# User Guide to Collection 6 MODIS Land Cover (MCD12Q1 and MCD12C1) Product

Damien Sulla-Menashe and Mark A Friedl

May 14, 2018

The MODIS Land Cover Type Product (MCD12Q1) provides a suite of science data sets (SDSs) that map global land cover at 500 meter spatial resolution at annual time step for six different land cover legends. The maps were created from classifications of spectro-temporal features derived of data from the Moderate Resolution Imaging Spectroradiometer (MODIS). This user guide provides the following information related to the C6 product:

1. An overview of the MCD12Q1 algorithm, with references to published literature where more details can be found.
2. Guidance on data portals, projections, and formats, to help users access and use the data.
3. Contact information for users with questions that cannot be addressed through information or websites provided in this document.
4. Tables describing the different data sets and legends provided with the product.

## 1 Product Overview

The MODIS Land Cover Type Product (MCD12Q1) supplies global maps of land cover at annual time steps and 500-m spatial resolution for 2001-present. The product contains 13 Science Data Sets (SDS; Table 1), including 5 legacy classification schemes (IGBP, UMD, LAI, BGC, and PFT; Tables 3- 7) and a new three layer legend based on the Land Cover Classification System (LCCS) from the Food and Agriculture Organization (Tables 8- 10; Di Gregorio, 2005; Sulla-Menashe et al., 2011). Also included are a Quality Assurance (QA; Table 11) layer, the posterior probabilities for the three LCCS layers, and the binary land water mask used by the product. MCD12Q1 has been Stage 2 Validated based on cross-validation of the training dataset used to create the maps.

The MCD12Q1 product is created using supervised classification of MODIS reflectance data (Friedl et al., 2002, 2010). In Collection 5 MCD12Q1, the IGBP scheme was classified using the C4.5 decision tree algorithm that ingested a full year of 8-day MODIS Nadir BRDF-Adjusted Reflectance (NBAR; Schaaf et al., 2002) data (MCD43A2 and MCD43A4). In Collection 6, we have made substantial changes to the MCD12Q1 SDSs, to the algorithm that pre-process and classify the data, and to the input features used in the classifications. Foremost among these changes is the development of a new legend based on a nested set of classifications (Figure 1). To create this LCCS legend, we added new class information to the site database

used to train the classifier. The second major change to the product is that we developed new gap-filled spectro-temporal features by applying smoothing splines to the NBAR time series, using NBAR QA data to weigh the observations. The smoothed time series were used to generate snow flags and calculate snow-free metrics including annual quantiles and variances for the spectral bands and several band combinations. These annual metrics were used as inputs to the RandomForest classifier for each layer of the hierarchy.

Following supervised classification of smoothed NBAR data, a set of post-processing steps that incorporate prior probability knowledge and adjust specific classes based on ancillary information are applied to the classification results (McIver and Friedl, 2002; Friedl et al., 2002). The final class-conditional probabilities have substantial levels of inter-annual variability caused by residual noise in input time series, missing data, and changes within the training database (Friedl et al., 2010). To reduce interannual variability caused by classifier instability, we developed an approach based on Hidden Markov Models that post-process map results for each year, which dramatically reduces inter-annual variability in the product (Abercrombie and Friedl, 2016). After stabilization, the classifications are condensed into the final set of six legends and associated QA information. Despite improving the stability to the product, *we urge users not to use the product to determine post-classification land cover change*. The amount of uncertainty in the land cover labels for any one year remains too high to distinguish real change from changes between classes that are spectrally indistinguishable at the coarse 500-m MODIS resolution. For more detailed information about the development and accuracy of the C6 MCD12Q1 product see Sulla-Menashe et al. (view).

To maximize utility to the science community, six different classification schemes are provided with the C6 MCD12Q1 product. These include the IGBP land cover classification (Loveland and Belward, 1997; Belward et al., 1999) (Table 3), the University of Maryland classification scheme (Hansen et al., 2000) (Table 4), the Biome classification scheme described by Running et al. (2004) (Table 6), the LAI/fPAR Biome scheme described by Myneni et al. (2002) (Table 5), and the Plant Functional Type scheme described by Bonan (2002) (Table 7). The LCCS scheme contains three layers, the first for land cover, the second for land use, and the third for surface hydrology (Tables 8-9).

