WORLD RESOURCES INSTITUTE

TECHNICAL NOTE

GLOBAL FOREST WATCH CLIMATE: SUMMARY OF METHODS AND DATA

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SUMMARY

The Global Forest Watch (GFW) Climate online platform catalyzes action on climate change by providing timely and credible answers to questions about the impacts of tropical deforestation on global climate change. Its wealth of data and analytical tools allow researchers, governments, donors, businesses, journalists, and civil society to access information on carbon dioxide emissions from tropical deforestation. This technical note outlines the initial scope of the GFW Climate platform and provides a brief summary of the data available on the site.

1. BACKGROUND

It is clear that to constrain the impacts of global climate change, global average temperatures must be stabilized within 2 degrees Celsius. Deforestation and forest degradation in tropical developing countries are a leading cause of global climate change, responsible for about 12 percent of global greenhouse gas (GHG) emissions (Edenhofer et al. 2014). Thus the global climate challenge is at its core also a land management challenge. The concept known as REDD+,[1] defined by the United Nations Framework Convention on Climate Change (UNFCCC), includes an effort to create value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. In addition, many governments and business leaders have recently committed to reduce deforestation, with climate change as a primary motivator.

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Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

Suggested Citation: Harris, N. 2016. "Global Forest Watch Climate: Summary of Methods and Data" Technical Note. Washington, D.C.: World Resources Institute. Available online at: www.wri.org/publication/gfw-climate-methods-data.

The goal of GFW Climate is to strengthen decision making by bridging gaps in methods, data, and technology through the presentation of clear, accurate, and reliable information about the forest-climate nexus in an interactive, user-friendly format. GFW Climate is an online platform enabling anyone with an Internet connection to produce easy-to-understand reports, visualizations, and analyses of the most up-to-date data available on forest carbon storage and emissions from deforestation, compare climate impacts across different areas of interest anywhere in the tropics, and generate custom analytical content to support policy decisions.

We recognize that there is no scientific consensus on a single global data set for deforestation rates or associated carbon emissions; with few exceptions, that lack of consensus applies at the national level as well. We hope that by increasing transparency and public understanding of data available at global, national, and local scales, we can contribute to the acceleration of improvements in these data sets and provide a venue for monitoring global progress toward climate mitigation goals.

2. SCOPE

We limit the scope of the initial (beta) GFW Climate website as follows:

GEOGRAPHIC SCOPE: Although the scope of the main GFW platform is global, GFW Climate covers the tropics only. Country pages on the GFW Climate platform are available for countries that fall entirely, or almost entirely, within the tropical belt. This is because most conversion of natural forest to new land use occurs in the tropics (Friedlingstein et al. 2010), so, by definition, these countries also have the most to contribute to deforestation reduction. Future versions of GFW Climate may expand globally as new data become available.

TEMPORAL SCOPE: GFW Climate includes annual estimates of carbon dioxide (CO_2) emissions from tropical deforestation covering the period 2001–14 and will be updated as new data become available. This decision was based on the availability of globally consistent annual data for this time period, and a biomass map representative of the year 2000. Recognizing the need for flexibility in user experience, we have built GFW Climate to allow users to dynamically change the time period of analysis for deforestation and emission estimates, so that users can customize output for specific years or time periods of interest.

LULUCF CATEGORIES AND REDD+ ACTIVITIES COVERED: The methodologies of the Intergovernmental Panel on Climate Change (IPCC) for greenhouse gas accounting, while used on GFW Climate as a framework to organize different estimates of emissions from deforestation, were designed to cover all emissions and removals from all land categories. **We focus GFW Climate on estimating emissions from tropical deforestation only and do not include estimates of emissions or sequestration from other REDD+ activities (degradation or enhancement of forest carbon stocks) at this time.** Methods and data for estimating emissions and removals from these other REDD+ activities are generally less developed than those for deforestation. Given the recent momentum behind global and regional restoration initiatives, future versions of GFW Climate may include estimates of carbon sequestration from potential forest gain as new data become available.

GREENHOUSE GASES COVERED: GFW Climate includes carbon dioxide (CO_2) emissions only and excludes methane (CH_4) and nitrous oxide (N_2O) emissions. While non-CO_2 emissions may occur as a result of forest fires, we do not include these gases at this time. One exception is the data we include on emissions from peat fires in Indonesia, where CO_2, CH_4, and N_2O emissions are included (separate from the biomass burning component) and reported as CO_2 equivalents (CO_2e) on Indonesia's country page.

CARBON POOLS COVERED: The country pages of the GFW Climate platform provide national and subnational estimates of aboveground biomass, belowground biomass, and soil carbon. No reliable data currently exist on dead wood and litter pools to provide consistent and credible estimation of these pools across the tropics. Spatially explicit maps of aboveground biomass and soil organic carbon are included on GFW Climate's interactive map page.

UNCERTAINTY: At this time we have not included uncertainty estimates with the summary statistics available on the country pages of GFW Climate. We do, however, visualize and make available for download an uncertainty map as part of the GFW Climate Aboveground Live Woody Biomass Density map. Additional work on uncertainty is underway and may be included in subsequent versions of GFW Climate.

3. METHODOLOGICAL FRAMEWORK

We use the IPCC Good Practice Guidance (2003) and IPCC Guidelines for National Greenhouse Gas Inventories (2006) as a framework for organizing different estimates of emissions arising from tropical deforestation. GHG emissions and removals from land-use change are estimated by combining activity data with emission factors. These parameters can be estimated using different approaches (in the case of activity data) and tiers (in the case of emissions), paraphrased briefly below and elaborated more fully in GOFC GOLD (2015).

