring System (NALCMS) initiative stems from the experience and dedication of many people over more than fifteen years. The NALCMS products, in their current state, wouldn't exist without them. Our sincere thanks to the following people:

(in alphabetical order of last name)

## In Memoriam

### Rasim Latifovic

Natural Resources Canada (NRCan)

For nearly 20 years, Rasim was a pillar and champion of the North American Land Change Monitoring System (NALCMS) initiative.

We will miss his extraordinary knowledge, expertise and dedication on remote sensing and land cover, as well as his cheerfulness.

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# Introduction

**Environmental actions on many fronts are now critical** in the 21st century, but it is crucial that these actions are informed by scientific knowledge. How much forest cover was lost in the last 10 years due to forest fires or logging operations? How much forest cover was gained through natural regeneration and replanting efforts? How did agricultural and urban expansion change the natural landscape over the years?

Efforts to protect and conserve the environment often mention that "You can't manage what you don't measure" but it is also important to remember that you can't measure what you can't identify. For efficient and effective protection and conservation of the environment, it is critical to understand the characteristics of the land and water you are trying to protect and conserve. A picture might be worth a thousand words, but only if you can identify what you see.

Land cover information helps in this regard by converting geospatial data into information and giving a name to what you "see": "this is forest," "this is water," "these are urban areas," etc.

> **"The importance of land cover information has been highlighted by national governments around the world, including in North America.**

Through the use of satellite data, complemented with ground observations, land cover refers to the classification of surface cover on the ground, whether forest, urban infrastructure, bodies of water or agricultural land, etc., helping to distinguish natural and anthropogenic features. Identifying, delineating, and mapping land cover is important for global, regional and local monitoring studies, resource management, and planning activities. Land cover classes can include natural features such as temperate forests, shrublands, grasslands, and water bodies, as well as human-made features such as urban areas and croplands.

The importance of land cover information has been highlighted by national governments around the world, including in North America. In the United States, for example, the US Environmental Protection Agency has indicated that it "uses land cover information for many key purposes, such as assessing nonpoint sources of pollution, understanding landscape variables for ecological analyses, assessing the behavior of chemicals, and analyzing the effects of air pollution."[1]

In 2011, the United Nations initiative on Global Geospatial Information Management (UN-GGIM) was established to promote the use of geospatial information in policymaking processes and development agendas and enhance global cooperation in geospatial information management. Following discussions in 2017–2018 with representatives from national governments and international organizations, 14 Global Fundamental Geospatial Data Themes were established, including a theme for "Land Cover and Land Use."[2]

Initiatives generating land cover information from geospatial data exist at different levels, from the national level up to a global level, but depending on user needs, one initiative might be more useful than another. What of regional/continental initiatives? They are less frequent because they often necessitate direct cooperation between different national initiatives, and this involves long-term coordination and commitments between governmental agencies from different countries. This is why the North American Land Change Monitoring System (NALCMS) is such a unique initiative whose story of collaboration is presented here to inform others around the world who might also need mid-level land cover initiatives to bridge the gap between national and global ones.

[1] United States Environmental Protection Agency – Report on the Environment, Land Cover
[2] United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM, 2019) – The Global Fundamental Geospatial Data Themes

# NALCMS History

**In 2006**, the North American Land Cover Summit was sponsored by different federal governmental agencies, private sector organizations and NGOs from Canada, Mexico, and the United States for the purpose of "...pursuing collaboration among institutions and government agencies across the continent, advancing the development and application of comprehensive land cover information."[3] The event happened at the National Academy of Sciences in Washington, DC, from 20–22 September 2006.

During the Summit, the North American Land Change Monitoring System (NALCMS) was initiated by the following agencies with the overarching goal of developing "...information that simultaneously meets needs at the continental scale, while also providing information to each country to complement existing country-specific monitoring programs."[4]

[3] NASA Landsat Science – Landsat at the North American Land Cover Summit: A Summary (September 22, 2006)
[4] Latifovic, Rasim, et al. "Chapter 20 North American Land-Change Monitoring System." Remote Sensing of Land Use and Land Cover: Principles and Applications (2012): 303.

**In Canada**
Natural Resources Canada (NRCan) through its Canada Centre for Remote Sensing

**In the United States**
United States Geological Survey (USGS) through its Earth Resources Observation and Science (EROS) Center

**In Mexico**
National Institute of Statistics and Geography (INEGI, *Instituto Nacional de Estadística y Geografía*) with the involvement of the National Commission for the Knowledge and Use of Biodiversity (CONABIO, *Comisión Nacional para el Conocimiento y Uso de la Biodiversidad*) and the National Forestry Commission (CONAFOR, Comisión Nacional Forestal).

## Each of the NALCMS partners contributes their knowledge and expertise related to the generation of land cover from geospatial data:

**Canada Centre for Remote Sensing, Natural Resources Canada (NRCan)**

As a division of the Canada Centre for Mapping and Earth Observation (CCMEO), Canada Centre for Remote Sensing (CCRS) is Canada's Centre of Excellence in remote sensing science, sensors, and data.
Its research and expertise is delivered on behalf of the Government of Canada.

Website

**Mexico's National Institute of Statistics and Geography (INEGI, *Instituto Nacional de Estadística y Geografía*)**

INEGI is an autonomous public body responsible for regulating and coordinating Mexico's National System of Statistical and Geographical Information and collecting and disseminating information concerning Mexico's territory, resources, population and economy, which aid innumerable decision-making processes.

Website

**Mexico's National Commission for the Knowledge and Use of Biodiversity (CONABIO, *Comisión Nacional para el Conocimiento y Uso de la Biodiversidad*)**

CONABIO's mission is to promote, coordinate, support and carry out activities aimed at the knowledge of biological diversity, as well as its conservation and sustainable use for the benefit of society. It was conceived as an applied research organization, a promoter of basic research, that compiles and generates information on biodiversity, develops human capacities in the area of biodiversity informatics, and is a public source of information and knowledge accessible to all of society.

Website

**Mexico's National Forestry Commission (CONAFOR, *Comisión Nacional Forestal*)**

CONAFOR is a decentralized public organization whose objective is to develop, promote and encourage productive conservation and restoration activities in forestry matters, as well as to participate in the formulation of plans, programs and the application of sustainable forest policies.

Website

**Earth Resources Observation and Science (EROS) Center, United States Geological Survey (USGS)**

The EROS Center studies land change and produces land change data products used by researchers, resource managers, and policy makers across the nation and around the world. It also operates the Landsat satellite program with NASA and maintains the largest civilian collection of images of the Earth's land surface in existence, including tens of millions of satellite images.

Website

Following its creation, NALCMS was integrated as a long-term initiative of the Commission for Environmental Cooperation (CEC), which provides managerial, administrative, and financial support to NALCMS activities.

# Timeline of major NALCMS events

**An important part of the work** of the NALCMS group is sharing knowledge and experiences between members, including presenting the NALCMS products through different events to increase their visibility.

A firsthand experience with the different landscapes of North America is also important for a true understanding of the different types of land cover across the region.

Here is a list of meetings and events involving the participation of the NALCMS group over the years:

## 2006
**20–22 September**

Washington, DC, United States

Creation of the North American Land Change Monitoring System (NALCMS) at the North American Land Cover Summit

## 2007
**12–13 April**

Aguascalientes, Aguascalientes, México


NALCMS meeting

## 2008
**2–3 December**

Aguascalientes, Aguascalientes, México

Technical meeting of the NALCMS group at INEGI

## 2009
**2–4 June**

Flagstaff, Arizona, United States

Technical meeting of the NALCMS group

## 2009
**17–18 November**

Washington, DC, United States

Presentation of the 2005 North American Land Cover map at the GEO-VI meeting

## 2009
**1–3 December**

Miami, Florida,
United States

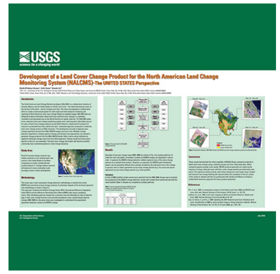
Technical meeting of the NALCMS group

## 2010
**25 March**

First publication of the 2005 North American Land Cover dataset (250m) (online & printed)

## 2010
**25–30 July**

Honolulu, Hawaii,
United States




Presentation of the NALCMS products at the 2010 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)

## 2010
**5–7 October**

Guadalajara, Jalisco,
México

Technical meeting of the NALCMS group

## 2011
**27–29 September**

Banff, Alberta,
Canada

Technical meeting of the NALCMS group

## 2012
**10–13 April**

Palm Desert, California,
United States

Technical meeting of the NALCMS group

## 2012
**4–6 December**

Mérida, Yucatán,
México

Technical meeting of the NALCMS group

## 2013
**12–15 November**

Pacific Forestry Center, Natural Resources Canada, Victoria, BC, Canada

Technical meeting of the NALCMS group

## 2014
**11 March**

First publication of the 2010 North American Land Cover dataset (250m) and of the 2005–2010 North American Land Cover Change dataset (250m) (online)

## 2014
**October**


Source: Photogrammetric Engineering and Remote Sensing, vol. 80, no. 10, October 2014.

2005–2010 North American Land Cover Change dataset promoted on the cover of the Photogrammetric Engineering & Remote Sensing (PE&RS) journal

## 2014
**28–29 October**

Boise, Idaho,
United States


Technical meeting of the NALCMS group

## 2015
**6–8 October**

Montreal, Quebec,
Canada

Technical meeting of the NALCMS group

## 2016
**12–16 September**

Homer, Arkansas,
United States

Presentation of NALCMS products at the 14th International Circumpolar Remote Sensing Symposium (ICRSS)

## 2016
**25–27 October**

Mexico City, CDMX,
México

Technical meeting of the NALCMS group

## 2017
**5–8 April**

Boston, Massachusetts,
United States

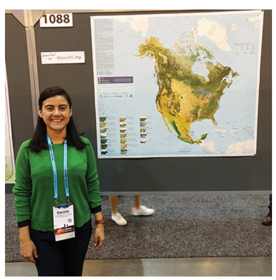
Presentation of NALCMS products at the 2017 Association of American Geographers (AAG) Annual Meeting

## 2017
**2 November**

First publication of the 2010 North American Land Cover dataset (30m)
(online & printed)

## 2017
**11–15 December**

New Orleans, Louisiana,
United States




Presentation of NALCMS products at the 2017 Fall Meeting of the American Geophysical Union (AGU)

## 2018
**30 May**

Technical meeting of the NALCMS group
(online)

## 2019
**2 October**

Montreal, Quebec,
Canada

Technical meeting of the NALCMS group

## 2020
**20 February**

First publication of the 2015 North American Land Cover dataset
(online)

## 2020
**12 November**

Technical meeting of the NALCMS group (online)

## 2020
**18 November**

First publication of the 2010–2015 North American Land Cover Change dataset (online)

## 2021
**28 October**

Technical meeting of the NALCMS group (online)

## 2023
**26–27 January**

Montreal, QC, Canada

Technical meeting of the NALCMS group

## 2023
**20 March**

20 March 2023—First publication of the 2020 North American Land Cover dataset (online)

## 2023
**19 July**

First publication of the 2015–2020 North America Land Cover Change dataset (online)

## 2024
**18–19 January**

Aguascalientes, Aguascalientes, México

Technical meeting of the NALCMS group

# National Land Cover Programmes

## Canada

**Canada Land Surface Characterization Project,**
Canada Centre for Remote Sensing,
Natural Resources Canada (NRCan)
Programme website

**Description and objectives of the programme**

- Canada's land cover products are created by the Canada Centre for Remote Sensing (CCRS), under the Canada Land Surface Characterization project. As a division of the Canada Centre for Mapping and Earth Observation (CCMEO), CCRS conducts research and delivers remote sensing expertise for the Government of Canada.

- The general objective of the Land Surface Characterization project is to develop a framework for characterization and monitoring the land surface at the national scale, using time-series data acquired by satellites. The resulting products detect changes in the landscape over time caused by natural and human factors, thereby supporting land use monitoring and reporting on international commitments.

**General creation process of national land cover products**

- Methods and software for generating national scale surface reflectance time series and derived land cover and land cover change information were developed. Growing season (mid-June to mid-September) composite tiles were produced from Landsat imagery over multiple years across Canada, using a multi-criteria algorithm to select the best available remote sensing measurements. In the case of the 2020 land cover product, a time interval between 2019 and 2021 was used, with the best measurements chosen as close to the middle of the time interval as possible.

- High-quality training and validation reference data were collected, processed, and compiled from various data sources. This data included field plots, ancillary data, previous land cover maps of Canada, interpretation of very high-resolution satellite/air photos, and expert interpretation of Landsat and Sentinel-2 data seeking to represent the diversity of Canada's ecosystems.

