National Climatic Data Center

DATA DOCUMENTATION

FOR

DATASET 9821

Historical Land-Cover Change and Land-Use Conversions Global Dataset

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National Climatic Data Center

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1. Objectives/Purpose

This dataset was developed to understand the consequences of historical changes in land use and land cover for ecosystem goods and services. In particular, the data sets can be used to study how global land-cover changes have influenced climate, biogeochemical cycles, water cycle, biodiversity, etc. This data set can be used directly within spatially-explicit climate and biogeochemical models. The data are unique by providing a complete reconstruction of the past, and, in terms of details in land-cover types and methodology, are also relatively flexible to implement in other models. The dataset provides new avenues for climate models to study how uncertainties in historical land-cover change translate into uncertainties in quantifying its impacts on environmental variables of interest.

2. Data Description

A set of three gridded estimates of land-cover types and annual transformations of land use are provided on a global 0.5°x0.5° lat/lon grid at annual time steps. The longest of the three estimates spans 1770-2010. The dataset presented here takes into account land-cover change due to four major land-use/management activities: (1) cropland expansion and abandonment, (2) pastureland expansion and abandonment, (3) urbanization, and (4) secondary forest regrowth due to wood harvest.

Due to uncertainties associated with estimating historical agricultural (crops and pastures) land use, we have used three widely accepted global reconstruction of cropland and pastureland in combination with common wood harvest and urban land data set to provide three distinct estimates of historical land-cover change and underlying land-use transformations/conversions (area of one land-cover type that was converted to another land-cover type, between two consecutive years). Hence, these distinct historical reconstructions offer a wide range of plausible regional estimates of uncertainty and extent to which different ecosystem have undergone changes.

The three historical land-cover data reconstructions (referred to as HYDE, RF, and HH) were based on cropland and pastureland area change in the three updated historical land-use change data sets: (1) HYDE 3.1 (Historical Database of the Global Environment) (Klein Goldewijk et al., 2011), (2) RF (Ramankutty, 2012; Ramankutty and Foley, 1999) including new pastureland estimates and updated cropland estimates based on and Ramankutty et al. (2008), and (3) Houghton and Hackler (2001) deforestation estimates updated in Houghton (2008) with revised deforestation rates from FAO (2005) respectively. The HYDE and RF data sets are both based on FAOSTAT agricultural statistics including data on change in agricultural land area (FAO, 2009) which is available from 1960, making assumptions on the change in other land cover (e.g. forest) to meet agricultural demand. The Houghton (2008) data set is based primarily on FAO FRA forest area change and biomass data (FAO, 2005) making assumptions about change in other land cover (e.g., croplands, pasture) to account for forest area change, supported by FAOSTAT data. A variety of other historical information is used to estimate land-use transitions prior to the availability of FAO data in each data set. A common spatially explicit data set for wood harvest based on FAO data (Hurtt et al., 2011) and urban land extent (Klein Goldewijk et al., 2010) was applied to all three reconstructions. All three reconstructions use a consistent methodology, and start with a common land-cover map during 1765 and follow different pathways as determined by the land-use/management data sets (cropland, pastureland, urbanization and wood harvest) to attain forest area distributions close to satellite estimates of forests for recent years. The satellite based estimates of forest area are based on MODIS (Friedl et al., 2010). The sum of non-forested land-cover types (herbaceous vegetation, cropland, pastureland and urban land) matches satellite estimates. However, discrepancies between the land-use data set and satellite estimates cause a mismatch in the extent of individual herbaceous land-cover types compared to satellite observations (note that forest area+ non-forested areas within each grid cell = 100% of grid cell area).

Temporal Coverage: HYDE estimates cover the period 1770-2010; RF estimates cover the period 1770-2007; HH estimates cover the period 1770-2005.

Temporal Resolution: Yearly.

Spatial Coverage: The data coverage is global, over land only.

Spatial Resolution: The data are provided in equal latitude/longitude Earth grids with spatial resolution of 0.5 by 0.5 in both latitude and longitude. Each gridded variable has 720 columns by 360 rows.

3. Summary of Parameters

The land-cover maps are reported as the percentage of grid cell area containing each of 28 land-cover types. The land-use conversion maps are reported as the percentage of the grid cell area transformed for each of 92 possible land-use conversions.