3.1 IPCC Approaches for Consistent Representation of Land Areas

Information about land area is needed to estimate carbon stocks and emissions and removals of greenhouse gases associated with agriculture and land-use activities. The IPCC Good Practice Guidance presents three approaches for representing land area, approaches that should be

- **Adequate:** capable of representing carbon stock changes and greenhouse gas emissions and removals and the relations between these and land use and land-use changes;
- **Consistent:** capable of representing management and land use consistently over time, without being unduly affected either by artificial discontinuities in time series data or by effects resulting from interference of sampling data with rotational or cyclical patterns of land use (e.g., the harvest-regrowth cycle in forestry);
- **Complete:** all land area within a country should be included; and
- **Transparent:** data sources, definitions, methodologies, and assumptions should be clearly described.

Approach 1 uses area data sets likely to have been prepared for other purposes, such as forestry or agricultural statistics (e.g., FAO Global Forest Resource Assessments). In Approach 1, total area for each individual land-use category is identified, but no detailed information is provided on changes of area among categories (i.e., changes from and to a category are not included) and the information is not spatially explicit other than at the national or regional level.

Approach 2 introduces tracking of land-use changes among categories. The essential feature of Approach 2 is that it provides a national or regional-scale assessment of not only the losses or gains in the area of specific land categories but also what these changes represent (i.e., changes from and to a category). Tracking land-use changes in this explicit manner will normally require estimation of initial and final land-use categories, as well as of total area of unchanged land by category. The final result of this approach can be presented as a non-spatially explicit land-use change matrix.

Approach 3 extends Approach 2 by allowing land-use changes to be tracked using spatially explicit observations of land use and land-use change. Approach 3 is comprehensive and relatively simple conceptually, but it is also data intensive to implement. Countries with poor accessibility and limited remote sensing resources historically have not had access to data suitable for Approach 2 or 3 and so tend to use Approach 1, either from FAO data or from other internationally available databases.

GFW Climate includes spatially explicit data (Approach 3) on the interactive map and as the default estimate on country pages. Data from FAO's Global Forest Resources Assessment (Approach 1) are also included on the country pages, as are estimates reported by individual countries using either Approach 2 or Approach 3.

3.2 IPCC Tiers for Estimating GHG Emissions/Removals

IPCC methodological guidance also introduces three hierarchical tiers for estimating emissions and removals of CO_2 and non-CO_2 that range from default data and simple equations to the use of country-specific data and models to accommodate national circumstances. These tiers, if properly implemented, successively reduce uncertainty and increase accuracy.

Tiers progress from least to greatest levels of certainty depending on methodological complexity, regional specificity of data, and spatial resolution and extent of activity data. Complete country-specific data may require subdivision to capture different ecosystems and site qualities, climatic zones, and management practice within a single land category. Moving from lower to higher tiers will usually require increased resources as well as increased institutional and technical capacity.

Tier 1 methods usually use activity data that are spatially coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps. The large uncertainties of Tier 1 values essentially reflect the problem of representativeness of single default values per ecological zone and continent as well as the lack of transparency in how these values were derived.

Tier 2 can use the same methodological approach as Tier 1, but it applies emission factors and activity data defined by the country for the most important land uses/activities. Tier 2 can also apply stock change methodologies based on country-specific data. Country-defined emission factors/activity data are more appropriate for the climatic regions and land-use systems in that country. Higher resolution activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use categories.

At Tier 3, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at subnational to fine grid scales. These higher order methods provide estimates of greater certainty than lower tiers and have a closer link between biomass and soil dynamics.

The biomass estimates available on GFW Climate represent alternative Tier 1 values, derived from a 30-meter pantropical biomass density map (described below). Until operational forest carbon stock monitoring becomes feasible to derive Tier 2 and 3 emission factors at the national level, the use of these alternative Tier 1 values based on pantropical biomass maps can be regarded as a viable solution for developing countries, thus adding more transparency to the Tier 1 approach (Lagner, Achard, and Grassi 2014).

4. DATA AVAILABLE ON GFW CLIMATE

GFW Climate focuses on providing the most up-to-date and credible data for monitoring tropical deforestation and carbon emissions from deforestation, with data provided from both individual country REDD+ processes and the broader scientific community. Individual country pages on GFW Climate contain estimates developed using different IPCC approaches (1–3) and tiers (1–2). No country included on GFW Climate currently derives its deforestation emission estimates using Tier 3 methods.

We do not include land use, land-use change, and forestry (LULUCF) estimates as reported by tropical developing countries in their national communications to the UNFCCC for GHG inventory reporting. Many of these estimates are out of date, use data of poor quality or documentation, or both. However, as more up-to-date country data become available (e.g., as part of national forest reference emission level [FREL] submissions to the UNFCCC for REDD+, new biennial update reports to the UNFCCC by non-Annex 1 Parties, or other national forest monitoring programs), we welcome the opportunity to present these data on GFW Climate. In the case of Brazil, up-to-date national estimates are included on GFW Climate from the country's System of Greenhouse Gas Emissions Estimates (SEEG) and consistent with Brazil's national GHG inventory. We also include data supplied in FREL submissions to the UNFCCC for REDD+ from Colombia, Ecuador, Guyana, and Mexico. Data from other countries will be added as new FRELs are submitted. We do not include estimates from the agriculture, forestry, and other land use (AFOLU) section of the IPCC Working Group III report because this presents a synthesis of global net CO_2 flux estimates from emissions as well as uptake from reforestation/regrowth. These data report global figures for net forest change, including forests in "northern" countries where forest area is increasing, and GFW Climate focuses on emissions from deforestation in the tropics only.