- A local optimization classification technique was developed to increase land cover spatial consistency and accuracy. Data processing was performed using a tile system to facilitate distributed processing. Training and classifying with local reference samples across partially overlapping areas (i.e., moving windows) ensured the optimization of the classifier to a local land cover distribution, and decreased the negative effect of signature extension. The final label for each pixel was determined through a weighted combination of labels from overlapping windows. Urban and cropland areas were mapped separately using additional sources of data, such as road density, night lights, and existing agriculture crop cover classification developed by Agriculture and Agri-Food Canada.

- To update land cover between periods, a change-based method was applied. Changes were detected by computing temporal metrics and using these data to classify change and no-change classes. The change areas were updated by classifying land cover and infilling. This approach ensures high consistency between land cover maps and differences between maps occur only in areas where the changes detected were of high confidence.

- Post-classification and quality assessment were performed using visual interpretation to ensure spatial and temporal consistency of reflectance and land cover patterns, assess overall land cover distribution, identify any cross-tile boundary disparities, and compare the final products with existing datasets to ensure consistency and accuracy.

More information can be found on the programme website and in the publications below.

**Selected publications**

Latifovic, Rasim, Darren Pouliot, and Ian Olthof. 2017. "Circa 2010 Land Cover of Canada: Local Optimization Methodology and Product Development" Remote Sensing 9, no. 11: 1098. (link)

Pouliot, D., R. Latifovic, and I. Olthof. 2017. "Development of a 30 m Spatial Resolution Land Cover of Canada: Contribution to the Harmonized North America Land Cover Dataset." American Geophysical Union, Fall Meeting 2017:GC52C-02. New Orleans, LA, USA. (link)

Latifovic, R., D. A. Pouliot, L. Sun, J. W. Schwarz, and W. Parkinson. 2015. "Moderate Resolution Time Series Data Management and Analysis: Automated Large Area Mosaicking and Quality Control" Geomatics Canada, Open File 6, no. 25. (link)

# United States

**National Land Cover Database (NLCD),**
Earth Resources Observation and Science (EROS) Center, US Geological Survey (USGS)
[Programme website]

**Description and objectives of the programme**

- In association with the Multi-Resolution Land Characteristics Consortium (MRLC), a group of US federal agencies coordinating land cover information at the national scale, USGS EROS Center has been providing the scientific community with the NLCD land cover products for more than 20 years.

- The primary objective of the NLCD is to provide nationally complete, current, consistent, and public domain information on the United States' land cover.

**General creation process of national land cover products**

- The NLCD product is created by primarily modeling land cover change over a multi-year interval. In the case of the NLCD 2021 product, it comprised the interval of time between 2019 and 2021 for the latest release, and used composite imagery generated directly from Landsat together with synthetic imagery from the LCMAP program to produce leaf-on and leaf-off imagery.

- Different detection methods were used, depending on the specific land cover classification (e.g., forest, water, cultivated crop).

- Classification training was based on previous NLCD classifications targeted to remove training from changed areas on the landscape. This change was generated with dataset models built from Landsat imagery and derived indices, spectral change products, trajectory analysis, and ancillary data. Changed areas were removed from base Land Cover training and updated to provide correct training for changed areas across the nation.

- Classification was done multiple times with and without specific land cover types (e.g., Urban, Wetland). Urban land cover is directly derived from the proportion of impervious surface in the impervious surface product, while wetland land cover (for example) is derived from the integration of different variables (e.g., a calculated wetland potential index).

- A post-classification refinement process was developed that aligns Land Cover through time. For example, freshly cleared forest in a continual harvest cycle can resemble many other cover types. The bare soil can spectrally mimic agriculture, new urban development, etc. Analysis through time aligns change succession so that erroneous flips to agriculture or urban are removed, and correct forest succession is maintained (forest harvest cycle is tree to grass, then shrub, and back to forest).

More information can be found on the programme website and in the publications below.

**Selected publications**

Wickham, James, Stephen V. Stehman, Daniel G. Sorenson, Leila Gass, and Jon A. Dewitz. 2023. “Thematic Accuracy Assessment of the NLCD 2019 Land Cover for the Conterminous United States.” GIScience & Remote Sensing 60 (1): 2181143. (link)

Jin, Suming, Jon Dewitz, Patrick Danielson, Brian Granneman, Catherine Costello, Kelcy Smith, and Zhe Zhu. 2023. “National Land Cover Database 2019: A New Strategy for Creating Clean Leaf-On and Leaf-Off Landsat Composite Images.” Journal of Remote Sensing 3 (February):0022. (link)

Jin, Suming, sjin@usgs.gov, Jon Dewitz, Congcong Li, Daniel Sorenson, Zhe Zhu, Md Rakibul Islam Shogib, et al. 2023. “National Land Cover Database 2019: A Comprehensive Strategy for Creating the 1986–2019 Forest Disturbance Product.” Journal of Remote Sensing 3 (February):0021. (link)

# Mexico

**Monitoreo de la cobertura de suelo,**
*Comisión Nacional para el Conocimiento y Uso de la Biodiversidad* (CONABIO)
Programme website

**Description and objectives of the programme**

- Mexico's land cover monitoring programme is the result of collaboration between three different institutions that provide expert knowledge and the outcomes of three different land cover mapping projects: the Monitoring Activity Data for the Mexican REDD+ (MAD-Mex) project conducted by the National Commission for the Knowledge and Use of Biodiversity (CONABIO); the Satellite System for Forest Monitoring (Sistema Satelital de Monitoreo Forestal, SAMOF) developed by the National Forestry Commission (CONAFOR); and the Land Use and Vegetation cartography program at the National Institute of Statistics and Geography (INEGI).

- The main objective of these programs is to provide land cover information at national and regional scales in different spatial resolution and at different time intervals. The availability of this historical data allows for consistent analysis of land cover changes and provides valuable information for studies where land cover dynamics either impact or are influenced by various factors.

**General creation process of national land cover products**

- The first map in the 30-meter land cover series (2010) was developed using version 4.3 of the Monitoring Activity Data for the Mexican REDD+ (MAD-MEX) project. This land cover classification is based on Landsat imagery from both the TM and ETM+ sensors, which served as inputs for an automated algorithm that considers various scene characteristics, such as surface reflectance, cloud cover, artifacts, and data gaps, along with ancillary layers and reference data.

- The 2015 land cover map was also produced through the MAD-MEX project. However, unlike the 2010 map, which relied on TM and ETM+ sensors, the 2015 classification used RapidEye imagery with a 5-meter spatial resolution. The mapping process included pre-processing, attribute calculation, image segmentation, and object-based attribute polygons extraction. Each polygon was assigned a land cover class along with a confidence value. Afterward, the polygons with thematic labels and confidence values were converted into raster format. In the final post-processing step, confidence values from different classifications were analyzed at the pixel level, and the class with the highest confidence was assigned.

- For Mexico's 2020 land cover map, a change detection process was conducted to evaluate land cover changes between 2015 and 2020, following a methodology established by the US Geological Survey. National image mosaics were created using data from the Operational Land Imager (OLI) on Landsat 8, incorporating images from 2018, 2019, and 2020, taken between June and October. The classification involved extracting change polygons from the 2020 mosaic and updating the land cover classes over those areas.

- To ensure accurate classification and avoid illogical changes, a conditional function model was applied through a matrix of allowed potential land cover changes over five-year periods. In addition, a minimum mapping unit criterion was defined, selecting polygons larger than 4,500 square meters (five 30-meter pixels). Finally, major land cover changes were assessed and refined through visual interpretation.

The land cover classification process also benefited from a national collaboration with both CONAFOR and INEGI through their respective land cover initiatives:

**CONAFOR:** Satellite system for forest monitoring (*Sistema Satelital de Monitoreo Forestal*, SAMOF), which is a collection of processes and tools used to create maps and information about forest cover and its changes over time to assess the country's forest cover changes, including deforestation, degradation, recovery, reforestation, afforestation, and other transitions, and also provide information to meet different reporting requirements related to climate change mitigation and adaptation. (link)

**INEGI:** Land use and vegetation (*Uso de suelo y vegetación*) (link)

More information can be found on the programme and initiatives websites and in the publications below.

**Selected publications**

Colditz, Rene R., Ricardo M. Llamas, and Rainer A. Ressl. 2014. "Detecting Change Areas in Mexico Between 2005 and 2010 Using 250 m MODIS Images." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 7* (8): 3358–72. (link)

Colditz, René R., Gerardo López Saldaña, Pedro Maeda, Jesús Argumedo Espinoza, Carmen Meneses Tovar, Arturo Victoria Hernández, Carlos Zermeño Benítez, Isabel Cruz López, and Rainer Ressl. 2012. "Generation and Analysis of the 2005 Land Cover Map for Mexico Using 250m MODIS Data." *Remote Sensing of Environment* 123 (August):541–52. (link)

Gebhardt, Steffen, Thilo Wehrmann, Miguel Angel Muñoz Ruiz, Pedro Maeda, Jesse Bishop, Matthias Schramm, Rene Kopeinig, 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): 3923–43. (link)

INEGI. 2023. *Guía Para La Interpretación De Cartografía. Uso Del Suelo Y Vegetación Escala 1: 250 000. Serie VII.* Aguascalientes, Aguascalientes: Instituto Nacional de Estadística y Geografía (México). (link)

# NALCMS Land Cover Classes

**The NALCMS 19 land cover classes** are based on the Land Cover Classification System (LCCS) standard developed by the Food and Agriculture Organization (FAO) of the United Nations[5]. Land Cover classes can include, for example, natural features such as tropical forest, shrubland, grassland, water bodies, and bare land, but also human-made features such as asphalt cover and cropland.

- Temperate or sub-polar needleleaf forest
- Sub-polar taiga needleleaf forest
- Tropical or sub-tropical broadleaf evergreen forest
- Tropical or sub-tropical broadleaf deciduous forest
- Temperate or sub-polar broadleaf deciduous forest
- Mixed forest
- Tropical or sub-tropical shrubland
- Temperate or sub-polar shrubland
- Tropical or sub-tropical grassland
- Temperate or sub-polar grassland
- Sub-polar or polar shrubland-lichen-moss
- Sub-polar or polar grassland-lichen-moss
- Sub-polar or polar barren-lichen-moss
- Wetland
- Cropland
- Barren land
- Urban and built-up
- Water
- Snow and ice

The following is a description of each of the 19 land cover classes on which all NALCMS products are based.

## 1 Temperate or sub-polar needleleaf forest

**(LCCS #20134)**

Forests generally taller than 3 meters and more than 20% of total vegetation cover.  This type occurs across the northern United States, Canada and mountainous zones of Mexico. The tree crown cover contains at least 75 percent of needle-leaved species.

## 2 Sub-polar taiga needleleaf forest

**(LCCS #20229)**

Forest and woodlands with trees generally taller than 3 meters and more than 5% of total vegetation cover with shrubs and lichens commonly present in the understory. The tree crown cover contains at least 75 percent of needle-leaved species. This type occurs across Alaska and northern Canada and may consist of treed muskeg or wetlands. Forest canopies are variable and often sparse, with generally greater tree cover in the southern latitude parts of the zone than the north.

[5] Food and Agriculture Organization of the United Nations – Land Cover Classification System (LCCS).

### 3 Tropical or sub-tropical broadleaf evergreen forest (LCCS #20090)

Forests generally taller than 5 meters and more than 20% of total vegetation cover. These occur in the southern United States and Mexico. These forests have greater than 75 percent of tree crown cover represented by evergreen species.

### 4 Tropical or sub-tropical broadleaf deciduous forest (LCCS #20132)

Forests generally taller than 5 meters and more than 20% of total vegetation cover. These occur in the southern United States and Mexico. These forests have greater than 75 percent of tree crown cover represented by deciduous species.

### 5 Temperate or sub-polar broadleaf deciduous forest (LCCS #20227)

Forests generally taller than 3 meters and more than 20% of total vegetation cover. These occur in the northern United States, Canada and mountainous zones of Mexico. These forests have greater than 75 percent of tree crown cover represented by deciduous species.

## 6 Mixed Forest

**(LCCS #20092, #20090, #20134, #20132, #20229, #20227)**

Forests generally taller than 3 meters and more than 20% of total vegetation cover. Neither needleleaf nor broadleaf tree species occupy more than 75 percent of total tree cover, but are co-dominant.

## 7 Tropical or sub-tropical shrubland

**(LCCS #21450-13476)**

Areas dominated by woody perennial plants with persistent woody stems less than 5 meters tall and typically greater than 20% of total vegetation. This class occurs across the southern United States and Mexico.

## 8 Temperate or sub-polar shrubland

**(LCCS #21450-12050)**

Areas dominated by woody perennial plants with persistent woody stems less than 3 meters tall and typically greater than 20% of total vegetation. This class occurs across the northern United States, Canada and highlands of Mexico.

## 9 Tropical or sub-tropical grassland
**(LCCS #21669)**

Areas dominated by graminoid or herbaceous vegetation generally accounting for greater than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. This class occurs across the southern United States and Mexico.