The 28 land-cover types considered in this study are reported in Table 1. For each land grid cell, the sum of the areas (as percentage of grid area) of 28 land-cover types will add up to 100%. The 92 possible transitions between the vegetation's are listed in Table 2.

Table 1: Land Cover Classification used in this study.

	Land Cover Type	Symbol
1*	Tropical Evergreen Broadleaf Forest	TrpEBF
2*	Tropical Deciduous Broadleaf Forest	TrpDBF
3*	Temperate Evergreen Broadleaf Forest	TmpEBF
4*	Temperate Evergreen Needleleaf Forest	TmpENF
5*	Temperate Deciduous Broadleaf Forest	TmpDBF
6*	Boreal Evergreen Needleleaf Forest	BorENF
7*	Boreal Deciduous Needleleaf Forest	BorDNF
8*	Savanna	Savanna
9*	C_3 Grassland/Steppe	C3grass
10*	C_4 Grassland/Steppe	C4grass
11*	Dense Shrubland	Denseshrub
12*	Open Shrubland	Openshrub
13*	Tundra	Tundra
14*	Desert	Desert
15*	Polar Desert/Rock/Ice	PdRI
16	Secondary Tropical Evergreen Broadleaf Forest	SecTrpEBF
17	Secondary Tropical Deciduous Broadleaf Forest	SecTrpDBF
18	Secondary Temperate Evergreen Broadleaf Forest	SecTmpEBF
19	Secondary Temperate Evergreen Needleleaf Forest	SecTmpENF
20	Secondary Temperate Deciduous Broadleaf Forest	SecTmpDBF
21	Secondary Boreal Evergreen Needleleaf Forest	SecBorENF
22	Secondary Boreal Deciduous Needleleaf Forest	SecBorDNF
23*	Water/Rivers	Water
24	C_3 Cropland	C3crop
25	C_4 Cropland	C4crop
26	C_3 Pastureland	C3past
27	C_4 Pastureland	C4past
28	Urban land	Urban

* Natural land-cover types

Table 2: The 92 types of possible land-use conversions. Grassland, pastureland and cropland are not distinguished as C_3/C_4 types while recording land-use conversions.

No	**Land-Use Conversions**	**No**	**Land-Use Conversions**	**No**	**Land-Use Conversions**	**No**	**Land-Use Conversions**
1	TrpEBF → SecTrpEBF	24	BorENF → Urban	47	PdRI → Crop	70	SecBorDNF → Urban
2*	TrpEBF → Crop	25	BorDNF → SecBorDNF	48	PdRI → Past	71	Crop → Savanna
3	TrpEBF → Past	26*	BorDNF → Crop	49	PdRI → Urban	72	Crop → Grass
4	TrpEBF → Urban	27	BorDNF → Past	50*	SecTrpEBF → Crop	73	Crop → Denseshrub
5	TrpDBF → SecTrpDBF	28	BorDNF → Urban	51	SecTrpEBF →Past	74	Crop → Openshrub
6*	TrpDBF → Crop	29	Savanna → Crop	52	SecTrpEBF → Urban	75	Crop → Tundra
7	TrpDBF → Past	30	Savanna → Past	53*	SecTrpDBF →Crop	76	Crop → Desert
8	TrpDBF → Urban	31	Savanna → Urban	54	SecTrpDBF → Past	77	Crop → PdRI
9	TmpEBF → SecTmpEBF	32	Grass → Crop	55	SecTrpDBF → Urban	78#	Crop → SecTrpEBF
10*	TmpEBF → Crop	33	Grass → Past	56*	SecTmpEBF → Crop	79#	Crop → SecTrpDBF
11	TmpEBF → Past	34	Grass → Urban	57	SecTmpEBF → Past	80#	Crop → SecTmpEBF
12	TmpEBF → Urban	35	Denseshrub → Crop	58	SecTmpEBF → Urban	81#	Crop → SecTmpENF
13	TmpENF → SecTmpENF	36	Denseshrub → Past	59*	SecTmpENF → Crop	82#	Crop → SecTmpDBF
14*	TmpENF → Crop	37	Denseshrub → Urban	60	SecTmpENF → Past	83#	Crop → SecBorENF
15	TmpENF → Past	38	Openshrub → Crop	61	SecTmpENF → Urban	84#	Crop → SecBorDNF
16	TmpENF → Urban	39	Openshrub → Past	62*	SecTmpDBF → Crop	85	Crop → Past
17	TmpDBF → SecTmpDBF	40	Openshrub → Urban	63	SecTmpDBF → Past	86	Crop → Urban
18*	TmpDBF → Crop	41	Tundra → Crop	64	SecTmpDBF → Urban	87	Past → Grass
19	TmpDBF → Past	42	Tundra → Past	65*	SecBorENF → Crop	88	Past → Crop
20	TmpDBF → Urban	43	Tundra → Urban	66	SecBorENF →Past	89	Past → Urban
21	BorENF → SecBorENF	44	Desert → Crop	67	SecBorENF →Urban	90	Urban → Grass
22*	BorENF → Crop	45	Desert → Past	68*	SecBorDNF → Crop	91	Urban → Crop
23	BorENF → Past	46	Desert → Urban	69	SecBorDNF → Past	92	Urban → Past