The goal of GFW Climate is to improve public understanding of trends in emissions from tropical deforestation at multiple scales: across the tropics as a whole as well as within specific countries and jurisdictions and key areas of interest within a country. We therefore organize data strategically to balance, on the one hand, user desire to see "the bottom line" on what's happening in forests with respect to carbon emissions from tropical deforestation according to the latest information available (on the "Pantropical Overview" page) and, on the other, the need for users also to see details and comparisons of different data sources for specific countries on GFW Climate's country pages.

4.1 Interactive Map

On the interactive map page of GFW Climate, users can turn on and off spatially explicit data layers related to forest carbon and other contextual information, analyze countries or jurisdictions for loss, and perform custom analysis by drawing shapes on the map. Data layers are organized into four main tabs:

4.1.1 Carbon Emissions tab

TREE BIOMASS LOSS (PANTROPICAL)

This map layer reflects estimated annual carbon dioxide emissions to the atmosphere as a result of aboveground biomass loss. Estimates are based on the colocation of aboveground live woody biomass density values for the year 2000 from Baccini et al. 2012 with annual tree cover loss data from 2001 through 2014 from Hansen et al. 2013, both at 30-meter spatial resolution. All of the aboveground carbon is considered to be "committed" emissions to the atmosphere upon clearing. Emissions are "gross" rather than "net" estimates, meaning that information about the fate of land after clearing, and its associated carbon value, is not incorporated. Emissions associated with other carbon pools, such as soil carbon, are excluded from this map layer but are shown under the carbon density map layers. Loss of biomass, like loss of tree cover, may occur for many reasons, including deforestation, fire, and logging in the course of forestry operations.

This data layer is currently visualized on a red-to-yellow color scale, with yellow pixels representing areas with highest biomass loss, and pixels with red shading indicating areas with less biomass loss. Users can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 percent and 30 percent, and emission estimates will update accordingly to reflect the new forest definition.

Users can also explore carbon emissions from tree biomass loss between 2001 and 2014 using the time slider, and also perform custom analysis on the map of carbon emissions within a user-drawn shape.

PEAT DRAINAGE (INDONESIA AND MALAYSIA)

Development of agriculture and other human activities on tropical peatlands requires drainage, which leads to increased CO_2 emissions to the atmosphere from peat decomposition. Highly productive croplands, including plantations, will always be 100 percent drained (Hooijer et al. 2010). IPCC Tier 1 methods were applied to estimate annual CO_2 emissions from peat drainage in Indonesia and Malaysia within plantation areas only, based on the area of overlap between mapped areas of plantations in 2013-14 (Transparent World 2015) and mapped areas of peatlands (Indonesian Ministry of Agriculture, 2012 for Indonesia; Wetlands International, 2004 for Malaysia). Emission factors for oil palm, acacia, and other species were assigned as 40, 73, and 55 t CO_2 ha^{-1} yr^{-1}, respectively, based on guidance provided in Equation 2.3 and Table 2.1 of IPCC Wetlands Supplement (2013). The value of 55 t CO_2 ha^{-1} yr^{-1} represents the average of emission factor estimates for oil palm and acacia plantations.

4.1.2 Carbon Density tab

We visualize carbon density layers for two carbon pools: Aboveground Live Woody Biomass and Soil Organic Carbon. This allows the user to see how forest carbon is distributed across the tropics. Users can also perform custom analysis on the Aboveground Live Woody Biomass Density layer.

ABOVEGROUND LIVE WOODY BIOMASS DENSITY (PANTROPICAL)

This is a higher-resolution data product that expands on the methodology presented in Baccini et al. (2012) to generate a pantropical map of aboveground live woody biomass density at 30-meter resolution for the year 2000. Along with the biomass density values, there is an error map available for download at the same spatial resolution providing the uncertainty in aboveground biomass density estimation. The statistical relationship derived between ground-based measurements of forest biomass density and colocated Geoscience Laser Altimeter System (GLAS) LiDAR waveform metrics as described by Baccini et al. (2012) were used to estimate the biomass density of more than 40,000 GLAS footprints throughout the tropics. Then, using randomForest models, the GLAS-derived estimates of biomass density were correlated to continuous, gridded variables including Landsat 7 ETM+ satellite imagery and products (e.g., reflectance), elevation, and biophysical variables. By using continuous gridded data sets as inputs to the randomForest models, a wall-to-wall

30-meter resolution map of aboveground woody biomass density across the tropics was produced as well as the associated uncertainty layer. The uncertainty layer takes into account the errors from allometric equations, the LiDAR based model, and the randomForest model. All the errors are propagated to the final biomass estimate. Biomass density values are shown on the map; carbon density values can be estimated as 50 percent of biomass density values. On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent, and biomass density estimates will update accordingly to reflect the new forest definition.

SOIL ORGANIC CARBON DENSITY (PANTROPICAL)

Soil organic carbon (SOC) is a major component of soil organic matter, which is derived from residual, decomposed plant and animal material. Natural factors (such as land cover, vegetation, topography, and climate) as well as human factors (such as land use and management) can influence the amount of soil organic matter, and thus soil organic carbon, present in soils.