## 10 Temperate or sub-polar grassland
**(LCCS #21537-12212)**

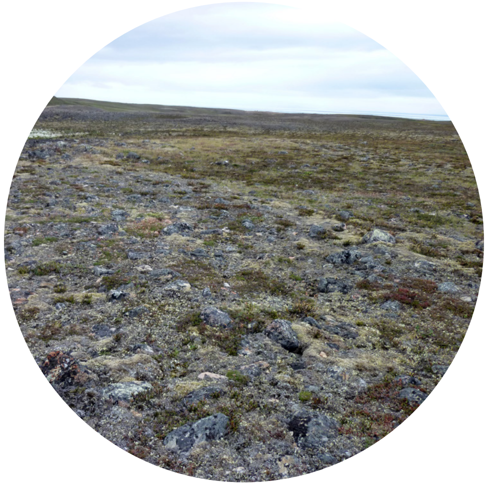
Areas dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. This class occurs across Canada, United States and highlands of Mexico.

## 11 Sub-polar or polar shrubland-lichen-moss
**(LCCS #20022-12050, #21454-12212, #21439-3012)**

Areas dominated by dwarf shrubs with lichen and moss typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.

## 12 Sub-polar or polar grassland-lichen-moss
**(LCCS #21454-12212, #20022-12050, #21439-3012)**

Areas dominated by grassland with lichen and moss typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.



## 13 Sub-polar or polar barren-lichen-moss
**(LCCS #21468, #21454-12212, #20022-12050)**

Areas dominated by a mixture of bare areas with lichen and moss that typically account for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.

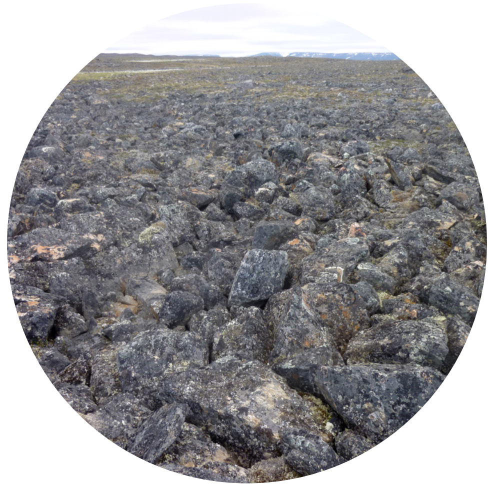
## 14 Wetland
**(LCCS #42349, #41809)**

Areas dominated by dwarf shrubs with lichen and moss typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.

## 15 Cropland
(LCCS #10037, #10025, #21441, #21453)

Areas dominated by intensively managed crops. These areas typically require human activities for their maintenance. This includes areas used for the production of annual crops, such as corn, soybeans, wheat, maize, vegetables, tobacco, cotton, etc. and also perennial grasses for grazing and woody crops such as orchards and vineyards.

Crop vegetation accounts for greater than 20 percent of total vegetation. This class does not represent natural grasslands used for light to moderate grazing.



## 16 Barren Lands
(LCCS #6001, #6004)

Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no “green” vegetation present regardless of its inherent ability to support life. Generally, vegetation accounts for less than 10% of total cover.

## 17 Urban and Built-up
(LCCS #5003)

Areas that contain at least 30 percent or greater urban constructed materials for human activities (cities, towns, transportation etc.).

## 18 Water
**(LCCS #8001, #7001)**

Areas of open water, generally with less than 25% cover of non-water cover types. This class refers to areas that are consistently covered by water.

## 19 Snow and Ice
**(LCCS #8005, #8008)**

Areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.

# NALCMS Products

## NALCMS Harmonization Process

To produce a seamless land cover map of North America, the four national land cover sections (Canada, Mexico, the Conterminous United States (CONUS), and Alaska) are reprojected from their respective national coordinate systems into the standard CEC Lambert Azimuthal Equal Area projection, centered at 100°W and 45°N. The datum is based on a sphere with a radius of 6,370,997 meters and aligned to a common reference grid.

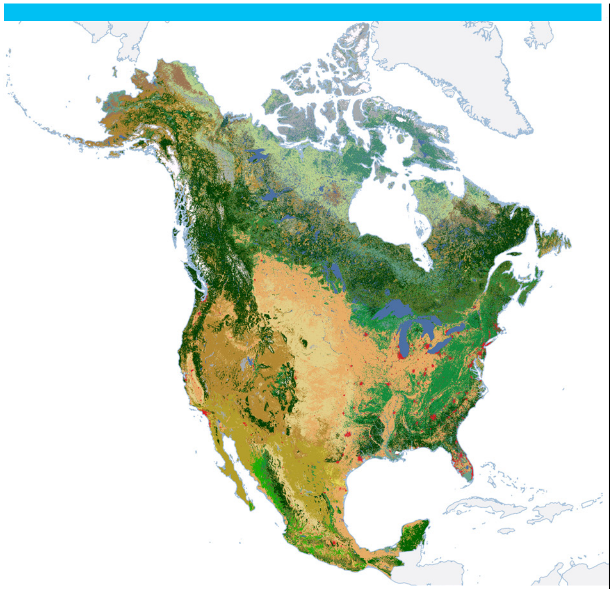
Sparse areas containing small patches of empty pixels, particularly in northern regions or transboundary water bodies, are filled using neighboring pixel information or reference data from previous land cover maps.

Water buffers present in some of the national land cover products are removed to define coastlines more accurately, ensuring that areas classified as land remain intact. Coastal lagoons, bays, river deltas, estuaries, and other outlets to the sea are separated from ocean water through visual interpretation, using a combination of various reference sources.

All sections of the map are merged within a common bounding box and edge-matched along country borders. Empty pixels between section borders are filled using additional sources such as previous land cover maps, pixel majority analysis, or manual editing.

A minimum mapping unit of 5 connected pixels is applied using the “Smart Eliminate” tool developed by the USGS as part of the NLCD project. While the tool allows the exclusion of specific classes (e.g., background) from the minimum mapping unit analysis, all classes, including the background, are considered. This ensures that individual pixels or small pixel patches in sea areas remaining after the water buffer removal are eliminated.

The final land cover map files are exported in 8-bit TIFF format, with the NALCMS color scheme applied. The land cover class names, in English, French, and Spanish, for the 19 NALCMS classes are added to the map’s auxiliary files, and raster pyramids are calculated for faster display, along with raster statistics.



## North American Land Cover 2005 (MODIS, 250m)

Webpage

**Description**

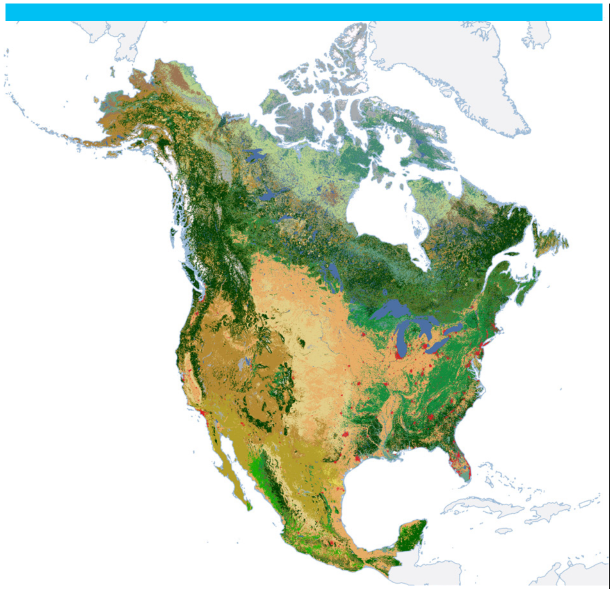
This map of North American land cover at a spatial resolution of 250 meters provides a harmonized view of the physical cover of Earth's surface across the continent, based on 2005 Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery.

**Versions**

**2005 Version 3, 250m (Released in 2013)**

Version 3.0 of the 2005 North America Land Cover map at 250 meters spatial resolution has removed the water buffer along the coastline of North America. This ensured consistency in the statistics calculations of class 18 (water) without incorporating ocean water.

**Note:** Land cover and land cover change products at 250m spatial resolution are now considered "legacy products" and will not be updated again.



## North American Land Cover 2010 (MODIS, 250m)

Webpage

**Description**

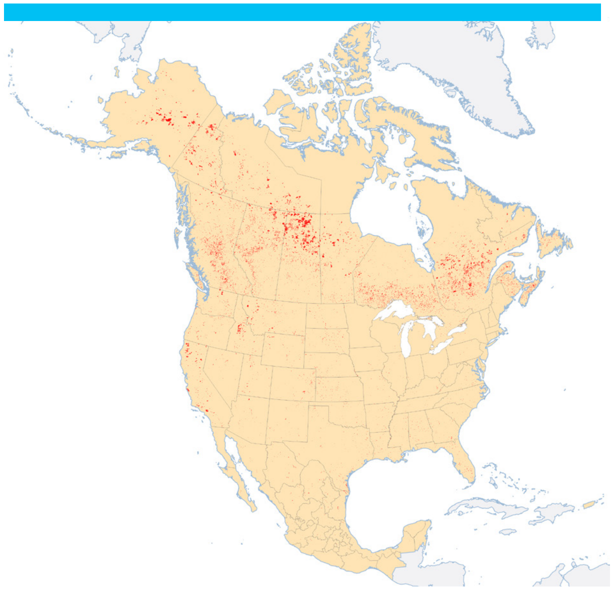
This map of North American land cover at a spatial resolution of 250 meters provides a harmonized view of the physical cover of Earth's surface across the continent based on 2010 Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery.

**Versions**

**2010 Version 2, 250m (Released in 2013)**

Version 2.0 of the North America Land Cover map at 250 meters spatial resolution has removed the water buffer along the coastline of North America. This ensured consistency in the statistics calculations of class 18 (water) without incorporating ocean water.

**Note:** Land cover and land cover change products at 250m spatial resolution are now considered "legacy products" and will not be updated again.



## North American Land Cover Change 2005–2010 (MODIS, 250m)

Webpage

**Description**

This map demonstrates land cover change between 2005 and 2010 in North America at a spatial resolution of 250 meters. The NALCMS product displayed in this map represents land cover change based on monthly composites of 2005 and 2010 Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery.

Land cover change products are always derived from the latest available version of their respective land cover products.

**Note:** Land cover and land cover change products at 250m spatial resolution are now considered "legacy products" and will not be updated again.

# North American Land Cover 2010 (Landsat, 30m)

Webpage

### Description

This map of North American land cover at a spatial resolution of 30 meters provides a harmonized view of the physical cover of Earth's surface across the continent based on 2010 Landsat satellite imagery.

### Versions

#### 2010 Version 1 (Released in 2017)

**Canada**

Land cover data was provided by the Canada Centre for Remote Sensing (CCRS) and corresponds to year 2010. The data was already delivered in the 19 classes of the NALCMS classification scheme. The source map was produced using information from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) Landsat sensors.

**Mexico**

Data was derived from the MAD-MEX land cover map (version 4.3) provided by the National Commission for the Knowledge and Use of Biodiversity (CONABIO). The source map was produced using information from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) Landsat sensors.

**United States**

Land cover data for Alaska and the Conterminous United States was derived from the National Land Cover Database (NLCD) 2011, and cross-walked to the NALCMS classification scheme by the United States Geological Survey (USGS). The source map was produced using information from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) Landsat sensors.

**North America**

The minimum mapping unit for the first version was defined as 1 pixel for the urban class and 5 pixels for the rest of the land cover classes in the NALCMS classification scheme. This map version showed a water buffer along the coast of the three countries.

#### 2010 Version 2 (Released in 2020)

**North America**

The water buffer along the coastline was removed to ensure consistency in the statistical calculations of class 18 (water), without including ocean water.
In the three countries, there was a change in the minimum mapping unit. Different from Version 1, where a minimum mapping unit of 1 pixel was defined for urban classes and 5 pixels for the rest of the land cover classes, in Version 2, a standard minimum mapping unit of 5 pixels was defined for all classes.

In calculating the minimum mapping unit, Class 0 (background) was excluded. Any cluster of fewer than 5 pixels surrounded by Class 0 (e.g., pixels in sea areas) was not eliminated and thus remained on the map. No changes were made along the coastline, as Class 0 was not allowed to expand.

**2010 Version 3 (Released in 2024)**

### Canada

Version 3 integrates an update of the Canadian Land Cover dataset delivered by the Canada Centre for Remote Sensing (CCRS) in February 2024. The newest version of the 2010 Canadian land cover dataset is derived from updated detection of change areas between 2015-2010, using the previously updated 2015 land cover map that was derived from change detection between 2020 and 2015. The 2020 Canada land cover map is the result of improved classification methods used in the first version of the maps. As a result, Canada uses 2020 as the base year for change detection instead of 2010.