* Forest to cropland conversions; # Cropland to forest conversions

4. Dataset File Organization

The datasets are provided as classic NetCDF files (file extension: nc). You can use any of these software's (click here) to display/manipulate the NetCDF files.

The entire data collection is organized into six compressed tarball files (extension: tar.gz). The six files are named following the convention:

land-cover_<attribute>_<type>_s<BeginDate>_e<EndDate>c<YYYYmmdd>.tar.gz

The field definitions associated with the file names are as follows:

File Name Field Definitions	Description
<attribute>	The agricultural data source used. There are three possible entries: hh, hyde, and rf.
<type>	The type of data file. There are two possible entries: 1. landcover - indicates the file contains land-cover maps 2. conversions – indicates the file contains the land-use conversion/transition information (.i.e.) the area transitioned for each of the 92 possible conversions from one land-cover type to another.
s<BeginDate>	Begin year of the file
e<EndDate>	End year of the file
c<YYYYmmdd>	Create date of file

There are two types of files ("landcover" and "conversions") corresponding to each of the three agricultural data source used ("HYDE", "RF" and "HH"), totaling to six files. For example, the file name "land-cover_hyde_landcover_c20130830.tar.gz" indicates that the file contains annual land-cover maps that utilize agricultural information from the HYDE database.

First, the compressed tarball files must be decompressed and expanded using a TAR utility (click here for help). Once extracted to a folder, you will see an array of NetCDF files that are organized by the year of historical record following the convention:

land-cover_<attribute>_<type>_<yrXXXX>.nc

The <attribute>, and <type> field names follows the same definitions as used for naming the compressed tarball files. The field name <yrXXXX> represents the year corresponding to the file. For example, the file name "land-cover_rf_landcover_yr2010.nc", indicates that the NetCDF file contains the land-cover maps for the year 2010, that utilize agricultural information from the RF database. This file would be found within the compressed file "land-cover_rf_landcover_c20130831.tar.gz".

5. Information on Variables within the NetCDF files

Detailed information associated with each variable is included as attributes (metadata) within the respective NetCDF file. Here, we summarize information on key variables only.

<u>Variable information corresponding to land-cover files (<type> = “landcover”)</u> are listed in table 3. Please note that all the variables listed in table 3 are gridded variables with the dimension 360x720 (lat/lon). All the ocean points are filled with a missing value (see metadata for details).

Table 3: Variable descriptions for the land cover NetCDF files.