The MODIS Land Cover Climate Modeling Grid Product (MCD12C1) provides a spatially aggregated and reprojected version of the tiled MCD12Q1 product. Maps of the IGBP, UMD, and LAI schemes are provided at a 0.05° spatial resolution in geographic lat/long projection (Table 2). Also provided are the sub-pixel proportions of each land cover class in each 0.05° pixel and the aggregated quality assessment information for the IGBP scheme.

Essential information required for accessing and using these data include the following:

- Data set characteristics (temporal coverage, spatial resolution, image size, data types, etc.).
- Science data sets included in the MODIS Land Cover Type Product, and their associated definitions.
- Information and specifications related to the MODIS Land Cover Type QA Science data set.

Up-to-date information related to each of these topics including science data sets, data formats, and quality information are available from the Land Processes DAAC at `https://doi.org/10.5067/MODIS/MCD12Q1.006` for MCD12Q1 and `https://doi.org/10.5067/MODIS/MCD12C1.006` for MCD12C1.

## 2 Data Formats and Projection

MCD12Q1 data are provided as tiles that are approximately 10°x 10°at the Equator using a Sinusoidal grid in HDF4 file format. MCD12C1 data are provided as a global mosaic in geographic lat/long projection also

in HDF4 file format (3600 rows x 7200 columns). Information related to the MODIS sinusoidal projection and the HDF4 file format can be found at:

- MODIS tile grid: `http://modis-land.gsfc.nasa.gov/MODLAND_grid.html`
- MODIS HDF4: `http://www.hdfgroup.org/products/hdf4/`

Several parameters are needed to reproject the Sinusoidal HDF4 files to other projections using widely used software such as GDAL. Here we provide the values used for the upper left corner of the grid, the size of a single pixel, and the Sinusoidal projection string in Cartographic Projections Library (PROJ4) and Well-Known Text (WKT) formats.

- ULY Grid = 10007554.677, ULX Grid = -20015109.354
- Pixel Size (m) = 463.312716525
- Number of Pixels per Tile = 2400
- Projection Information

  PROJ4: '+proj=sinu +a=6371007.181 +b=6371007.181 +units=m'

  WKT:

```
PROJCS["Sinusoidal", GEOGCS["GCS_unnamed ellipse",
DATUM["D_unknown", SPHEROID["Unknown",6371007.181,0]],
PRIMEM["Greenwich",0], UNIT["Degree",0.017453292519943295]],
PROJECTION["Sinusoidal"], PARAMETER["central_meridian",0],
PARAMETER["false_easting",0], PARAMETER["false_northing",0],UNIT["Meter",1]
```

## 2.1 Accessing MODIS Data Products

Several ways to access the MODIS data products are listed below. More info about the data sets, data formats, and quality information are available from the Land Processes DAAC. For MCD12Q1 the link is `https://doi.org/10.5067/MODIS/MCD12Q1.006` and for MCD12C1, `https://doi.org/10.5067/MODIS/MCD12C1.006`.

- Bulk download: LP DAAC Data Pool and DAAC2Disk.
- Search and browse: USGS EarthExplorer and NASA Earthdata Search.

## 2.2 Known Issues and Sources of Uncertainty

- Areas of permanent sea ice are mapped as water if they are identifed as water according to the C6 Land/Water mask (Carroll et al., 2009). Some land areas, for example glaciers within permanent topographic shadows, were mapped as water according to this mask, which introduces isolated errors in the product.
- Wetlands are under-represented.
- In areas of the tropics where cropland field sizes tend to be much smaller than a MODIS pixel, agriculture is sometimes underrepresented (i.e., labeled as natural vegetation).

- Areas of temperate evergreen needleleaf forests are misclassified as broadleaf evergreen forests in Japan, the Pacific Northwest of North America, and Chile. Similarly, areas of evergreen broadleaf forests are misclassified as evergreen needleleaf forests in Australia and parts of South America.
- Some grassland areas are classified as savannas (sparse forest).
- There is a glacier in Chile that is screened as if it were permanently cloud covered and is partially classified as grassland.