According to CCRS, the most recent update in the land cover time series includes improvements in the mapping of mining areas. High-resolution data and some auxiliary information were used to verify and enhance accuracy over mining sites, along with minor adjustments in a few cities. Corrections were necessary because some parts of mining areas were mislabeled as barren land or areas of low vegetation.

Sparse areas with small patches of empty pixels in northern Quebec and the Labrador Peninsula were corrected by filling them with values from the previous Canada 2010 land cover map.

### Mexico

The Mexican section for the North American Land Cover map did not require any updates. Version 2 of the NALCMS Mexico map was used as input for Version 3 of the North American Land Cover map.

### United States

The latest map delivered in February 2024 by the USGS for Alaska features a significantly improved road network, particularly in the far north. The map is now cleaner along the Arctic coast, as it has fewer speckled areas over the original water buffer. Additionally, it provides a more accurate representation of elongated islands in the Arctic Ocean, many of which were missing in version 2 of the 2010 NALCMS North American map. A few empty pixels on the mainland were also filled using the values from neighboring pixels.

Similar to the Alaska section of the North American map, the USGS delivered an updated version of the Conterminous United States Land Cover map in February 2024. This new version has been converted to align with the NALCMS land cover classification scheme and is based on the latest version of the National Land Cover Database (NLCD) 2011. Compared to previous versions, this updated map features a more accurately delineated coastline and fewer speckled areas over the water buffer.
In order to convert NLCD legend classes to NALCMS legend classes a sub-tropical mask for the conterminous United States and a sub-polar mask for Alaska were required. These masks were necessary to differentiate between temperate and sub-tropical/sub-polar areas.

As with the previous version, the water buffer included in each USGS delivery has been removed to ensure consistency in the calculation of all land cover classes, including continental water, and to avoid the inclusion of sea areas.

### North America

The minimum mapping unit remains 5 pixels for all classes; however, in this new version, Class 0 (background) has been included, allowing pixel patches smaller than 5 pixels surrounded by Class 0 to be reclassified as background. This adjustment helps eliminate individual pixels or small pixel patches in the sea area that remained after the water buffer was removed. Additionally, this change allows Class 0 to expand along the coastline when small pixel patches were not primarily surrounded by other land class values.

# North American Land Cover 2015 (Landsat & RapidEye, 30m)

Webpage

**Description**

This map of North American land cover at a spatial resolution of 30 meters provides a harmonized view of the physical cover of Earth's surface across the continent based on 2015 Landsat satellite imagery for Canada and the United States, and RapidEye imagery for Mexico.

**Versions**

**2015 Version 1 (Released in 2020)**

**Canada**

Land cover data, provided by the Canada Centre for Remote Sensing (CCRS), corresponds to the year 2015 and was already delivered in the 19 classes of the NALCMS classification scheme. The land cover dataset for Canada was produced using observation from Operational Land Imager (OLI) Landsat sensor.

**Mexico**

Unlike the NALCMS 2010 land cover map, which utilized information from sensors onboard Landsat satellites, the 2015 Mexican land cover dataset is based on the MAD-MEX land cover map derived from RapidEye data with a resolution of 5 meters. The 2015 MAD-MEX map was resampled to 30 meters to align with the resolution of the other national maps in North America, and the map legend was cross-walked to the NALCMS classification scheme.

**United States**

Land cover data for Alaska and the Conterminous United States was sourced from the National Land Cover Database (NLCD) 2016 and adapted to the NALCMS classification scheme by the United States Geological Survey (USGS).

**North America**

The water buffer along the coastline was eliminated to maintain consistency in the statistical calculations for Class 18 (water), excluding ocean water. A minimum mapping unit of 5 pixels was established for all classes. In defining this minimum unit, Class 0 (background) was excluded from the calculations. Clusters smaller than 5 pixels that were surrounded by Class 0 (such as pixels in ocean areas) were not removed and remained visible on the map.

**2015 Version 2 (Released in 2020)**

**United States**

In July 2020, USGS provided an updated land cover map of Alaska, which was subsequently integrated into the continental map, replacing version 1.
As with the previous version, the water buffer was removed to maintain consistency in the calculation of all land cover classes, including continental water, and to prevent the inclusion of sea areas.

**2015 Version 3 (Released in 2023)**

### Canada

Land Cover over the Canada section was updated using a revised version of the Canadian dataset, which was released on May 1, 2023.

The water buffer present in the map provided by CCRS was removed to ensure consistency in the calculation of all land cover classes, including continental water, and to avoid the inclusion of sea areas. Sparse areas with small patches of empty pixels in northern Quebec and the Labrador Peninsula were corrected by filling them with values from the previous Canada 2015 land cover map.

**2015 Version 4 (Released in 2024)**

### Canada

Version 4 includes an updated Canadian Land Cover dataset provided by the Canada Centre for Remote Sensing (CCRS) in February 2024. This latest iteration of the 2015 Canadian land cover dataset is based on refreshed change detection from 2020 to 2015. The 2020 Canada land cover map utilizes improved classification techniques. Consequently, Canada has established 2020 as the reference year for change detection, replacing the previous base year of 2010. As noted by CCRS, the latest update in the land cover time series features enhancements in the mapping of mining regions. High-resolution data, along with additional information, was employed to verify and improve accuracy in mining areas, alongside minor adjustments made in certain urban locations. These corrections were essential as some sections of mining regions had been incorrectly categorized as barren land or areas of low vegetation.

In northern Quebec and the Labrador Peninsula, sparse areas with small clusters of empty pixels were rectified by filling them with values from the previous Canada 2015 land cover map.

### Mexico

The Mexico section of the North American map has not been updated in the fourth version of the 2015 NALCMS map. The version used for the Mexico map still corresponds to its version 1.

### United States

The Alaska and Conterminous United States sections of the North American land cover map represent an update provided by USGS in February 2024. Both maps were generated from the latest version of the 2016 NLCD products for Alaska and the

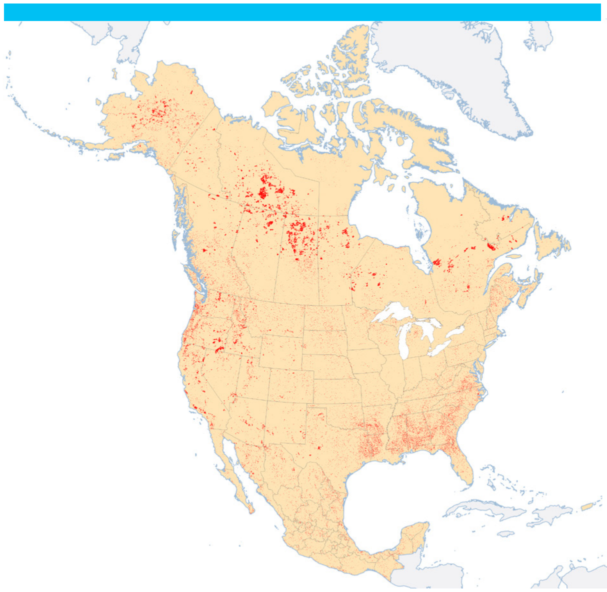
Conterminous United States. The USGS aligned the NLCD classification scheme with the 19 land cover classes used by NALCMS.

In order to differentiate sub-polar and temperate areas in Alaska, a dataset identifying areas of permafrost was used to identify potential sub-polar regions. Areas of the dataset with values greater than or equal to a permafrost occurrence greater than 50 percent were considered sub-polar. Some additional localized modeling and hand-editing was required to generate the final sub-polar mask

A few empty pixels on the mainland were filled using values from adjacent pixels. As with previous versions, the water buffer included in each USGS delivery was removed to maintain consistency in the calculation of all land cover classes, including continental water, and to prevent the inclusion of sea areas.

### North America

The water buffer along the coastline was eliminated to maintain consistency in the statistical calculations for Class 18 (water), excluding ocean water.
The minimum mapping unit continues to be 5 pixels for all classes; however, this new version includes Class 0 (background), which enables pixel patches smaller than 5 pixels that are surrounded by Class 0 to be reclassified as background. This modification assists in removing isolated pixels or small patches in the sea area that persisted after the water buffer was eliminated. Furthermore, this change allows Class 0 to extend along the coastline when small pixel patches are not primarily surrounded by other land class values.

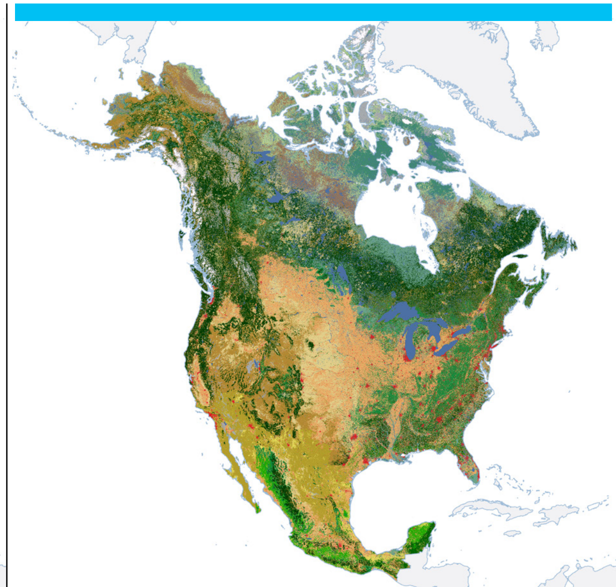


# North American Land Cover Change 2010–2015 (Landsat, 30m)

Webpage

This map demonstrates land cover change between 2010 and 2015 in North America at a spatial resolution of 30 meters. The NALCMS product displayed in this map represents land cover change based on monthly composites of 2010 and 2015 Landsat satellite imagery.

Land cover change products are always derived from the latest available version of their respective land cover products.



# North American Land Cover 2020 (Landsat, 30m)

Webpage

**Description**

This map of North American land cover provides a harmonized view of the physical cover of Earth's surface across the continent at a spatial resolution of 30 meters, based on Landsat satellite imagery for Canada, Mexico, and the United States.

**Versions**

**2020 Version 1 (Released in 2023)**

### Canada

This version of the Canadian land cover dataset was generated by CCRS through change detection between 2015 and 2020. The 2015 land cover of Canada was previously calculated based on change detection from 2010 to 2015, with 2010 being the base year established in that version for the definitions of Canadian Land Cover series at 5-year intervals. The land cover dataset for Canada was produced using observation from Operational Land Imager (OLI) Landsat sensor.

In northern Quebec and the Labrador Peninsula, sparse areas with small clusters of empty pixels were rectified by filling them with values from the latest version of the 2015 land cover map.

### Mexico

Unlike the Mexican land cover input map used in 2015, which was derived from a 5-meter cell size input map, the 2020 land cover map provided by CONABIO is based on 30-meter resolution Landsat data and was generated based on change detection between 2015 and 2020 satellite data.

### United States

Unlike the NALCMS Maps from 2010 and 2015, which represented a 5-year time interval based on NLCD data from 2011 and 2016, the 2020 North American map presents a 3-year land change interval for the contiguous United States (CONUS) while maintaining a 5-year interval for Alaska.

The NLCD 2019 map for CONUS was the version available during the assembly of the North American map and was used by the USGS to create the cross-walked map within the NALCMS classification scheme. For Alaska, the USGS provided a land cover map representing 2021, generated in February 2023. The Alaska map used to align the NLCD classes with the NALCMS classification scheme is an internal file that has not yet been made publicly available.

### North America

The water buffer along the coastline was removed to ensure consistency in the statistical calculations for Class 18 (water), excluding ocean water.

A minimum mapping unit of 5 pixels was set for all classes, with Class 0 (background) excluded from these calculations. Clusters smaller than 5 pixels that were surrounded by Class 0, such as those in ocean areas, were not eliminated and remain visible on the map.

## 2020 Version 2 (Released in 2024)

### Canada

The map used for Canada was an update provided by CCRS in February 2024. The 2020 Canada land cover map results from improved classification methods applied in the first version of the maps. Consequently, Canada now uses 2020 as the base year for change detection, replacing the previous base year of 2010.

According to CCRS, the latest update in the land cover time series includes enhancements in the mapping of mining regions. High-resolution data, along with supplementary information, was used to verify and improve accuracy in these mining areas, as well as to make minor adjustments in certain urban locations. These corrections were necessary because some parts of mining regions had been misclassified as barren land or areas of low vegetation.

Sparse areas with small patches of empty pixels in northern Quebec and the Labrador Peninsula were rectified by filling them with values from the previous version of Canada 2020 land cover map.

### Mexico

The Mexican section for the North American Land Cover map did not require any updates. NALCMS Mexico map Version 1 was used as input for Version 2 of the North American Land Cover map.