Variable Name	Variable Description	Valid Data Range	Units	Scaling Factor Used[&]
Mask	Indicates if the grid cell belongs to land or ocean	0 = ocean 1 = land	None	None
Regionmask	Indicates the geographic region each land grid cell belongs to. The world has been classified into 10 regions.	1 = North America 2 = Latin America 3 = Europe 4 = North Africa 5 = Tropical Africa 6 = USSR 7 = China 8 = South and South East Asia 9 = Pacific Developed 10 = Antarctica and Greenland	None	None
Grid_area	The area of each grid cell	1.3475e+07f to 3.088224e+09f	m^2	None
Dominant_type***	The dominant land-cover category within each grid cell. The 28 land cover classes have been grouped into 17 broader categories for estimating dominant land-cover classes. "Dominant land cover type" is the land cover	1 = Tropical Evergreen Broadleaf Forest 2 = Tropical Deciduous Broadleaf Forest 3 = Temperate Evergreen Broadleaf Forest 4 = Temperate Evergreen Needleleaf Forest 5 = Temperate Deciduous Broadleaf Forest 6 = Boreal Evergreen Needleleaf Forest 7 = Boreal Deciduous Needleleaf Forest 8 = Savanna 9 = Grassland/ Steppe 10 = Shrubland	None	None

	category that occupies the largest area within the grid cell	11 = Tundra 12 = Desert 13 = Polar-Desert/ Rock/ Ice 14 = Water/Rivers 15 = Cropland 16 = Pastureland 17 = Urbanland		
TrpEBF	Area of Tropical Evergreen Broadleaf Forest	0 to 100	% of grid area	0.01
TrpDBF	Area of Tropical Deciduous Broadleaf Forest	0 to 100	% of grid area	0.01
TmpEBF	Area of Temperate Evergreen Broadleaf Forest	0 to 100	% of grid area	0.01
TmpENF	Area of Temperate Evergreen Needleleaf Forest	0 to 100	% of grid area	0.01
TmpDBF	Area of Temperate Deciduous Broadleaf Forest	0 to 100	% of grid area	0.01
BorENF	Area of Boreal Evergreen Needleleaf Forest	0 to 100	% of grid area	0.01
BorDNF	Area of Boreal Deciduous Needleleaf Forest	0 to 100	% of grid area	0.01
Savanna	Area of Savanna	0 to 100	% of grid area	0.01
C3grass	Area of C_3 Grassland/Steppe	0 to 100	% of grid area	0.01
C4grass	Area of C_4 Grassland/Steppe	0 to 100	% of grid area	0.01
Denseshrub	Area of Dense	0 to 100	% of	0.01

	Shrubland		grid area	
Openshrub	Area of Open Shrubland	0 to 100	% of grid area	0.01
Tundra	Area of Tundra	0 to 100	% of grid area	0.01
Desert	Area of Desert	0 to 100	% of grid area	0.01
PdRI	Area of Polar Desert/Rock/Ice	0 to 100	% of grid area	0.01
SecTrpEBF	Area of Secondary Tropical Evergreen Broadleaf Forest	0 to 100	% of grid area	0.01
SecTrpDBF	Area of Secondary Tropical Deciduous Broadleaf Forest	0 to 100	% of grid area	0.01
SecTmpEBF	Area of Secondary Temperate Evergreen Broadleaf Forest	0 to 100	% of grid area	0.01
SecTmpENF	Area of Secondary Temperate Evergreen Needleleaf Forest	0 to 100	% of grid area	0.01
SecTmpDBF	Area of Secondary Temperate Deciduous Broadleaf Forest	0 to 100	% of grid area	0.01
SecBorENF	Area of Secondary Boreal	0 to 100	% of grid	0.01

	Evergreen Needleleaf Forest		area	
SecBorDNF	Area of Secondary Boreal Deciduous Needleleaf Forest	0 to 100	% of grid area	0.01
Water	Area of Water/Rivers	0 to 100	% of grid area	0.01
C3crop	Area of C_3 Cropland	0 to 100	% of grid area	0.01
C4crop	Area of C_4 Cropland	0 to 100	% of grid area	0.01
C3past	Area of C_3 Pastureland	0 to 100	% of grid area	0.01
C4past	Area of C_4 Pastureland	0 to 100	% of grid area	0.01
Urban	Area of Urban land	0 to 100	% of grid area	0.01

****** Note on the variable "dominant_type":*** For representing the dominant land-cover type within each grid cell, we grouped the 28 land-cover types into 17 broader categories. We had to do this grouping because, for instance say if a grid cell has 30% of its area covered with primary (mature forest) tropical evergreen broadleaf forest, another 30% by secondary (re-growing forest) tropical evergreen broadleaf forest, and the rest 40% by savanna. This would result in classifying savanna as the dominant type, though 60% is actually covered by tropical evergreen broadleaf forest. Hence, we clubbed primary and secondary forest category into a single type, to avoid giving a wrong impression on the dominant vegetation. Similar line of argument applies for grouping the following pairs into a single category: C3 and C4 croplands; C3 and C4 pasturelands; C3 and C4 grasslands; dense and open shrublands.