# 3 Contact Information

User Contact:


- Damien Sulla-Menashe (dsm@bu.edu)
- Mark Friedl (friedl@bu.edu)


# 4 Science Data Sets

Table 1: MCD12Q1 Science Data Sets.

| **SDS Full Name** | **Short Name** | **Description** | **Units** | **Data Type** | **Valid Range** | **Fill Value** |
|---|---|---|---|---|---|---|
| Land Cover Type 1 | LC_Type1 | Annual IGBP classification | Class # | 8-bit unsigned | [1,17] | 255 |
| Land Cover Type 2 | LC_Type2 | Annual UMD classification | Class # | 8-bit unsigned | [0,15] | 255 |
| Land Cover Type 3 | LC_Type3 | Annual LAI classification | Class # | 8-bit unsigned | [0,10] | 255 |
| Land Cover Type 4 | LC_Type4 | Annual BGC classification | Class # | 8-bit unsigned | [0,8] | 255 |
| Land Cover Type 5 | LC_Type5 | Annual PFT classification | Class # | 8-bit unsigned | [0,11] | 255 |
| Land Cover Property 1 | LC_Prop1 | LCCS1 land cover layer | Class # | 8-bit unsigned | [1,43] | 255 |
| Land Cover Property 2 | LC_Prop2 | LCCS2 land use layer | Class # | 8-bit unsigned | [1,40] | 255 |
| Land Cover Property 3 | LC_Prop3 | LCCS3 surface hydrology layer | Class # | 8-bit unsigned | [1,51] | 255 |
| Land Cover Property 1 Assessment | LC_Prop1_Ass | LCCS1 land cover layer confidence | Percent x 100 | 8-bit unsigned | [0,100] | 255 |
| Land Cover Property 2 Assessment | LC_Prop2_Ass | LCCS2 land use layer confidence | Percent x 100 | 8-bit unsigned | [0,100] | 255 |
| Land Cover Property 3 Assessment | LC_Prop3_Ass | LCCS3 surface hydrology layer confidence | Percent x 100 | 8-bit unsigned | [0,100] | 255 |
| Land Cover QC | QC | Product quality flags | Flags | 8-bit unsigned | [0,10] | 255 |
| Land Water Mask | LW | Binary land (class 2) / water (class 1) mask derived from MOD44W | Class # | 8-bit unsigned | [1,2] | 255 |

Table 2: MCD12C1 Science Data Sets.

| **Full SDS name** | **Short Name** | **Description** | **Unit** | **Data Type** | **Valid range** | **Fill Value** |
|---|---|---|---|---|---|---|
| Majority Land Cover Type 1 | MLCT_1 | Most likely IGBP class for each 0.05 degree pixel | Class value | 8-bit unsigned integer | [0,16] | 255 |
| Majority Land Cover Type 1 Assessment | MLCT_1_A | Majority IGBP class confidence | Percent x 100 | 8-bit unsigned integer | [0,100] | 255 |
| Majority Land Cover Type 1 Percent | LCT_1_P | Percent cover of each IGBP class at each pixel | Percent x 100 | 8-bit unsigned integer | [0,100] | 255 |
| Majority Land Cover Type 2 | MLCT_2 | Most likely UMD class for each 0.05 degree pixel | Class value | 8-bit unsigned integer | [0,15] | 255 |
| Majority Land Cover Type 2 Assessment | MLCT_2_A | Majority UMD class confidence (filled with land/water mask) | Percent x 100 | 8-bit unsigned integer | [0,100] | 255 |
| Majority Land Cover Type 2 Percent | LCT_2_P | Percent cover of each UMD class at each pixel | Percent x 100 | 8-bit unsigned integer | [0,100] | 255 |
| Majority Land Cover Type 3 | MLCT_3 | Most likely LAI class for each 0.05 degree pixel | Class value | 8-bit unsigned integer | [0,10] | 255 |
| Majority Land Cover Type 3 Assessment | MLCT_3_A | Majority LAI class confidence (filled with land/water mask) | Percent x 100 | 8-bit unsigned integer | [0,100] | 255 |
| Majority Land Cover Type 3 Percent | LCT_3_P | Percent cover of each LAI class at each pixel | Percent x 100 | 8-bit unsigned integer | [0,100] | 255 |

# 5 Classification Legends

## 5.1 MCD12Q1 Legends

Table 3: MCD12Q1 International Geosphere-Biosphere Programme (IGBP) legend and class descriptions.