### United States

The Alaska and Conterminous United States sections of the North American land cover map reflect an update provided by the USGS in February 2024. Unlike version 1, where CONUS data was derived from NLCD 2019, this new version reinstates 5-year intervals for all map sections, as the input data for CONUS is now NLCD 2021.

For Alaska, the USGS provided a new version of the map in February 2024, representing 2021 land cover data. The updated Alaska map used to align the NLCD classes with the NALCMS classification scheme is an internal file that has not yet been made publicly available.

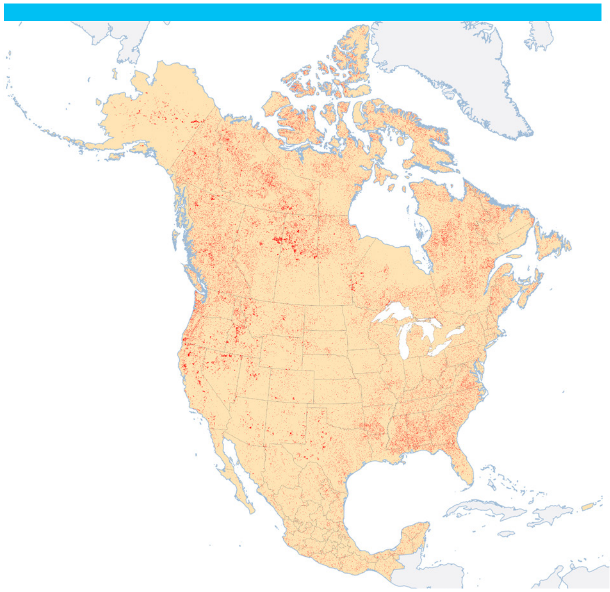
To distinguish sub-polar from temperate areas in Alaska, a dataset identifying permafrost regions was used to define potential sub-polar zones. Regions with permafrost occurrence equal to or greater than 50 percent were classified as sub-polar. Additional localized modeling and manual editing were necessary to produce the final sub-polar mask.

A few empty pixels on the mainland were filled using values from adjacent pixels. As in previous versions, the water buffer included in each USGS delivery was removed to ensure consistency in the calculation of all land cover classes, including continental water, and to prevent the inclusion of sea areas.

### North America

The water buffer along the coastline was removed to ensure consistency in the statistical calculations for Class 18 (water), excluding ocean water.

The minimum mapping unit remains 5 pixels for all classes; however, this new version introduces Class 0 (background), which allows pixel patches smaller than 5 pixels that are surrounded by Class 0 to be reclassified as background. This adjustment helps eliminate isolated pixels or small patches in the sea area that remained after the removal of the water buffer. Additionally, this change enables Class 0 to extend along the coastline when small pixel patches are not primarily bordered by other land class values.



## North American Land Cover Change 2015–2020 (Landsat, 30m)

Webpage

**Description**

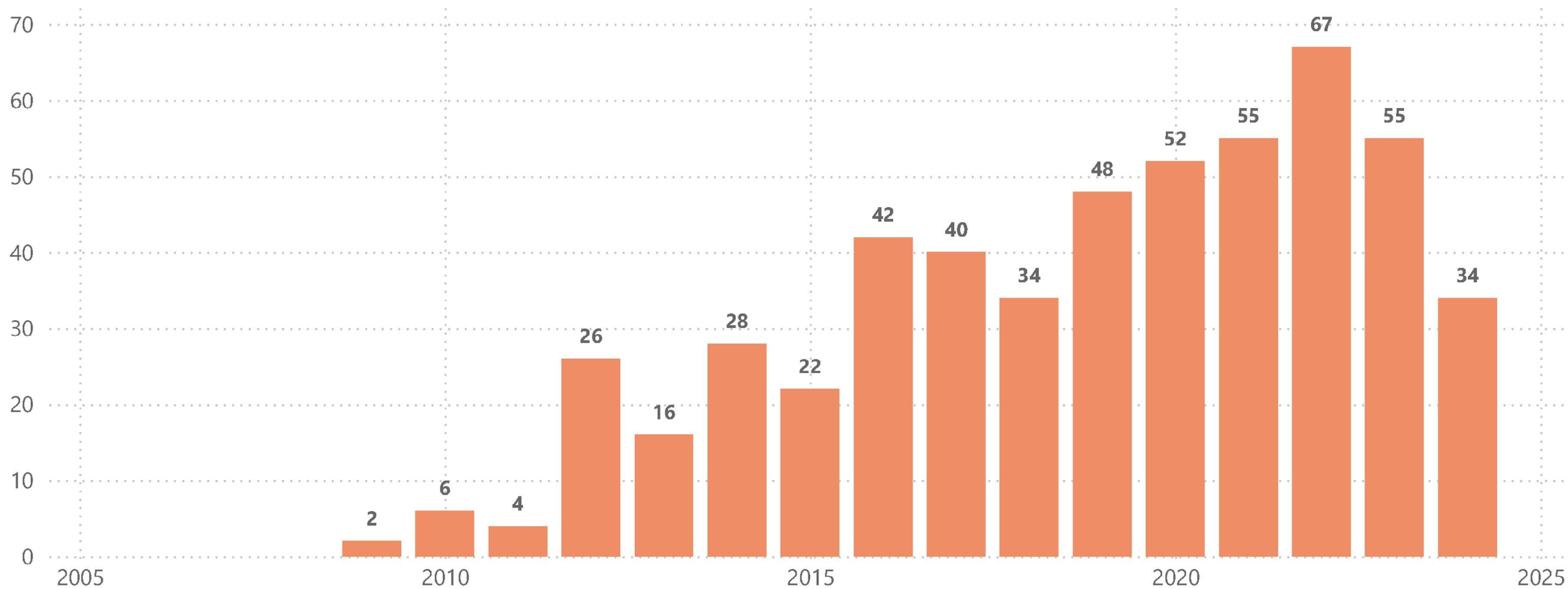
This map demonstrates land cover change between 2015 and 2020 in North America at a spatial resolution of 30 meters. The NALCMS product displayed in this map represents land cover change based on monthly composites of 2015 and 2020 Landsat satellite imagery.

Land cover change products are always derived from the latest available version of their respective land cover products.

**More information and all products mentioned can be found on the NALCMS website.**

# NALCMS Usage in Research and Decision-Making

**Over the years**, more than 500 research articles, tools, and presentations showcasing the use of NALCMS products have been published both in North America and internationally (as of September 2024).



## Examples of external publications

Below are 10 selected examples showing the wide range of NALCMS applications by different authors and organizations, including governmental agencies, academia, and non-governmental organizations. An exhaustive and updated list of all publications showcasing NALCMS products, along with these selected examples, can be found on the North American Environmental Atlas website. (link)

**Great Lakes mercury connections—The extent and effects of mercury pollution in the Great Lakes Region (2011)** (link)

Main authors & affiliations:

- David C. Evers, Biodiversity Research Institute
- James G. Wiener, Biodiversity Research Institute / University of Wisconsin La Crosse
- Charles T. Driscoll, Biodiversity Research Institute / Department of Civil and Environmental Engineering, Syracuse University
- David A. Gay, Biodiversity Research Institute / National Atmospheric Deposition Program, Illinois State Water Survey, University of Illinois
- Niladri Basu, Biodiversity Research Institute / Department of Environmental Health Science, School of Public Health, University of Michigan

Sponsored by the Great Lakes Commission, the purpose of this project was to foster collaboration between researchers and decision-makers in Canada and the United States focusing on mercury contamination in the Great Lakes region. The North American Land Cover 2005 product was used to delineate the Great Lakes region and drainage basin, and to study how the types of land cover (e.g. forest, cropland, etc.) influence the accumulation of mercury in the Great Lakes region.

**Keywords**: Mercury, drainage basin, Great Lakes, collaboration, fish

**Landscape Genetics of Leaf-Toed Geckos in the Tropical Dry Forest of Northern Mexico (2013)** (link)

Main authors & affiliations:

- Christopher Blair, Department of Ecology and Evolutionary Biology, University of Toronto / Department of Natural History, Royal Ontario Museum
- Victor H. Jiménez Arcos, Laboratorio de Herpetología, Instituto de Biología, Universidad Nacional Autónoma de México
- Fausto R. Mendez de la Cruz, Laboratorio de Herpetología, Instituto de Biología, Universidad Nacional Autónoma de México
- Robert W. Murphy, Department of Ecology and Evolutionary Biology, University of Toronto / Department of Natural History, Royal Ontario Museum / State Key Laboratory of Genetic Resources and Evolution, Kunming Institute of Zoology, the Chinese Academy of Sciences

Habitat fragmentation can affect the genetic variation of a species across space. This study looks at how landscape changes (e.g., deforestation) affects this genetic variation for the leaf-toed geckos to inform conservation efforts in the context of tropical dry forests. The research used the North American Land Cover 2005 product by reclassifying data based on non-forested versus forested habitat, and identifying resistance surfaces which represent the degree to which some landscape feature impedes or facilitates the movement of a species.

**Keywords:** Biodiversity, habitat fragmentation, genetic variation, Tropical Dry Forest, species conservation

**A Concise Experiment Plan for the Arctic-Boreal Vulnerability Experiment (2014)** (link)

Main authors & affiliations:

- Eric S. Kasischke, University of Maryland
- Daniel J. Hayes, Oak Ridge National Laboratory
- Sharon Billings, University of Kansas
- Natalie Boelman, Lamont-Doherty Earth Observatory, Columbia University
- Stephen Colt, University of Alaska, Anchorage

The concise experiment plan identifies the research to be conducted under NASA's Arctic-Boreal Vulnerability Experiment (ABoVE) program (above.nasa.gov), a large-scale study of environmental change in the Arctic and boreal region of western North America and its implications for social-ecological systems. The concise experiment plan used the North American Land Cover 2005 product to identify the land cover types of the study domain.

**Keywords**: NASA, ABoVE, climate change, modeling, decision-making

**Potential relocation of climatic environments suggests high rates of climate displacement within the North American protection network (2017)** (link)

Main authors & affiliations:

- Enric Batllori, Centre de Recerca Ecològica i Aplicacions Forestals (CREAF) / Centre de Ciència i Tecnologia Forestal de Catalunya (CTFC)
- Marc-André Parisien, Northern Forestry Centre, Canadian Forest Service, Natural Resources Canada
- Sean A. Parks, Aldo Leopold Wilderness Research Institute, Rocky Mountain Research Station, USDA Forest Service
- Max A. Moritz, Division of Ecosystem Sciences, Department of Environmental Science, Policy, and Management, University of California, Berkeley
- Carol Miller, Aldo Leopold Wilderness Research Institute, Rocky Mountain Research Station, USDA Forest Service

The network of protected areas in North America helps preserve ecological processes and biodiversity, but its conservation capacity might be affected by climate change as ecosystems change and species migrate in an attempt to adapt. The North American Land Cover 2005 product was used to extract the land cover characteristics in protected areas and compare them with their past and future characteristics, assessing the vulnerability of these protected areas.

**Keywords**: Protected area, climate change, conservation, vulnerability, climate migration

**Characterizing Drought Effects on Vegetation Productivity in the Four Corners Region of the US Southwest (2018)** (link)

Main authors & affiliations:

- Mohamed Abd Salam EL-Vilaly, International Food Policy Research Institute
- Kamel Didan, Department of Biosystems Engineering, University of Arizona
- Stuart E. Marsh, Arizona Remote Sensing Center, School of Natural Resources and the Environment, University of Arizona
- Michael A. Crimmins, Department of Soils, Water and Environmental Science, University of Arizona
- Armando Barreto Munoz, Department of Biosystems Engineering, University of Arizona

The study looks at drought drivers over time and how they shaped vegetation productivity in the Four Corners Region indigenous lands. This geospatial assessment provides information for planning, mitigation, and decision-making purposes especially in relation to protecting biodiversity. The North American Land Cover 2005 product was used, from which the main land cover types of the region were extracted: shrubland, grassland, and needleleaf forest. The assessment combined these land cover types with seasonal climate data, topographical data, and NDVI-related productivity.

**Keywords**: Drought, food security, Indigenous Peoples, climate change, monitoring

**Physically based cold regions river flood prediction in data-sparse regions: The Yukon River Basin flow forecasting system (2022)** (link)

Main authors & affiliations:

- Mohamed Elshamy, Centre for Hydrology & Global Institute for Water Security, University of Saskatchewan
- Youssef Loukili, Centre for Hydrology & Global Institute for Water Security, University of Saskatchewan
- John W. Pomeroy, Centre for Hydrology, University of Saskatchewan
- Alain Pietroniro, Centre for Hydrology, University of Saskatchewan / National Hydrological Service, Environment and Climate Change Canada / Department of Civil Engineering, University of Calgary
- Dominique Richard, Centre for Hydrology, University of Saskatchewan
- Daniel Princz, National Hydrological Service, Environment and Climate Change Canada

The research looks into a new modelling approach for flood forecasting in the Yukon River Basin as requested by the Yukon Government and considering the particularities of cold regions (snowmelt, glacier melt, freezing-thawing, etc.) when forecasting streamflow. The Yukon River Basin is an important river network shared between Canada and the United States and is one of the largest river basins in the subarctic region of North America. The North American Land Cover 2010 product (at 30m resolution), along with its classification of 19 land cover classes was used to develop the model of the study area.