To calculate topsoil organic carbon density, we use data from the Harmonized World Soil Database (HWSD), a compilation of four soil databases: the European Soil Database (ESDB), the 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database), and the Soil Map of the World. The HWSD contains information on soil parameters, such as organic carbon, pH, water storage capacity, soil depth, total exchangeable nutrients, and salinity. Soil carbon estimates, and soil information in general, have long been considered highly uncertain, and the HWSD makes major improvements by integrating existing regional and national soil information worldwide into a harmonized format. This data set currently constitutes the best available spatially explicit soil carbon data for most regions. The spatial resolution of the data is 1 kilometer.

Topsoil organic carbon density (measured in tons per hectare) was calculated using inputs of percent carbon content, bulk density, and gravel volume. We use relative bulk density values except for Andosols and Histosols, which are typically overestimated by this method. Values are calculated for 0–30-centimeter depth. For more information on calculating SOC from the HWSD, see Hiederer and Köchy 2011.

4.1.3 Land Use and Land Cover tabs

Most data layers in the land use and land cover tab are also available on the main GFW platform and are meant to provide context for the carbon emissions and carbon density layers.

MANAGED FORESTS (SELECT COUNTRIES)

Managed forests refers to areas allocated by a government for harvesting timber and other wood products in a public forest. Managed forests are distinct from wood fiber concessions, where tree plantations are established for the exclusive production of pulp and paper products. *Concession* is used as a general term for licenses, permits, or other contracts that confer rights to private companies to manage and extract timber and other wood products from public forests; terminology varies at the national level, however, and includes *forest permits*, *tenures*, *licenses*, and other terms.

This data set displays managed forest concessions as a single layer assembled by aggregating data for multiple countries. The data may come from government agencies, change to non-governmental organizations, or other organizations and varies by date and data sources.

MINING (SELECT COUNTRIES)

Mining concession refers to an area allocated by a government or other body for the extraction of minerals. The terminology for these areas varies from country to country. *Concession* is used as a general term for licenses, permits, or other contracts that confer rights to private companies to manage and extract minerals from public lands; terminology varies at the national level, however, and includes mineral or mining *permits*, *tenures*, *licenses*, and other terms.

This data set displays mining concessions as a single layer assembled by aggregating concession data for multiple countries. The data may come from government agencies, NGOs, or other organizations and varies by date and data sources.

OIL PALM (SELECT COUNTRIES)

Oil palm concession refers to an area allocated by a government or other body for industrial-scale oil palm plantations.

This data set displays oil palm concessions as a single layer assembled by aggregating concession data for multiple countries. The data may come from government agencies, NGOs, or other organizations and varies by date and data sources.

WOOD FIBER (SELECT COUNTRIES)

Wood fiber concession refers to an area allocated by a government or other body for establishment of fast-growing tree plantations for the production of timber and wood pulp for paper and paper products.

This data set displays wood fiber concessions as a single layer assembled by aggregating concession data for multiple countries. The data may come from government agencies, NGOs, or other organizations and varies by date and data sources.

MAJOR DAMS (GLOBAL)

The State of the World's Rivers is an interactive web database that illustrates data on ecological health in the world's 50 major river basins. Indicators of ecosystem health are grouped into the categories of river fragmentation, biodiversity, and water quality. The database was created and published by International Rivers in 2014.

The Dam Hotspots data contain over 5,000 dam locations determined by latitude and longitude coordinates. These locations were confined to the world's 50 major river basins. The data set comes from multiple sources and was corrected for location errors by International Rivers. The "project status"—a moving target—was determined by acquiring official government data, as well as through primary research from the University of California, Berkeley, and five International Rivers regional offices. The data are grouped in the following categories:

- **Operational:** Already existing dams
- **Under construction:** Dams currently being constructed
- **Planned:** Dams whose studies or licensing have been completed, but whose construction has yet to begin
- **Inventoried:** Dams whose potential site has been selected, but for which neither studies nor licensing have occurred
- **Suspended:** Dams temporarily or permanently suspended, deactivated, canceled, or revoked
- **Unknown:** No data currently available

INTACT FOREST LANDSCAPES (GLOBAL, 2001/2013)

The Intact Forest Landscapes (IFL) data set identifies unbroken expanses of natural ecosystems within the zone of forest extent that show no signs of significant human activity and are large enough that all native biodiversity, including viable populations of wide-ranging species, could be maintained. To map IFL areas, a set of criteria was developed and designed to be globally applicable and easily replicable, the latter to allow for repeated assessments over time as well as verification. IFL areas were defined as unfragmented landscapes, at least 50,000 hectares in size, and with a minimum width of 10 kilometers. These were then mapped from Landsat imagery for the years 2000 and 2013.

Changes in the extent of IFLs were identified within the year 2000 IFL boundary using the global wall-to-wall Landsat image composite for the year 2013 and the global forest cover loss data set (Hansen et al. 2013). Areas identified as "reduction in extent" met the IFL criteria in 2000, but no longer met the criteria in 2013. The main causes of change were clearing for agriculture and tree plantations, industrial activity such as logging and mining, fragmentation resulting from infrastructure and new roads, and fires assumed to be caused by humans.

This data can be used to assess forest intactness, alteration, and degradation at global and regional scales. More information about the data set and methodology is available at www.intactforests.org.