| Name | Value | Description |
|---|---|---|
| Evergreen Needleleaf Forests | 1 | Dominated by evergreen conifer trees (canopy >2m). Tree cover >60%. |
| Evergreen Broadleaf Forests | 2 | Dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%. |
| Deciduous Needleleaf Forests | 3 | Dominated by deciduous needleleaf (larch) trees (canopy >2m). Tree cover >60%. |
| Deciduous Broadleaf Forests | 4 | Dominated by deciduous broadleaf trees (canopy >2m). Tree cover >60%. |
| Mixed Forests | 5 | Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2m). Tree cover >60%. |
| Closed Shrublands | 6 | Dominated by woody perennials (1-2m height) >60% cover. |
| Open Shrublands | 7 | Dominated by woody perennials (1-2m height) 10-60% cover. |
| Woody Savannas | 8 | Tree cover 30-60% (canopy >2m). |
| Savannas | 9 | Tree cover 10-30% (canopy >2m). |
| Grasslands | 10 | Dominated by herbaceous annuals (<2m). |
| Permanent Wetlands | 11 | Permanently inundated lands with 30-60% water cover and >10% vegetated cover. |
| Croplands | 12 | At least 60% of area is cultivated cropland. |
| Urban and Built-up Lands | 13 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Cropland/Natural Vegetation Mosaics | 14 | Mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation. |
| Permanent Snow and Ice | 15 | At least 60% of area is covered by snow and ice for at least 10 months of the year. |
| Barren | 16 | At least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation. |
| Water Bodies | 17 | At least 60% of area is covered by permanent water bodies. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 4: University of Maryland (UMD) legend and class definitions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Water bodies | 0 | At least 60% of area is covered by permanent water bodies. |
| Evergreen Needleleaf Forests | 1 | Dominated by evergreen conifer trees (canopy >2m). Tree cover >60%. |
| Evergreen Broadleaf Forests | 2 | Dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%. |
| Deciduous Needleleaf Forests | 3 | Dominated by deciduous needleleaf (larch) trees (canopy >2m). Tree cover >60%. |
| Deciduous Broadleaf Forests | 4 | Dominated by deciduous broadleaf trees (canopy >2m). Tree cover >60%. |
| Mixed Forests | 5 | Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2m). Tree cover >60%. |
| Closed Shrublands | 6 | Dominated by woody perennials (1-2m height) >60% cover. |
| Open Shrublands | 7 | Dominated by woody perennials (1-2m height) 10-60% cover. |
| Woody Savannas | 8 | Tree cover 30-60% (canopy >2m). |
| Savannas | 9 | Tree cover 10-30% (canopy >2m). |
| Grasslands | 10 | Dominated by herbaceous annuals (<2m). |
| Permanent Wetlands | 11 | Permanently inundated lands with 30-60% water cover and >10% vegetated cover. |
| Croplands | 12 | At least 60% of area is cultivated cropland. |
| Urban and Built-up Lands | 13 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Cropland/Natural Vegetation Mosaics | 14 | Mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation. |
| Non-Vegetated Lands | 15 | At least 60% of area is non-vegetated barren (sand, rock, soil) or permanent snow and ice with less than 10% vegetation. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 5: Leaf Area Index (LAI) legend and class definitions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Water Bodies | 0 | At least 60% of area is covered by permanent water bodies. |
| Grasslands | 1 | Dominated by herbaceous annuals (<2m) including cereal croplands. |
| Shrublands | 2 | Shrub (1-2m) cover >10%. |
| Broadleaf Croplands | 3 | Dominated by herbaceous annuals (<2m) that are cultivated with broadleaf crops. |
| Savannas | 4 | Between 10-60% tree cover (>2m). |
| Evergreen Broadleaf Forests | 5 | Dominated by evergreen broadleaf and palmate trees (>2m). Tree cover >60%. |
| Deciduous Broadleaf Forests | 6 | Dominated by deciduous broadleaf trees (>2m). Tree cover >60%. |
| Evergreen Needleleaf Forests | 7 | Dominated by evergreen conifer trees (>2m). Tree cover >60%. |
| Deciduous Needleleaf Forests | 8 | Dominated by deciduous needleleaf (larch) trees (>2m). Tree cover >60%. |
| Non-Vegetated Lands | 9 | At least 60% of area is non-vegetated barren (sand, rock, soil) or permanent snow and ice with less than 10% vegetation. |
| Urban and Built-up Lands | 10 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 6: BIOME-Biogeochemical Cycles (BGC) legend and class definitions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Water Bodies | 0 | At least 60% of area is covered by permanent water bodies. |
| Evergreen Needleleaf Vegetation | 1 | Dominated by evergreen conifer trees and shrubs (>1m). Woody vegetation cover >10%. |
| Evergreen Broadleaf Vegetation | 2 | Dominated by evergreen broadleaf and palmate trees and shrubs (>1m). Woody vegetation cover >10%. |
| Deciduous Needleleaf Vegetation | 3 | Dominated by deciduous needleleaf (larch) trees and shrubs (>1m). Woody vegetation cover >10%. |
| Deciduous Broadleaf Vegetation | 4 | Dominated by deciduous broadleaf trees and shrubs (>1m). Woody vegetation cover >10%. |
| Annual Broadleaf Vegetation | 5 | Dominated by herbaceous annuals (<2m). At least 60% cultivated broadleaf crops. |
| Annual Grass Vegetation | 6 | Dominated by herbaceous annuals (<2m) including cereal croplands. |
| Non-Vegetated Lands | 7 | At least 60% of area is non-vegetated barren (sand, rock, soil) or permanent snow/ice with less than 10% vegetation. |
| Urban and Built-up Lands | 8 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 7: Plant Functional Types (PFT) legend and class definitions.