**Keywords**: Flood, Yukon River, forecasting, cold regions

**Large increases in methane emissions expected from North America's largest wetland complex (2023)** (link)

Main authors & affiliations:

- Sheel Bansal, U.S. Geological Survey, Northern Prairie Wildlife Research Center
- Max Post van der Burg, U.S. Geological Survey, Northern Prairie Wildlife Research Center
- Rachel R. Fern, U.S. Geological Survey, Northern Prairie Wildlife Research Center / Texas Parks and Wildlife Department
- John W. Jones, U.S. Geological Survey, Hydrologic Remote Sensing Branch
- Rachel Lo, U.S. Geological Survey, Northern Prairie Wildlife Research Center

Using both geospatial information and in-situ measurements, this research evaluates the natural methane emissions of the Prairie Pothole Region, North America's largest wetland complex, especially in the context of climate change and increasing temperature, changes in hydrology and vegetation, and the role of land use. The North American Land Cover 2010 product (at 30m resolution) was used to determine surrounding land cover such as grassland or cropland in the binational Prairie Pothole Region, which includes land in both in both Canada and the United States.

**Keywords**: Methane, wetland, climate change, natural emission, Prairie Pothole Region

**Self-reported tick exposure as an indicator of Lyme disease risk in an endemic region of Quebec, Canada (2024)** (link)

Main authors & affiliations:

- Natasha Bowser, Groupe de Recherche en Épidémiologie des Zoonoses et Santé Publique (GREZOSP) & Département de Pathologie et de Microbiologie, Faculté de Médecine Vétérinaire, Université de Montréal / Centre de Recherche en Santé Publique (CReSP) de l'Université de Montréal et du CIUSSS du Centre-Sud-de-l'Île-de-Montréal
- Catherine Bouchard, Groupe de Recherche en Épidémiologie des Zoonoses et Santé Publique (GREZOSP) & Département de Pathologie et de Microbiologie, Faculté de Médecine Vétérinaire, Université de Montréal / Public Health Risk Sciences Division, National Microbiology Laboratory, Public Health Agency of Canada
- Miguel Sautié Castellanos, Plateforme IA-Agrosanté, Faculté de Médecine Vétérinaire, Université de Montréal
- Geneviève Baron, Direction de la Santé Publique, CIUSSS de l'Estrie-CHUS / Département Des Sciences de la Santé Communautaire, Faculté de Médecine et Des Sciences de la Santé, Université de Sherbrooke
- Hélène Carabin, Groupe de Recherche en Épidémiologie des Zoonoses et Santé Publique (GREZOSP) & Département de Pathologie et de Microbiologie, Faculté de Médecine Vétérinaire, Université de Montréal / Centre de Recherche en Santé Publique (CReSP) de l'Université de Montréal et du CIUSSS du Centre-Sud-de-l'Île-de-Montréal / Département de Médecine Sociale et Préventive, École de santé publique de l'Université de Montréal

As Lyme disease and other tick-borne diseases are increasingly becoming an issue in Canada, geospatial information is used for estimation and surveillance purposes. Through a combination of self-reported tick exposure, risk indicators, and ecological variables, this research evaluates the value of self-reported exposure as a potential geospatial indicator for Lyme disease. The research used the North American Land Cover 2015 product to identify the proportion of forest cover (deciduous and mixed forests), which is a parameter in the evaluation of the location of tick habitats.

**Keywords**: Public health, Lyme disease, tick, exposure risk, indicator

**Mortality Burden From Wildfire Smoke Under Climate Change (2024)** (link)

Main authors & affiliations:
- Minghao Qiu, Stanford University
- Jessica Li, Department of Economics, University of California, San Diego
- Carlos F. Gould, School of Public Health University of California San Diego
- Renzhi Jing, Stanford University
- Makoto Kelp, Stanford University

This research examines the relationship between wildfire smoke and health by quantifying the mortality burden in the United States due to particulate matter (PM2.5) from wildfire smoke. Statistical and machine learning models have been constructed in combination with geospatial data to estimate PM2.5-mortality based on actual recorded deaths over time. The North American Land Cover 2015 product was used to identify land variables such as cropland, forest, and grassland and predict wildfire emissions.

**Keywords**: Wildfire smoke, health, mortality rate, climate change, air pollution

**Predicting Flood Damages using Machine Learning and National Flood Insurance Program Data (2024)** (link)

Main authors & affiliations:
- Azara Boschee, St. Cloud State University, St. Cloud, MN
- Tom Corringham, Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, La Jolla, CA
- Weiming Hu, James Madison University, Harrisonburg, VA

This research examines flood damages in the United States reported to the National Flood Insurance Program and methods to predict them with machine learning based on both a regression model and a classification model. The North American Land Cover 2020 product was used to identify the proportion of urban land cover as one of the variables for the models. Variables of importance in the accuracy of the models included runoff, soil moisture, and precipitation.

**Keywords**: Flood, insurance, machine learning, random forest, prediction

# Testimonials from External Users of NALCMS Products

**We also asked researchers directly why they selected the NALCMS products for their research. The following are testimonials from a few of them.**

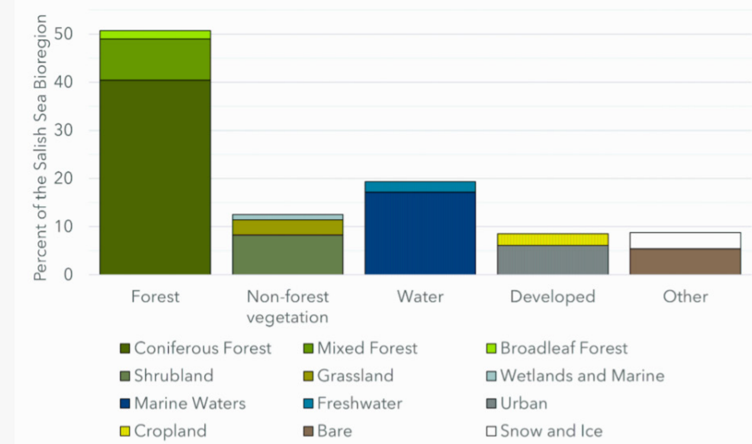

**AQUILA FLOWER**
Professor of Geography and Environmental Studies, and Director of the Spatial Institute College of the Environment, Western Washington University Bellingham, Washington, United States


NALCMS product used:
**North American Land Cover 2015 (Landsat & RapidEye, 30m)**

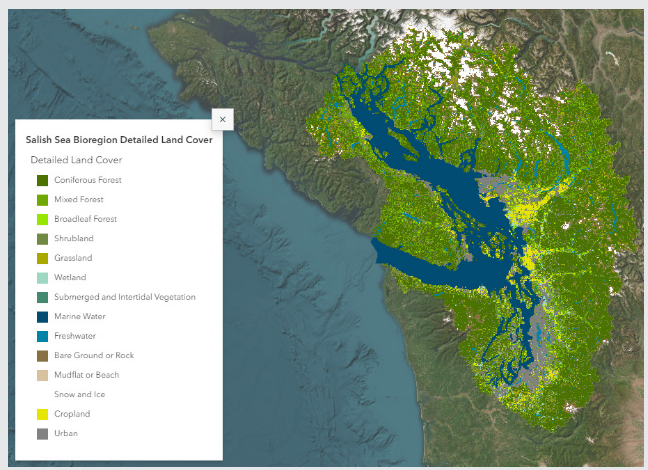
"I am writing an open-access, digital atlas for the Salish Sea Bioregion. The Salish Sea and its watersheds span the international border between Canada and the United States on the Pacific Coast. This transboundary setting makes it very challenging to find cohesive international datasets and maps, as many datasets stop at the international border.

I used the marvellously cohesive NALCMS dataset, with some modifications, to map and assess land cover across the Salish Sea Bioregion. I have also used the same data to create maps for several publications, including the State of the Salish Sea Report."

You can view the published chapters of the Salish Sea Atlas. ([link](link))




*Land Cover for the Salish Sea Bioregion. "Wetlands and Marine" includes both wetlands on land and inundated/intertidal marine vegetation. "Bare" includes bare soil, rock, beaches, and mudflats. Data based on 2015 Landsat imagery.*

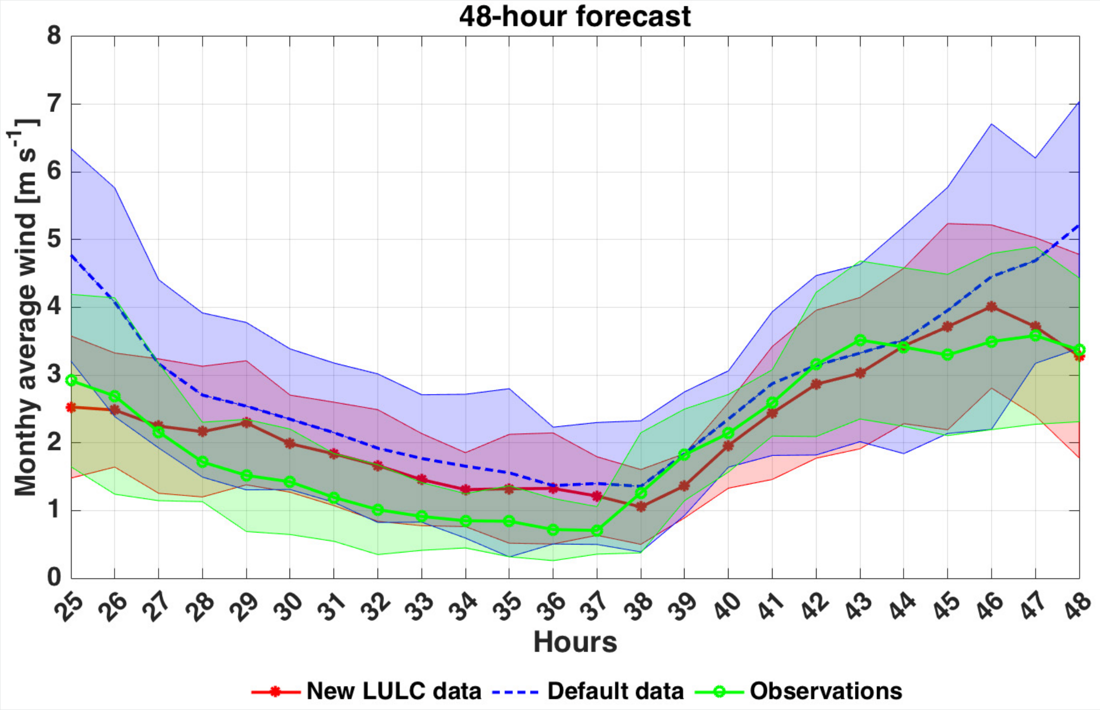



**ERIKA DANAÉ LÓPEZ ESPINOZA**
Researcher and Academic Secretary, Institute of Atmospheric Sciences and Climate Change (*Instituto de Ciencias de la Atmósfera y Cambio Climático, ICAyCC*)
National Autonomous University of Mexico (*Universidad Nacional Autónoma de México, UNAM*)
Mexico City, Mexico

NALCMS product used:
**North American Land Cover 2005 and 2010 (MODIS, 250m)**

"My lines of research focus on numerical modeling of the atmosphere, analysis of extreme events with observations and numerical modeling, as well as analysis of the impact of Land Use and Land Cover (LULC) change on climatic conditions.

I used the North American Land Change Monitoring System (NALCMS) land cover data from 2005 within an academic research, with the aim of analyzing the sensitivity of the Weather Research and Forecasting (WRF) atmospheric model to forecast the variables of air temperature, wind and precipitation. A statistical analysis published in 2020 showed that the forecast of wind speed and air temperature can be improved by using the NALCMS data because they better represent the LULC conditions of the study region (Central Mexico). In particular, a reduction in forecast error was observed over the 48 to 72 hours forecast." (link)




The NALCMS products from 2005 and 2010 were also used to analyze the temperature, wind and precipitation forecast for the Yucatan Peninsula through research I supervised as part of a UNAM's bachelor's thesis: Barrales Hassan, Rebeca Guadalupe. 2017. "Impacto del cambio de uso de suelo y cobertura vegetal en el pronóstico numérico del tiempo." Licenciatura en Ciencias de la Tierra, Ciudad de México: Universidad Nacional Autónoma de México. (link)

**Credit:** Graphical abstract from López-Espinoza, Erika Danaé, Jorge Zavala-Hidalgo, Rezaul Mahmood, and Octavio Gómez-Ramos. 2020. "Assessing the Impact of Land Use and Land Cover Data Representation on Weather Forecast Quality: A Case Study in Central Mexico." Atmosphere 11 (11): 1242.