& Note on the scaling Factor used: Scaling factors are used for efficient data storage. If present for a variable, the data are to be multiplied by this factor after the data are read by the application that accesses the data.

Variable information corresponding to land-use conversions files (<type> = "landcover"):
There are two key variables corresponding to land-use conversion files (<type> = "conversions"): "Transitions" and "landuse_transitions".

The variable “Transitions” is a three dimensional variable of the dimension 92x360x720 (transitions x latitude x longitude). In other words, for each grid cell (identified by the latitude and longitude), the variable “Transitions” provide the area transformed for each of the 92 possible land-use transitions (see table 2). The units are “% of grid cell area”. Please note that we have used a scaling factor of 0.001 for this variable. All the ocean points are filled with a missing value of “-1000”.

The variable “landuse_transitions” provides a list of the 92 types of unique land-use transitions that are possible. This variable contains the same information listed in table 2, but in numeric form, for use in programs (along with the variable “Transitions”). This variable has a dimension of 92 rows and 3 columns. Each row indicates the two land-cover types between which transition occurs. The first column indicates the row number; second column indicates the land-cover type removed, and the third column indicates the land-cover type created after removing the land-cover type listed in the second column. Each number in the second and third column corresponds to a unique land-cover type.

The land-cover types and their corresponding numbers are as follows:

1 = Tropical Evergreen Broadleaf Forest
2 = Tropical Deciduous Broadleaf Forest
3 = Temperate Evergreen Broadleaf Forest
4 = Temperate Evergreen Needleleaf Forest
5 = Temperate Deciduous Broadleaf Forest
6 = Boreal Evergreen Needleleaf Forest
7 = Boreal Deciduous Needleleaf Forest
8 = Savanna
9 = Grassland/Steppe
10 = Dense Shrubland
11 = Open Shrubland
12 = Tundra
13 = Desert
14 = Polar Desert/Rock/Ice
15 = Secondary Tropical Evergreen Broadleaf Forest
16 = Secondary Tropical Deciduous Broadleaf Forest
17 = Secondary Temperate Evergreen Broadleaf Forest
18 = Secondary Temperate Evergreen Needleleaf Forest
19 = Secondary Temperate Deciduous Broadleaf Forest
20 = Secondary Boreal Evergreen Needleleaf Forest
21 = Secondary Boreal Deciduous Needleleaf Forest
22 = Water/Rivers (No changes occur)
23 = Cropland
24 = Pastureland
25 = Urbanland

Please note that, we have considered only 25 land-cover types in calculation of land-use transitions as opposed to 28 land-cover types used in land-cover maps. This is because we have grouped the C3 and C4 types into a single category (for grasslands, cropland and pastureland).