| **Name**<br>**Color Hex Code** | **Value** | **Description** |
|---|---|---|
| Water Bodies | 0 | At least 60% of area is covered by permanent water bodies. |
| Evergreen Needleleaf Trees | 1 | Dominated by evergreen conifer trees (>2m). Tree cover >10%. |
| Evergreen Broadleaf Trees | 2 | Dominated by evergreen broadleaf and palmate trees (>2m). Tree cover >10%. |
| Deciduous Needleleaf Trees | 3 | Dominated by deciduous needleleaf (larch) trees (>2m). Tree cover >10%. |
| Deciduous Broadleaf Trees | 4 | Dominated by deciduous broadleaf trees (>2m). Tree cover >10%. |
| Shrub | 5 | Shrub (1-2m) cover >10%. |
| Grass | 6 | Dominated by herbaceous annuals (<2m) that are not cultivated. |
| Cereal Croplands | 7 | Dominated by herbaceous annuals (<2m). At least 60% cultivated cereal crops. |
| Broadleaf Croplands | 8 | Dominated by herbaceous annuals (<2m). At least 60% cultivated broadleaf crops. |
| Urban and Built-up Lands | 9 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Permanent Snow and Ice | 10 | At least 60% of area is covered by snow and ice for at least 10 months of the year. |
| Barren | 11 | At least 60% of area is non-vegetated barren (sand, rock, soil) with less than 10% vegetation. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 8: FAO-Land Cover Classification System land cover (LCCS1) legend and class definitions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Barren | 1 | At least of area 60% is non-vegetated barren (sand, rock, soil) or permanent snow/ice with less than 10% vegetation. |
| Permanent Snow and Ice | 2 | At least of area 60% is covered by snow and ice for at least 10 months of the year. |
| Water Bodies | 3 | At least 60% of area is covered by permanent water bodies. |
| Evergreen Needleleaf Forests | 11 | Dominated by evergreen conifer trees (>2m). Tree cover >60%. |
| Evergreen Broadleaf Forests | 12 | Dominated by evergreen broadleaf and palmate trees (>2m). Tree cover >60%. |
| Deciduous Needleleaf Forests | 13 | Dominated by deciduous needleleaf (larch) trees (>2m). Tree cover >60%. |
| Deciduous Broadleaf Forests | 14 | Dominated by deciduous broadleaf trees (>2m). Tree cover >60%. |
| Mixed Broadleaf/Needleleaf Forests | 15 | Co-dominated (40-60%) by broadleaf deciduous and evergreen needleleaf tree (>2m) types. Tree cover >60%. |
| Mixed Broadleaf Evergreen/Deciduous Forests | 16 | Co-dominated (40-60%) by broadleaf evergreen and deciduous tree (>2m) types. Tree cover >60%. |
| Open Forests | 21 | Tree cover 30-60% (canopy >2m). |
| Sparse Forests | 22 | Tree cover 10-30% (canopy >2m). |
| Dense Herbaceous | 31 | Dominated by herbaceous annuals (<2m) at least 60% cover. |
| Sparse Herbaceous | 32 | Dominated by herbaceous annuals (<2m) 10-60% cover. |
| Dense Shrublands | 41 | Dominated by woody perennials (1-2m) >60% cover. |
| Shrubland/Grassland Mosaics | 42 | Dominated by woody perennials (1-2m) 10-60% cover with dense herbaceous annual understory. |
| Sparse Shrublands | 43 | Dominated by woody perennials (1-2m) 10-60% cover with minimal herbaceous understory. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 9: FAO-Land Cover Classification System land use (LCCS2) legend and class definitions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Barren | 1 | At least 60% of area is non-vegetated barren (sand, rock, soil) or permanent snow/ice with less than 10% vegetation. |
| Permanent Snow and Ice | 2 | At least 60% of area is covered by snow and ice for at least 10 months of the year. |
| Water Bodies | 3 | At least 60% of area is covered by permanent water bodies. |
| Urban and Built-up Lands | 9 | At least 30% of area is made up of impervious surfaces including building materials, asphalt, and vehicles. |
| Dense Forests | 10 | Tree cover >60% (canopy >2m). |
| Open Forests | 20 | Tree cover 10-60% (canopy >2m). |
| Forest/Cropland Mosaics | 25 | Mosaics of small-scale cultivation 40-60% with >10% natural tree cover. |
| Natural Herbaceous | 30 | Dominated by herbaceous annuals (<2m). At least 10% cover. |
| Natural Herbaceous/Croplands Mosaics | 35 | Mosaics of small-scale cultivation 40-60% with natural shrub or herbaceous vegetation. |
| Herbaceous Croplands | 36 | Dominated by herbaceous annuals (<2m). At least 60% cover. Cultivated fraction >60%. |
| Shrublands | 40 | Shrub cover >60% (1-2m). |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 10: FAO-Land Cover Classification System surface hydrology (LCCS3) legend and class descriptions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Barren | 1 | At least 60% of area is non-vegetated barren (sand, rock, soil) or permanent snow/ice with less than 10% vegetation. |
| Permanent Snow and Ice | 2 | At least 60% of area is covered by snow and ice for at least 10 months of the year. |
| Water Bodies | 3 | At least 60% of area is covered by permanent water bodies. |
| Dense Forests | 10 | Tree cover >60% (canopy >2m). |
| Open Forests | 20 | Tree cover 10-60% (canopy >2m). |
| Woody Wetlands | 27 | Shrub and tree cover >10% (>1m). Permanently or seasonally inundated |
| Grasslands | 30 | Dominated by herbaceous annuals (<2m) >10% cover. |
| Shrublands | 40 | Shrub cover >60% (1-2m). |
| Herbaceous Wetlands | 50 | Dominated by herbaceous annuals (<2m) >10% cover. Permanently or seasonally inundated. |
| Tundra | 51 | Tree cover <10%. Snow-covered for at least 8 months of the year. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