DEMOCRATIC REPUBLIC OF THE CONGO PRIMARY FORESTS (2000)

This data set, available only for the Democratic Republic of the Congo, shows the coverage of primary humid tropical forest in the DRC in the year 2000 at a 60-meter resolution. *Primary* forest is defined in this data set as mature humid tropical forest with greater than 60 percent canopy cover and differs from *secondary forest* (regrowing forest with greater than 60 percent canopy cover) and *woodlands* (between 30 percent and 60 percent canopy cover). The authors created a composite of cloud-free Landsat imagery during the growing season of 2000 to conduct the analysis. Within forest areas, primary forests were separated from secondary forests and woodlands using supervised classification. For more information on methodology, see Potapov et al. 2012.

TREE PLANTATIONS (SELECT COUNTRIES)

This data set was created by Transparent World, with the support of Global Forest Watch. Many studies depicting forest cover and forest change cannot distinguish between natural forests and plantations. This data set attempts to distinguish tree plantations from natural forests for seven key countries: Brazil, Cambodia, Colombia, Indonesia, Liberia, Malaysia, and Peru.

Given the variability of plantations and their spectral similarity to natural forests, this study used visual interpretations of satellite imagery, primarily Landsat, supplemented by high-resolution imagery (Google Maps, Bing Maps, or Digital Globe), where available, to locate plantations. Analysts hand-digitized plantation boundaries based on several key visual criteria, including texture, shape, color, and size.

Each polygon is labeled with the plantation type and, when possible, the species. A "gr" in front of the species name indicates a group of species, such as pines or fruit, where the individual species was not identifiable. The percentage of plantation coverage indicates a rough estimate of the prevalence of plantation within a polygon (as in the case of a mosaic). Types are defined as follows:

- **Large industrial plantation:** single plantation units larger than 100 hectares
- **Mosaic of medium-sized plantations:** mosaic of plantation units < 100 hectares embedded within patches of other land use
- **Mosaic of small plantations:** mosaic of plantation units < 10 hectares embedded within patches of other land use
- **Clearing/very young plantation:** bare ground with contextual clues suggesting it will become a plantation (shape or pattern of clearing, proximity to other plantations, distinctive road network, etc.)

For more information on this data set and how it was produced, see Peterson et al. 2016, the WRI technical note associated with this project.

4.2 Pantropical Overview

The pantropical overview page of GFW Climate shows a data visualization of the contribution of total emissions from tropical deforestation disaggregated by country, by continent, and how country contributions have changed over the 21st century. For each country, we compiled the data that we estimate reflect the best available information on emissions from deforestation (Table 1; see Zarin et al. 2016 for further details). As new data emerge, we will update the visualization to take into account new and improving data.

Table 1 | **Sources of data used for deforestation emission estimates in the Pantropical Overview data visualization on GFW Climate**

COUNTRY	DATA SOURCE
Brazil	SEEG 2001–13
Guyana	UNFCCC REDD+ reference level, 2001–12*
Mexico	UNFCCC REDD+ reference level, 2001–10*
Ecuador	UNFCCC REDD+ reference level, 2001–8*
Colombia	UNFCCC REDD+ reference level, 2001–12*
All others	UMD/Woods Hole, 2001–13^
Indonesia	Primary forests only, based on Margono et al. 2013^
DRC	Primary forests only, based on Potapov et al. 2010^

* Where not included in UNFCCC REDD+ reference level, emission estimates for later years were assigned as the historical average.
^ Estimates for 2013 based on revisions to tree cover loss data in the 2014 update. Values for 2014 were not included in the visualization but will be included once the 2015 tree cover loss update is released.

4.3 Country Profile Pages

Individual country pages of GFW Climate are designed to give the user more detail than the pantropical overview page by including multiple sources of data where available. Country pages are organized into separate tabs that display statistics at different spatial scales: national, subnational, and within specific areas that may be of interest to the user. Different data sources are available only in national mode; data for scales below the national level reflect calculations performed in a geographic information system (GIS) for specific geographic extents using only the data sources that are spatially explicit. The text below reflects the same information that is available on the country profile pages by clicking the "Read More" buttons for each indicator.

4.3.1 Deforestation Rate

There is currently no scientific consensus on a global data set for deforestation rates, and in many cases this lack of consensus extends to the national level. We include multiple data sources on GFW Climate in the hopes of fostering transparency and understanding of data differences.

GROSS TREE COVER LOSS: Estimates are based on Hansen et al. 2013 and subsequent annual updates available on Global Forest Watch. Hansen et al. use Landsat satellite imagery at 30-meter pixel resolution to measure the magnitude of annual tree cover loss, counting all tree cover or forest area lost without regard to regeneration or reforestation of natural forest. Tree cover is a proxy for forest cover, defined as all vegetation 5 meters or taller. On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 percent and 30 percent, and gross tree cover loss estimates will update accordingly to reflect the new forest definition.

NET FOREST CONVERSION: Estimates are based on the FAO's *Global Forest Resources Assessment 2015*, which compiles country-level data on forest area that are self-reported by countries every 5 years using their own inventories, surveys, and maps. Forests are defined based on national land-use classifications, with a minimum threshold of 0.5 hectare land area, trees over 5 meters, and a 10 percent minimum canopy cover. Figures for net forest conversion are reported by subtracting the total natural forest area reported for one reporting period from the previous reporting period. **Whereas gross forest loss treats the deforestation term as categorically distinct from regeneration, net forest loss conflates the two.**

OTHER NATIONAL DEFORESTATION DATA: Gross deforestation estimates for Brazil are from the System of Greenhouse Gas Emissions Estimates (SEEG) and estimates for the Amazon biome are consistent with the annual deforestation monitoring by Brazil's National Institute for Space Research (INPE). Data for other countries reflect gross deforestation rates included in country Forest Reference Emission Level submissions to the UNFCCC.