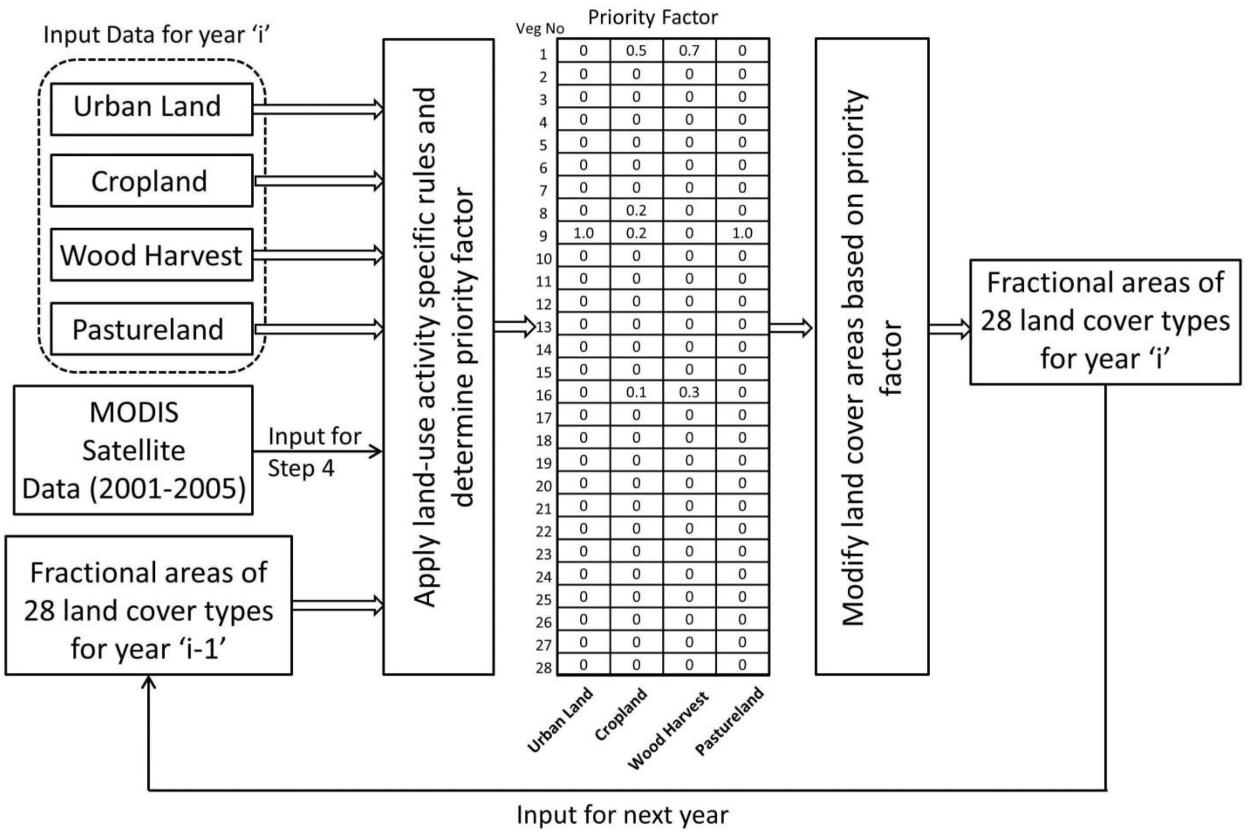
For example, the first row of the variable “landuse_transitions” is \"1 1 15\" that indicates Tropical Evergreen Broadleaf Forest (land-cover type number 1 in column 2) is converted to Secondary Tropical Evergreen Broadleaf Forest (land-cover type number 15 in column 3).

6. Modeling Methodology and Algorithm

Please refer to Meiyappan and Jain (2012) for full details. Here, we provide a summary.

We start with a map of potential vegetation at 0.5 by 0.5 lat/lon resolution, which is indicate of the land cover that would have existed if human activities were absent. We then advance in time (starting from 1765 to 2010), by superimposing the year-to-year cropland, pastureland, wood harvest and urban land maps in the same order of preference. We define rules, specific to each land disturbance activity (cropland, pastureland, wood harvest and urban land), for replacing natural vegetation upon superimposing. In general, following cropland and pastureland expansion, the natural vegetation's present in a grid cell are removed proportional to its area and demand for cropland/pastureland. Upon abandonment (reduction in cropland/pastureland area between two consecutive years), the land recovers back to the dominant potential vegetation in the grid cell. Wood is preferentially harvested from primary forest, and secondary (regrowing) forest is used when the extent of primary forest is lesser than the demand. Urban land expansion usually occurs at the expense of cropland abandonment and in other cases from natural vegetation's. The resulting land cover maps for the period 2000 - 2005 are compared with remote sensing based land cover maps (500m resolution MODIS data - Friedl et al., 2010) spanning the same period. Discrepancies in forest area between satellite data and model estimates are used to accordingly adjust the land-disturbance activity specific rules to increase (or decrease) the proportions at which forest was cleared (or regrown) historically following expansion (or abandonment) of agricultural activity, such that rerunning the model with adjusted rules results in land-cover maps whose forest distribution closely agrees with remote sensing observations for recent years. Thus, the three reconstructions start with a common potential vegetation map and end with a map whose forest distribution are consistent with satellite estimate, but the pathway they follow between the starting and ending point is constrained by the land-use data sets used. See figure 1 for schematic of the methodology.