Table 11: Quality Assurance (QA) legend and class descriptions.

| **Name** | **Value** | **Description** |
|---|---|---|
| Classified land | 0 | Has a classification label and is land according to the water mask. |
| Unclassified land | 1 | Not classified because of missing data but land according to the water mask, labeled as barren. |
| Classified water | 2 | Has a classification label and is water according to the water mask. |
| Unclassified water | 3 | Not classified because of missing data but water according to the water mask. |
| Classified sea ice | 4 | Classified as snow/ice but water mask says it is water and less than 100m elevation, switched to water. |
| Misclassified water | 5 | Classified as water but water mask says it is land, switched to secondary label. |
| Omitted snow/ice | 6 | Land according to the water mask that was classified as something other than snow but with a maximum annual temperature below 1°C, relabeled as snow/ice. |
| Misclassified snow/ice | 7 | Land according to the water mask that was classified as snow but with a minimum annual temperature greater than 1°C, relabeled as barren. |
| Backfilled label | 8 | Missing label from stabilization, filled with the pre-stabilized result. |
| Forest type changed | 9 | Climate-based change to forest class. |
| No data | 10 | Missing label from the water mask. |

## 5.2 MCD12C1 IGBP Legend

Table 12: MCD12C1 International Geosphere-Biosphere Programme (IGBP) legend and class descriptions. The other class legends of the MCD12C1 product are identical to the MCD12Q1 product above.