SOURCE	SPATIAL RESOLUTION	REFERENCE TIME PERIOD	INPUT DATA	FREQUENCY OF UPDATES
Hansen et al. 2013	30 x 30 m	2001–14	Landsat	Annual
FAO 2015	National	2000–2015	(FAO table)	Every 5 years
OTHER NATIONAL DEFORESTATION DATA				
Brazil	30 x 30 m	1970–2013	Landsat	Annual (Amazon), variable (other biomes)
Colombia	Subnational (Colombian Amazon only)	2000–2012	Landsat	Biennial
Ecuador	National	1990–2000, 2000–2008	Landsat, ASTER	Unspecified
Guyana	National	2000–2012	Landsat (to 2010), RapidEye (2011 onward)	Annual

4.3.2 CO_2 Emissions

Carbon emissions from deforestation reflect the carbon dioxide emitted to the atmosphere as a result of forest biomass clearing, and country-level estimates are commonly expressed in units of carbon (Tg) or carbon dioxide (Mt CO_2). For tropical forested countries, most emission estimates are derived using IPCC guidelines for Tier 1 accounting by multiplying an estimate of the area of deforestation by an estimate of the biomass carbon of the deforested area, and these are assumed to be "committed" emissions to the atmosphere. Carbon sequestration from growing vegetation after clearing is generally excluded from large-scale carbon assessments; this requires additional information on the fate of the cleared land, which is often lacking. Emissions from tropical organic (peat) soils in Southeast Asia are also either excluded or reported separately; estimates of peat emissions are available on GFW Climate as separate indicators.

CARBON EMISSIONS FROM GROSS TREE COVER LOSS: Estimates are based on the colocation of aboveground live woody biomass density values for the year 2000 from Baccini et al. 2015, with annual tree cover loss data from 2001 through 2014 from Hansen et al. 2013, both at 30-meter spatial resolution. Emissions associated with other carbon pools, such as belowground biomass and soil carbon, are excluded from country estimates at this time, although users can visualize these layers on the interactive map page. Loss of biomass, like loss of tree cover, may occur for many reasons, including deforestation, fire, and logging in the course of sustainable forestry operations. Emissions are "gross" rather than "net" estimates, meaning that information about the fate of land after clearing, and its associated carbon value, is not incorporated. For the DRC, Indonesia, and Malaysia, emissions estimates are further disaggregated to approximate those arising specifically from deforestation (vs. tree cover loss) consistent with Zarin et al. 2016. On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent, and emission estimates will update accordingly to reflect the new forest definition.

CARBON EMISSIONS FROM NET FOREST CONVERSION: Estimates reflect data on net forest conversion and biomass carbon stock density, as reported by countries every 5 years to the FAO's Forest Resources Assessment (FRA) using their own inventories, surveys, and maps. Estimates of net forest conversion are used as a proxy for deforestation (Federici et al. 2015), and estimates of woody biomass carbon stock density are in most cases derived using conversion factors to estimate total living biomass stocks from nationally reported wood volumes. FRA data do not allow for quantification of gross forest area changes or gross emissions.

CARBON EMISSIONS FROM OTHER NATIONAL DEFORESTATION DATA: Emission estimates for Brazil are from the System of Greenhouse Gas Emissions Estimates (SEEG). Data for other countries reflect annual carbon emission estimates included in country forest reference emission level (FREL) submissions to the UNFCCC. We will include these data for other countries as and when they become publicly available.

SOURCE	SPATIAL RESOLUTION	REFERENCE TIME PERIOD	INPUT DATA
WHRC/WRI	30 m	2001–14	Landast, ICEsat lidar, MODIS, inventory plots
Federici et al. 2015/FAO 2015	National	2000–2015	FAO 2015
OTHER NATIONAL DATA			
Brazil	National	1990–2013	RADAMBRASIL 1981
Colombia	Subnational	2000–2012	721 plots collected between 1990 and 2014
Ecuador	National	1990–2000, 2000–2008	National forest inventory plots collected between 2012 and 2014
Guyana	National	2001–12	66 plots collected between 2012 and 2014; four 0.1 ha subplots per plot
Mexico	National	2002/2003, 2007/2008, 2012/2013	21,811 systematically distributed national inventory plots collected between 2004 and 2007; four 0.04 ha subplots per plot

4.3.3 Forest Area 2000

The definition of the word *forest* differs from region to region and country to country based on different objectives such as management, land use, vegetation type, composition, and altitude. As such, there are over 800 definitions worldwide (Lund 2002). Here we present two common sources of forest area data for tropical countries included on GFW Climate.

TREE COVER FOR THE YEAR 2000. *Percent tree cover* is defined as the density of tree canopy coverage of the land surface within a 30-meter (0.09 hectare) pixel. Pixels 30 x 30 meters were aggregated to estimate the area of tree cover at the relevant scale of analysis (national, subnational, etc.). On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent and the area of tree cover will update accordingly to reflect the new forest definition.

FOREST AREA FOR THE YEAR 2000. National forest area statistics for the year 2000 are reported by countries to the Food and Agriculture Organization as part of its *Global Forest Resources Assessment 2015*. Forests are defined based on national land-use classifications, with a minimum threshold of 0.5 hectare land area, trees over 5 meters and a 10 percent minimum canopy cover.