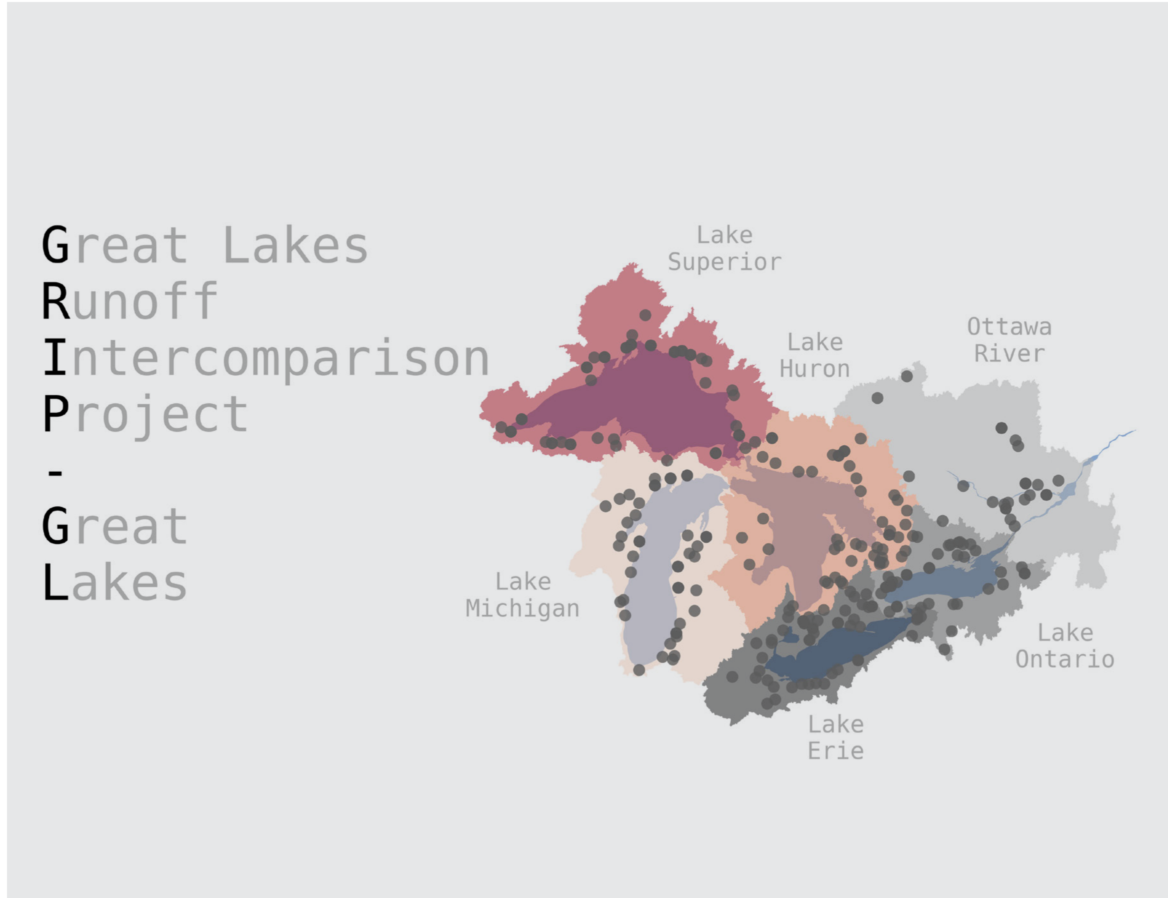
**JULIANE MAI**
Research Associate Professor,
Department of Earth and
Environmental Sciences
University of Waterloo
Waterloo, Ontario, Canada.

NALCMS product used:
**North American Land Cover 2010 (Landsat, 30m)**

"I am a computational hydrologist focussing on large-scale modeling, model intercomparisons and data dissemination.

We used the NACLMS data in a multi-year cross-institutional model intercomparison project where we compared 13 hydrologic and land surface models regarding their performance regarding streamflow simulations and secondary variables such as actual evapotranspiration, surface soil moisture, and snow water equivalent. This project, which won the 2022 Jim Dooge Award, agreed on a common dataset that every model had to use exclusively for model setup, training, and validation.

The landcover classification provided in NALCMS over the Great Lakes watershed (~ 1 million km2) was used to setup 13 hydrologic and land-surface models as well as data-driven models. The landcover dataset chosen was NALCMS as it was providing the data needed by everyone while being very well structured and documented."




The publication can be found here: (link)

Results of the project are presented on interactive maps here: (link)

My website provides additional information about my research activities: (link)

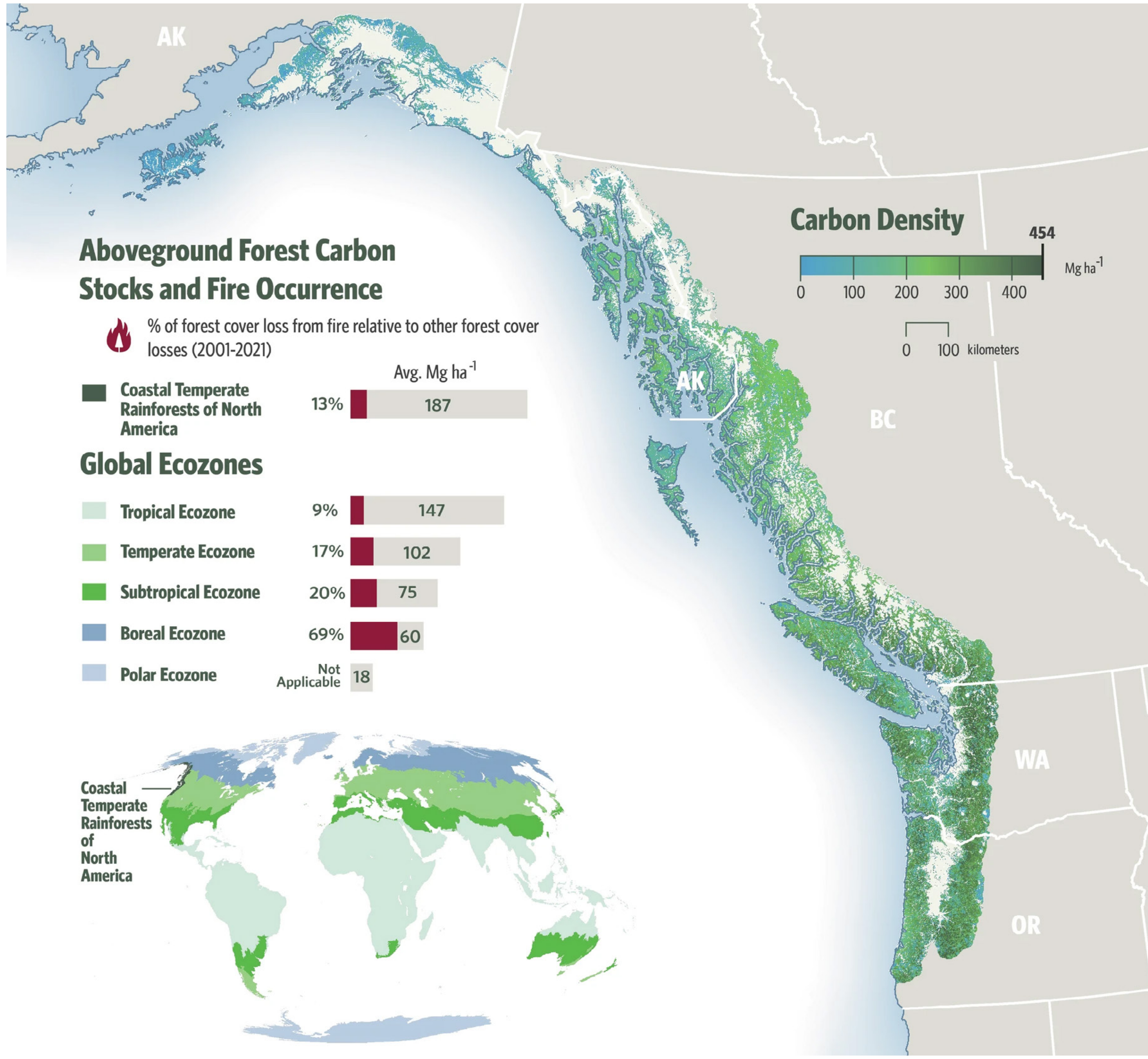
**COLIN SHANLEY**
Principal, Northwest GIS LLC
Juneau, Alaska, United States

NALCMS product used:
**North American Land Cover 2015 (Landsat & RapidEye, 30m)**

"I'm the founder of Northwest GIS (northwestgis.com), an environmental research consulting company based in Juneau, Alaska, that specializes in spatial analysis for land management and conservation applications. I used the NALCMS dataset in the research project "Mapping forest-based natural climate solutions" with results published in Communications Earth & Environment. (link)

The NALCMS land cover product was an ideal dataset for this project because our project area spanned the coastal temperate rainforest ecoregion of western North America that includes parts of Oregon (US), Washington (US), British Columbia (Canada), and Alaska (USA).

A consistent land cover dataset such as the NALCMS product that makes ecoregional analyses possible is a valuable tool for scientists to think beyond state and country boarders."




**Credit:** Figure 1 from Shanley et al. 2024. "Mapping Forest-Based Natural Climate Solutions." *Communications Earth & Environment* 5 (1): 1–12.

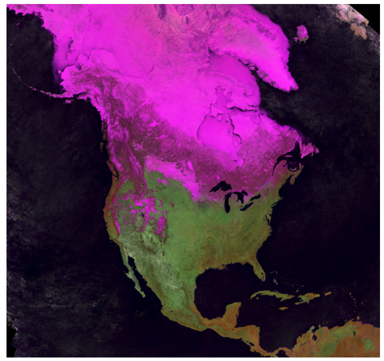
# Knowledge-Sharing Among NALCMS Members

**Over the years, the NALCMS members** have benefited from each other's expertise when working on both national and regional initiatives. This long-standing collaboration and sharing of knowledge has helped to strengthen the creation process of land cover datasets and maps in all three countries and in North America as a whole.

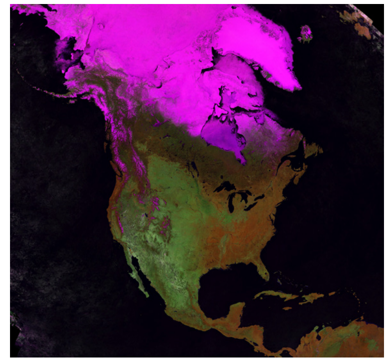
Here are a few examples illustrating this knowledge-sharing experience.

## Creation of the North American Land Cover Change 2005–2010 (MODIS, 250m) dataset

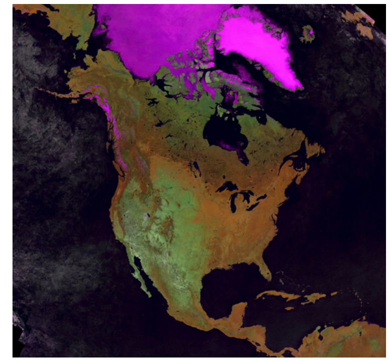
During the creation of the land cover change 2005–2010, the NALCMS members from Canada Centre for Remote Sensing produced the North American MODIS monthly composites for the period and shared them with the group. These composite images were used to support the North American classification of land cover for both periods of 2005 and 2010 as well as supported the national land cover change detection work in Mexico.



March 2008



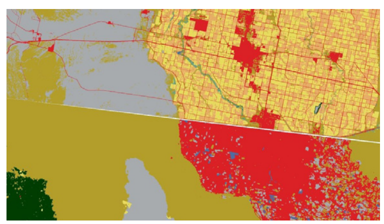
May 2008



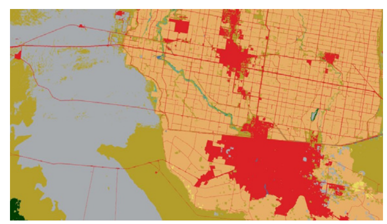
July 2008

## Creation of the North American Land Cover 2010 and 2015 (30m) datasets

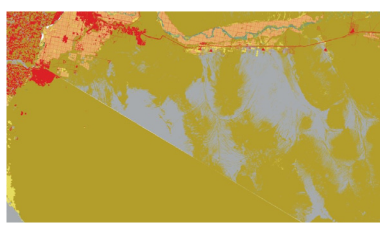
During the creation of the original versions of the 2010 and 2015 land cover maps at 30 m resolution, several discussions occurred between all NALCMS members to address border discontinuities. Experts from both sides of each border agreed, through these discussions, on how to modify certain areas of land cover to optimize the harmonization process and provide seamless land cover data at the North American level.