| **Name** | **Value** | **Description** |
|---|---|---|
| Water Bodies | 0 | At least 60% of area is covered by permanent water bodies. |
| Evergreen Needleleaf Forests | 1 | Dominated by evergreen conifer trees (canopy >2m). Tree cover >60%. |
| Evergreen Broadleaf Forests | 2 | Dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%. |
| Deciduous Needleleaf Forests | 3 | Dominated by deciduous needleleaf (larch) trees (canopy >2m). Tree cover >60%. |
| Deciduous Broadleaf Forests | 4 | Dominated by deciduous broadleaf trees (canopy >2m). Tree cover >60%. |
| Mixed Forests | 5 | Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2m). Tree cover >60%. |
| Closed Shrublands | 6 | Dominated by woody perennials (1-2m height) >60% cover. |
| Open Shrublands | 7 | Dominated by woody perennials (1-2m height) 10-60% cover. |
| Woody Savannas | 8 | Tree cover 30-60% (canopy >2m). |
| Savannas | 9 | Tree cover 10-30% (canopy >2m). |
| Grasslands | 10 | Dominated by herbaceous annuals (<2m). |
| Permanent Wetlands | 11 | Permanently inundated lands with 30-60% water cover and >10% vegetated cover. |
| Croplands | 12 | At least 60% of area is cultivated cropland. |
| Urban and Built-up Lands | 13 | At least 30% impervious surface area including building materials, asphalt, and vehicles. |
| Cropland/Natural Vegetation Mosaics | 14 | Mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation. |
| Permanent Snow and Ice | 15 | At least 60% of area is covered by snow and ice for at least 10 months of the year. |
| Barren | 16 | At least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation. |
| Unclassified | 255 | Has not received a map label because of missing inputs. |