4.3.4 Total Carbon Stored in Trees

Carbon is stored in trees both above and below the soil, including in trees' stems, stumps, branches, bark, seeds, and leaves, as well as in live roots. Average biomass carbon density values, as estimated from forest inventories and/or spatially explicit mapping products, can be used to estimate the total amount of carbon stored in trees within an area of interest by multiplying density values by the forest area under consideration at the relevant scale of analysis (national, subnational, or within specific areas of interest).

SATELLITE-BASED ESTIMATES (WHRC): Estimates of the carbon stored in trees are based on the biomass density maps on GFW Climate produced by Woods Hole Research Center at a 30-meter spatial resolution and representative of the year 2000. Values for each map pixel refer to the average aboveground biomass value per hectare of forests within the pixel and can be aggregated to estimate total carbon stored in biomass at the relevant scale of analysis (national, subnational, or within specific areas of interest). Because of methodological difficulties associated with measuring root biomass, applying a default root:shoot ratio is a core method for estimating belowground (root) biomass from the more easily measured aboveground biomass. Biomass of the forest understory is generally excluded from the aboveground biomass estimates in broad-scale carbon accounting.

On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent and biomass carbon stock estimates will update accordingly to reflect the new forest definition.

FAO 2015: Estimates of above- and belowground biomass carbon stocks in the year 2000 are based on the FAO's *Global Forest Resource Assessment 2015*, which compiles country-level data that are self-reported by countries every 5 years using their own inventories, surveys, and maps.

4.3.5 Average Carbon Stored in Trees per Unit Area

A number of different methodological approaches yield estimates of tree biomass carbon density, or the average carbon content stored in trees per unit land area. At the most fundamental level, all of these rely on the collection of reliable data within inventory plots on the ground, where the diameter at breast height (DBH) of individual trees is measured by field technicians and converted to biomass using allometric equations. Because of methodological difficulties associated with measuring root biomass, applying a default root:shoot ratio is a core method for estimating belowground (root) biomass from the more easily measured aboveground biomass in broad-scale carbon accounting.

SATELLITE-BASED ESTIMATES (WHRC): Estimates of aboveground biomass density are derived from a 30-meter resolution map of aboveground woody biomass density across the tropics, developed by Woods Hole Research Center using a combination of ground measurements, GLAS LiDAR waveform metrics and Landsat 7 ETM+ satellite imagery and products, elevation, and other biophysical variables. Belowground biomass density is calculated from aboveground biomass using an equation from Mokany, Raison, and Prokushkin (2006). On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent and biomass carbon density estimates will update accordingly to reflect the new forest definition.

FAO 2015: Estimates of above- and belowground biomass carbon density in the year 2000 are based on FAO's *Global Forest Resources Assessment 2015*, which compiles country-level data that are self-reported by countries every 5 years using their own inventories, surveys, and maps. Source data on biomass estimates from FAO country reports are summarized in Annex 2.

4.3.6 Total Carbon Stored in Soil

Soil organic carbon is a major component of soil organic matter, which is derived from residual, decomposed plant and animal material. Natural factors (such as land cover, vegetation, topography, and climate) as well as human factors (such as land use and management) can influence the amount of soil organic matter, and thus soil organic carbon, present in soils.

To calculate topsoil organic carbon (to 30 centimeter depth), we use data from the Harmonized World Soil Database (HWSD), a compilation of four soil databases: the European Soil Database (ESDB), the 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database), and the Soil Map of the World. The HWSD contains information on soil parameters, such as organic carbon, pH, water storage capacity, soil depth, total exchangeable nutrients, and salinity. Soil carbon estimates, and soil information in general, have long been considered highly uncertain, and the HWSD makes major improvements by integrating existing regional and national soil information worldwide into a harmonized format. This data set currently constitutes the best available spatially explicit soil carbon data for most regions. The spatial resolution of the data is 1 kilometer.

The amount of carbon stored in soils to 30 centimeter depth in each 1 kilometer pixel was calculated using inputs of percent carbon content, bulk density, and gravel volume. We use relative bulk density values except for Andosols and Histosols, which are typically overestimated by this method. Values are calculated for 0–30 centimeter depth. For more information on calculating SOC from the HWSD, see Hiederer and Köchy 2011.

Total soil organic carbon within an area of interest can be estimated by multiplying soil organic carbon density values by the amount of forest area at the relevant scale of analysis (national, subnational, or within specific areas of interest). On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent and soil organic carbon stock estimates will update accordingly to reflect the new forest definition.

4.3.7 Carbon Stored in Soil per Unit Area

Soil organic carbon is a major component of soil organic matter, which is derived from residual, decomposed plant and animal material. Natural factors (such as land cover, vegetation, topography, and climate) as well as human factors (such as land use and management) can influence the amount of soil organic matter, and thus soil organic carbon, present in soils. On GFW Climate, a user can adjust the minimum tree canopy density threshold for what defines a forest at a value between 10 and 30 percent and average carbon stored in soil per unit area will update accordingly to reflect the new forest definition.

To calculate topsoil organic carbon (to 30 centimeter depth), we use data from the Harmonized World Soil Database (HWSD), a compilation of four soil databases: the European Soil Database (ESDB), the 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database), and the Soil Map of the World. The HWSD contains information on soil parameters, such as organic carbon, pH, water storage capacity, soil depth, total exchangeable nutrients, and salinity. Soil carbon estimates, and soil information in general, have long been considered highly uncertain, and the HWSD makes major improvements by integrating existing regional and national soil information worldwide into a harmonized format. This data set currently constitutes the best available spatially explicit soil carbon data for most regions. The spatial resolution of the data is 1 kilometer.