Figure 1: Schematic diagram showing the process involved in estimating land-cover change and land-use conversions. This figure is from Meiyappan and Jain (2012). ‘i’ denotes year which increases from 1765 to 2005/2007/2010 (HH/ RF/ HYDE) in annual time steps. The priority factors shown here is just an example and it varies for each land-cover type from year-to-year between each grid cell.



7. Errors

Errors/biases in both the methodology used to derive this dataset and errors in the spatial reconstructions of land use/management activities will affect the quality of this historical dataset. See Meiyappan and Jain (2012) for more details.

8. Data Validation by Source

A systematic quality assessment of the dataset described here has not been performed due to lack of validation sources. The dataset presented here, however utilizes satellite information to constrain the accuracy of the data set for the contemporary time period.

9. Accuracy Judgment

In the land-cover files (<type> = "landcover"), the area of land-cover types that are less than 0.01% of the grid cell area have been set to zero, and the area of other land-cover types was correspondingly adjusted, so that the sum of area of the 28 land-cover types adds up to 100%. In the land-use conversions files (<type> = "conversions"), transitions that were less than 0.001 % of the grid cell area have been screened out.

For the variable “Transitions” within the land-use conversion files (<type> = “conversions”), we have assigned the valid maximum value (attribute name: “valid_max”) to be equal to 10% of the grid cell area. In principle, the “valid_max” value should be set to 100%, although such conversions do not occur in reality. The assigned “valid_max” value of 10% is itself a very rare barrier to break. However, please note that for certain grid cells, some transitions do exceed 10% of the grid cell area for certain years.

10. Measurement Error for Parameters and Variables

Not available at this revision.

11. Additional Quality Assessment Applied

The entire data collection have already been implemented and tested thoroughly within a process based land-surface model. Please see Jain et al. (2013) and Barman et al. (2013a, b) for details.

12. Usage Guidance

The data are recommended for use only for continental-to-global scale studies. This dataset may not be accurate enough for site-level studies. There are no constraints on the time scales in which the data should be applied. However, users should be aware that the uncertainties would be higher as we move farther back in time from the contemporary time period. The idea behind producing three different land-cover estimates is because changes in historical land cover are highly uncertain. Therefore, we recommend using all the three estimates produced here to understand the range of uncertainties resulting from land-cover change.

Please note that HH data originally provides the annual rate of deforestation/reforestation due to cropland and pastureland, in addition to afforestation rates, for ten regions covering the entire globe, rather than by geographic details, as in the case of RF and HYDE data sets. These datasets were gridded to 0.5 by 0.5 lat/lon resolution using the method described in Meiyappan and Jain (2012). Because HH data provides only information on the agricultural land created from clearing the forested vegetation (ignoring those created from non-forested land-cover types), the actual area of cropland and pastureland in the HH based estimation of land cover are significantly lower than that compared to HYDE and RF data. Especially, pasturelands are preferentially created from grasslands; hence pastureland estimates in HH data represent a major outlier compared to RF and HYDE case. Therefore, the HH based land-cover maps do not represent a true land cover distribution. However, HH based estimates of land-use transitions form an important addition for studies focusing on terrestrial biogeochemistry (e.g. to estimate carbon emissions from land-use change, where deforestation and forest regrowth plays the dominant role).

13. Acknowledgement Request

Users of this dataset are requested to provide the following acknowledgement:

"The Historical Land-Cover Change and Land-Use Conversions Global Dataset used in this study were acquired from NOAA's National Climatic Data Center (http://www.ncdc.noaa.gov/)."

14. Citation Request

Please cite the following peer-reviewed journal publication when these data are used:

Meiyappan, P., and Jain, A. K. (2012). Three distinct global estimates of historical land-cover change and land-use conversions for over 200 years. *Frontiers of Earth Science*, *6*(2), 122-139. DOI: 10.1007/s11707-012-0314-2.

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18. Acknowledgements

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