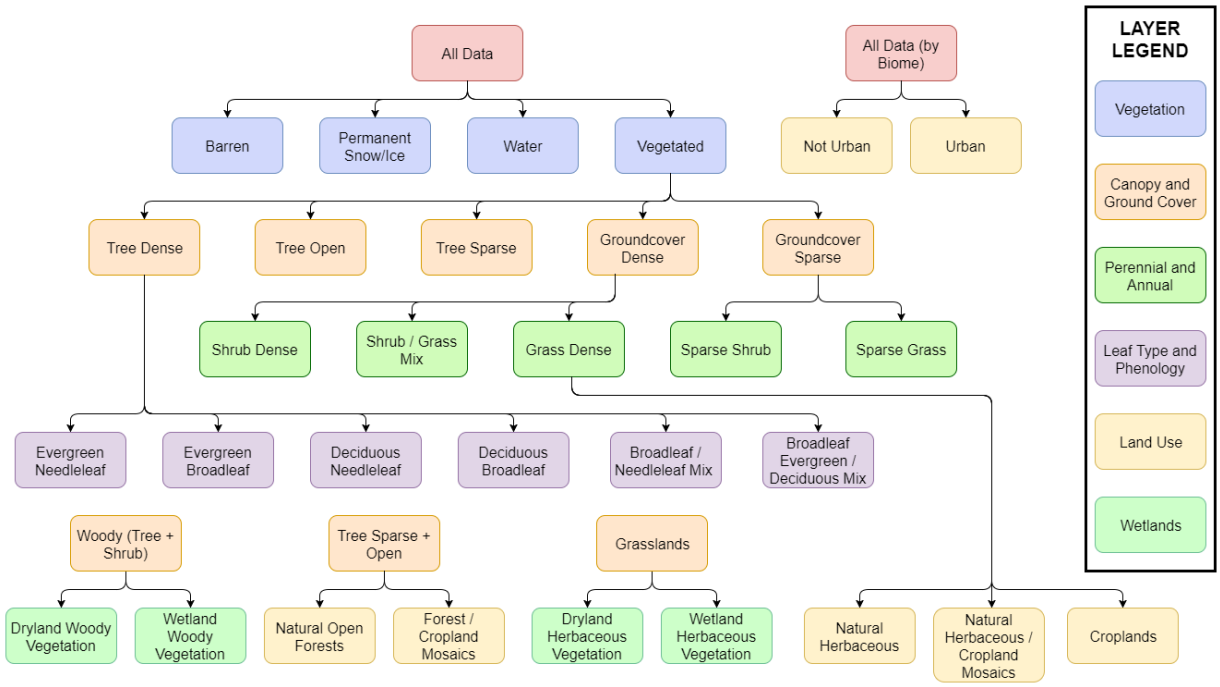


Figure 1: A diagram showing the nested classifications used to produce the LCCS scheme. Each set of arrows that originates from a parent node represents a single classification with the children nodes the output classes. Each color represents a different layer of the classification hierarchy. The surface hydrology and land use layers contain different information than land cover but overlap in certain definitions. The hierarchical nature allows for users to create their own custom legends.

## References


Abercrombie, S. P. and Friedl, M. A. (2016). Improving the Consistency of Multitemporal Land Cover Maps Using a Hidden Markov Model. *IEEE Transactions on Geoscience and Remote Sensing*, 54(2):703–713.

Belward, A. S., Estes, J. E., and Kline, K. D. (1999). The igbp-dis global 1-km land-cover data set discover: A project overview. *Photogrammetric Engineering and Remote Sensing*, 65(9):1013–1020.

Bonan, G. B. (2002). Landscapes as patches of plant functional types: An integrating concept for climate and ecosystem models. *Global Biogeochemical Cycles*, 16(2):1021.

Carroll, M. L., Townshend, J. R., DiMiceli, C. M., Noojipady, P., and Sohlberg, R. A. (2009). A new global raster water mask at 250 m resolution. *International Journal of Digital Earth*, 2(4):291–308.

Di Gregorio, A. (2005). *Land cover classification system: classification concepts and user manual: LCCS*. Number 8. Food & Agriculture Organization, Rome, Italy.

Friedl, M. A., McIver, D. K., Hodges, J., Zhang, X. Y., Muchoney, D., Strahler, A. H., Woodcock, C. E., Gopal, S., Schneider, A., Cooper, A., Baccini, A., Gao, F., and Schaaf, C. (2002). Global land cover mapping from MODIS: algorithms and early results. *Remote Sensing of Environment*, 83(1):287–302.

Friedl, M. A., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A., and Huang, X. (2010). MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote Sensing of Environment*, 114(1):168–182.

Hansen, M. C., Defries, R. S., Townshend, J. R., and Sohlberg, R. (2000). Global land cover classification at 1 km spatial resolution using a classification tree approach. *International Journal of Remote Sensing*, 21(6-7):1331–1364.

Loveland, T. R. and Belward, A. S. (1997). The international geosphere biosphere programme data and information system global land cover data set (DISCover). *Acta Astronautica*, 41(4):681–689.

McIver, D. K. and Friedl, M. A. (2002). Using prior probabilities in decision-tree classification of remotely sensed data. *Remote Sensing of Environment*, 81(2):253–261.

Myneni, R. B., Hoffman, S., Knyazikhin, Y., Privette, J. L., Glassy, J., Tian, Y., Wang, Y., Song, X., Zhang, Y., Smith, G. R., Lotsch, A., Friedl, M., Morisette, J. T., Votava, P., Nemani, R. R., and Running, S. V. (2002). Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data. *Remote Sensing of Environment*, 83(1):214–231.

Running, S. W., Nemani, R. R., Heinsch, F. A., Zhao, M., Reeves, M. C., and Hashimoto, H. (2004). A Continuous Satellite-Derived Measure of Global Terrestrial Primary Production. *BioScience*, 54(6):547.

Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X., Tsang, T., Strugnell, N. C., Zhang, X., Jin, Y., and Muller, J.-P. (2002). First operational BRDF, albedo nadir reflectance products from MODIS. *Remote Sensing of Environment*, 83(1):135–148.

Sulla-Menashe, D., Friedl, M. A., Krankina, O. N., Baccini, A., Woodcock, C. E., Sibley, A., Sun, G., Kharuk, V., and Elsakov, V. (2011). Hierarchical mapping of Northern Eurasian land cover using MODIS data. *Remote Sensing of Environment*, 115(2):392–403.

Sulla-Menashe, D., Gray, J. M., Abercrombie, S. P., and Friedl, M. A. (in review). Hierarchical mapping of annual global land cover 2001 to present: The modis collection 6 land cover product. *Remote Sensing of Environment*.