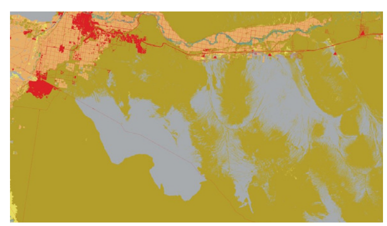
Mexicali Calexico — Before



Mexicali Calexico — After



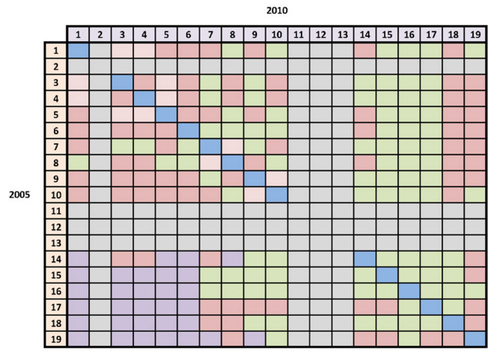
Yuma Sonora — Before



Yuma Sonora — After

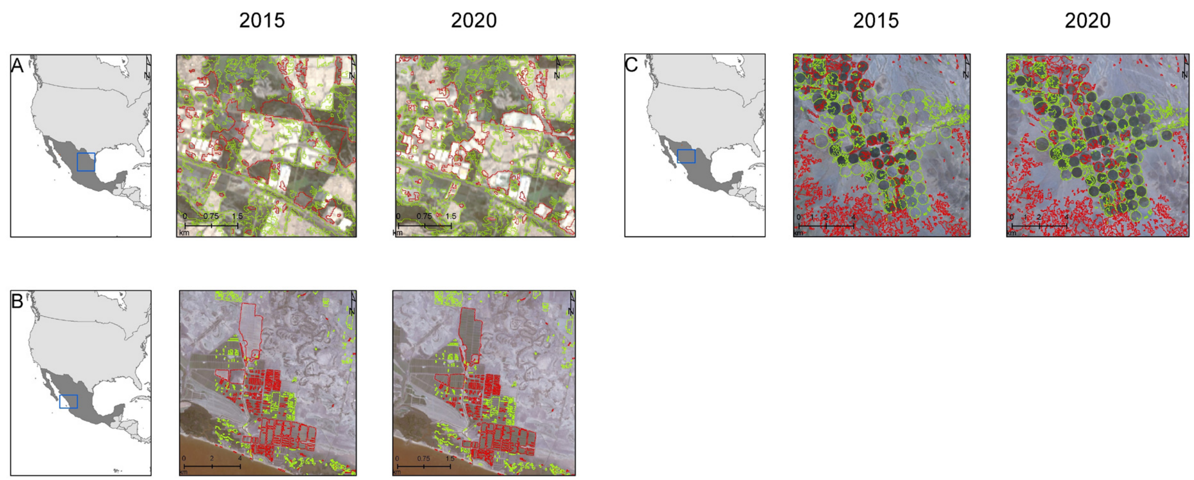
## Creation of the North American Land Cover Change 2010–2015 (30m) dataset

NALCMS members from CONAFOR proposed a matrix of allowed changes that was used across the three countries to determine what should be considered a change or not, based on a set of logical land cover class transitions.



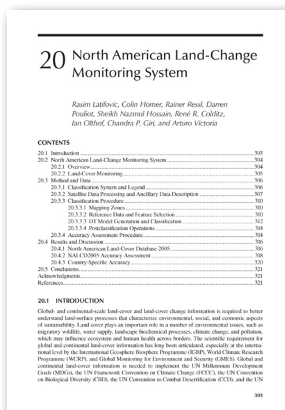

## Creation of the North American Land Cover Change 2015–2020 dataset

NALCMS members from USGS shared a change detection method with NALCMS members in Mexico to facilitate the detection of land cover change. The Multi-Index Integrated Change Analysis (MIICA) method, developed by USGS and used with the United States' National Land Cover Database (NLCD) products, was used to detect land cover change in Mexico and subsequently incorporated into the North American Land Cover Change 2015–2020 product.




## Collaboration between NALCMS members for publications of scientific articles

Many scientific articles and conference papers were created by NALCMS members from the three countries. These writing and publication efforts were always great opportunities for the members to support each other and promote their collaborative work. A great example of this was the publication of a chapter[6] focusing entirely on the North American Land Change Monitoring System in the book, Remote Sensing of Land Use and Land Cover: Principles and Applications (CRC Press, 2012).


20 North American Land-Change Monitoring System

*Rasim Latifovic, Colin Homer, Rainer Ressl, Darren Pouliot, Sheikh Nazmul Hossain, René R. Colditz, Ian Olthof, Chandra P. Giri, and Arturo Victoria*

CONTENTS

20.1 INTRODUCTION

[6] Latifovic, Rasim, Collin Homer, Rainer Ressl, Darren Pouliot, Sheikh Nazmul Hossain, René R. Colditz, and Arturo Victoria. 2012. "North American Land Change Monitoring System." In Remote Sensing of Land Use and Land Cover: Principles and Applications, edited by Chandra Giri, 303–24. Boca Raton, FL: Taylor & Francis Series in Remote Sensing Applications: CRC Press. (Link)

# Conclusion

**Since its creation in 2006**, the North American Land Change Monitoring System (NALCMS) initiative has addressed, through trinational collaboration, the persistent challenges of integrating geospatial data from different land cover programmes and maintaining consistency across different countries and over many years.

Used by hundreds of researchers, including from the governmental agencies that are members of the NALCMS themselves, and cited in hundreds of scientific publications and reports, the geospatial products stemming from the NALCMS initiative are truly considered a worldwide reference for land cover information in North America.

After nearly two decades of successful and impactful collaboration among multiple governmental agencies with many experts meeting in different parts of North America, the NALCMS initiative can serve as a role-model for other regional initiatives across the world at a time of an ever-increasing demand for geospatial data extending further than national borders.

Land cover information is necessary for a large range of applications related to environmental decision-making, natural resource management, adaptation to climate impacts, emergency response, environmental conservation and restoration, etc. The goal of the NALCMS initiative is to support policy- and decision-makers, researchers, international and intergovernmental organizations, NGOs, land managers, among many others, from local up to global levels, by allowing them to better understand the dynamics and patterns of North America's land cover and to conduct both regional and local-level analyses.

While continuous efforts have been made over the years, future efforts are needed on further developing advanced data harmonization techniques and standardization among different and evolving national programmes to strengthen the longevity of the NALCMS initiative. The NALCMS will have to adapt to a changing digital environment where users are increasingly asking for faster delivery of products having a higher resolution, and where there is a need to connect with other similar initiatives across the planet. It is important to evaluate the evolving needs and demands of geospatial data users, especially considering an increase in automatically-generated land cover data, which often sacrifice accuracy in order to provide data quicker.

We hope the present document can serve as a reference to all practitioners who need information about the history and the land cover products of the North American Land Change Monitoring System (NALCMS) initiative, and that this document can support further geospatial collaboration between Canada, Mexico, and the United States in the coming years.

# Related Publications


Colditz, René R., Gerardo López Saldaña, Pedro Maeda, Jesús Argumedo Espinoza, Carmen Meneses Tovar, Arturo Victoria Hernández, Carlos Zermeño Benítez, Isabel Cruz López, and Rainer Ressl. 2012. "Generation and Analysis of the 2005 Land Cover Map for Mexico Using 250m MODIS Data." Remote Sensing of Environment 123 (August):541–52. (Link)

Colditz, Rene R., Ricardo M. Llamas, and Rainer A. Ressl. 2014. "Detecting Change Areas in Mexico Between 2005 and 2010 Using 250 m MODIS Images." IEEE *Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 7 (8): (Link)

Colditz, René R., Darren Pouliot, Ricardo M. Llamas, Collin Homer, Rasim Latifovic, Rainer A. Ressl, Carmen Meneses, Arturo Victoria, and Karen Richardson. 2014. "Detection of North American Land Cover Change between 2005 and 2010 with 250m MODIS Data." *Photogrammetric Engineering & Remote Sensing* 80 (10): 918–24. (Link)

Gebhardt, Steffen, Thilo Wehrmann, Miguel Angel Muñoz Ruiz, Pedro Maeda, Jesse Bishop, Matthias Schramm, Rene Kopeinig, 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): 3923–43. (Link)

Homer, Collin, Jon Dewitz, Limin Yang, Suming Jin, Patrick Danielson, George Xian, John Coulston, Nathaniel Herold, James Wickham, and Kevin Megown. 2015. "Completion of the 2011 National Land Cover Database for the Conterminous United States — Representing a Decade of Land Cover Change Information." *Photogrammetric Engineering & Remote Sensing* 81 (5): 345–54. (Link)

Homer, Collin, Jon Dewitz, Suming Jin, George Xian, Catherine Costello, Patrick Danielson, Leila Gass, et al. 2020. "Conterminous United States Land Cover Change Patterns 2001–2016 from the 2016 National Land Cover Database." *ISPRS Journal of Photogrammetry and Remote Sensing* 162 (April): 184–99. (Link)

INEGI. 2023. *Guía Para La Interpretación De Cartografía. Uso Del Suelo Y Vegetación Escala 1: 250 000. Serie VII.* Aguascalientes, Aguascalientes: Instituto Nacional de Estadística y Geografía (México). (Link)

Jin, Suming, Collin Homer, Limin Yang, Patrick Danielson, Jon Dewitz, Congcong Li, Zhe Zhu, George Xian, and Danny Howard. 2019. "Overall Methodology Design for the United States National Land Cover Database 2016 Products" Remote Sensing 11, no. 24: 2971. (Link)

Jin, Suming, Jon Dewitz, Patrick Danielson, Brian Granneman, Catherine Costello, Kelcy Smith, and Zhe Zhu. 2023. "National Land Cover Database 2019: A New Strategy for Creating Clean Leaf-On and Leaf-Off Landsat Composite Images." *Journal of Remote Sensing* 3 (February):0022. (Link)

Jin, Suming, Jon Dewitz, Congcong Li, Daniel Sorenson, Zhe Zhu, Md Rakibul Islam Shogib, et al. 2023. "National Land Cover Database 2019: A Comprehensive Strategy for Creating the 1986–2019 Forest Disturbance Product." *Journal of Remote Sensing* 3 (February):0021. (Link)

Jin, Suming, Limin Yang, Patrick Danielson, Collin Homer, Joyce Fry, and George Xian. 2013. "A Comprehensive Change Detection Method for Updating the National Land Cover Database to circa 2011." *Remote Sensing of Environment* 132 (May):159–75. (Link)

Latifovic, Rasim, Collin Homer, Rainer Ressl, Darren Pouliot, Sheikh Nazmul Hossain, René R. Colditz, and Arturo Victoria. 2012. "North American Land Change Monitoring System." In *Remote Sensing of Land Use and Land Cover: Principles and Applications*, edited by Chandra Giri, 303–24. Boca Raton, FL: Taylor & Francis Series in Remote Sensing Applications: CRC Press. (Link)

Latifovic, R., D. A. Pouliot, L. Sun, J. W. Schwarz, and W. Parkinson. 2015. "Moderate Resolution Time Series Data Management and Analysis: Automated Large Area Mosaicking and Quality Control" *Geomatics Canada, Open File* 6, no.25. (Link)

Latifovic, Rasim, Darren Pouliot, and Ian Olthof. 2017. "Circa 2010 Land Cover of Canada: Local Optimization Methodology and Product Development" *Remote Sensing* 9, no. 11: 1098. (Link)

Pouliot, D., R. Latifovic, and I. Olthof. 2017. “Development of a 30 m Spatial Resolution Land Cover of Canada: Contribution to the Harmonized North America Land Cover Dataset.” American Geophysical Union, Fall Meeting 2017:GC52C-02. New Orleans, LA, USA. (Link)

Wickham, James, Stephen V. Stehman, Daniel G. Sorenson, Leila Gass, and Jon A. Dewitz. 2021. “Thematic Accuracy Assessment of the NLCD 2016 Land Cover for the Conterminous United States.” *Remote Sensing of Environment* 257 (May):112357. (Link)

Wickham, James, Stephen V. Stehman, Daniel G. Sorenson, Leila Gass, and Jon A. Dewitz. 2023. “Thematic Accuracy Assessment of the NLCD 2019 Land Cover for the Conterminous United States.” *GIScience & Remote Sensing* 60 (1): 2181143. (Link)

Yang, Limin, Suming Jin, Patrick Danielson, Collin Homer, Leila Gass, Stacie M. Bender, Adam Case, et al. 2018. “A New Generation of the United States National Land Cover Database: Requirements, Research Priorities, Design, and Implementation Strategies.” *ISPRS Journal of Photogrammetry and Remote Sensing* 146 (December):108–23. (Link)

NALCMS products are available in the [North American Environmental Atlas](#).

CEC