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4.3.8 Emissions from Peat Drainage

Development of agriculture and other human activities on tropical peatlands requires drainage, which leads to increased CO_2 emissions to the atmosphere from peat decomposition. Highly productive croplands, including plantations, will always be 100 percent drained (Hooijer et al. 2010). IPCC Tier 1 methods were applied to estimate annual CO_2 emissions from peat drainage in Indonesia and Malaysia within plantation areas only, based on the area of overlap between mapped areas of plantations in 2013-14 (Transparent World 2015) and mapped areas of peatlands (Indonesian Ministry of Agriculture, 2012 for

Indonesia; Wetlands International, 2004 for Malaysia). Emission factors for oil palm, acacia, and other species were assigned as 40, 73, and 55 t CO_2 ha^{-1} yr^{-1}, respectively, based on guidance provided in Equation 2.3 and Table 2.1 of IPCC Wetlands Supplement (2013). The value of 55 t CO_2 ha^{-1} yr^{-1} represents the average of emission factor estimates for oil palm and acacia plantations.

4.3.9 Emissions from Peat Fires

Tropical peatland fires contribute to the buildup of carbon dioxide in the atmosphere. Van der Werf et al. (2010) combined satellite information on fire activity and vegetation productivity to develop global estimates of monthly burned area and fire emissions, and data are available in the Global Fire Emissions Database (GFED, http://www.globalfiredata.org/). The current version is 4, which has a spatial resolution of 0.25 degrees and is available from 1997 to 2014.

Here we present GFED emission estimates for fire emissions attributed specifically to tropical peat burning. Emissions from the loss of biomass caused by fires was taken into account when deforestation emissions were calculated. Greenhouse gases included in this peat burning emissions estimate include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), all expressed in units of carbon dioxide equivalents (CO_2e) using Global Warming Potential values from the IPCC Assessment Report (Myhre et al. 2013) with a time horizon of 100 years. These estimates contain a substantial amount of uncertainty but remain the best available data for this source of emissions.

4.3.10 Deforestation Emissions versus Fossil Fuel Emissions

In many tropical developing countries, greenhouse gas emissions from deforestation can equal or exceed emissions from fossil fuel use.

Here we compare national estimates of emissions from deforestation (Zarin et al. 2016) against national estimates of emissions from fossil fuels (http://cait.wri.org). See the latter source for more information about how fossil fuel emissions are estimated.

4.3.11 Deforestation and Degradation Drivers

Drivers of deforestation and forest degradation in tropical countries are complex and multifaceted, and include both direct and indirect drivers. Kissinger, Herold, and de Sy (2012) estimate that agriculture is the direct driver for approximately 80 percent of deforestation worldwide. Indirect drivers are complex interactions of social, economic, political, cultural, and technological processes that affect the direct drivers to cause deforestation, and act at multiple scales.

Here we list the main drivers of deforestation and forest degradation as reported by countries in their REDD+ Readiness Preparation Proposal (R-PP) submissions to the World Bank's Forest Carbon Partnership Facility (2015).

4.3.12 Human Population Trends

Demographic factors including population growth, population density, migration, and urbanization all contribute to the complex relationship between human population trends and deforestation trends. Population growth is one of the most commonly cited indirect drivers of deforestation in many tropical forested countries, particularly in tropical Africa.

Here we display national data on urban and rural population growth (%/yr) as estimated by the United Nations, accessed through the World Bank's World Development Indicators website (World Bank 2014).

4.3.13 Export Value of Primary Commodities

According to Kissinger, Herold, and de Sy (2012) and DeFries et al. (2010), global economic growth based on the export of primary commodities and increased demand for timber and agricultural products are critical indirect drivers of deforestation and forest degradation.

Following DeFries et al. (2010), here we display the net export value per capita of each country's primary agricultural commodity and wood product commodity, defined using FAOSTAT data (FAO 2014) as the single commodity with the largest absolute increase in net value over the time period 2001 to the latest year of data available (2013 for agricultural commodities, 2014 for wood product commodities).

4.3.14 Top Five Crops Expanding in Area

While agricultural expansion is not a driver of deforestation in all countries, Kissinger, Herold, and de Sy (2012) estimate that agriculture is the direct driver for around 80 percent of deforestation worldwide. Here we list the five crops that expanded most in area between 2001 and 2012 (latest available year) in this country according to FAOSTAT. If total crop area in the country decreased between 2001 and 2012, then data for top expanding crops are not shown on the assumption that agriculture was not a driver of new deforestation during this time period.

ENDNOTES

1. Countries' efforts to Reduce Emissions from Deforestation and forest Degradation, as well as foster conservation, sustainable management of forests, and enhancement of forest carbon stocks.

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ACKNOWLEDGMENTS

This publication was made possible by the World Resources Institute's Forests Program and the Global Forest Watch partnership. The author would like to thank the following people for their insight, review and assistance: Carolyn Ciciarelli, Fred Stolle, Craig Hanson, Donna Lee, Timothy Pearson, Dan Zarin. For their guidance, feedback, and original research, the author would also like to thank: Alessandro Baccini, Matthew Hansen, Guido van der Werf, Dmitry Aksenov, Peter Potapov, Belinda Margono, Michael Wolosin, Evan Notman, and many others on the GFW Climate Advisory Panel.

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Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.