USING SPATIAL INFORMATION TO SUPPORT DECISIONS ON
SAFEGUARDS AND MULTIPLE BENEFITS FOR REDD+

STEP-BY-STEP TUTORIAL: VERSION 2.0
UNDERSTANDING AND COMPARING CARBON DATASETS, USING QGIS 2.18

UN-REDD
PROGRAMME

Food and Agriculture Organization of the United Nations
UNDP
Empowered lives. Resilient nations.
UN environment

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. The Programme was launched in September 2008 to assist developing countries prepare and implement national REDD+ strategies, and builds on the convening power and expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and UN Environment.

The UN Environment World Conservation Monitoring Centre (UNEP-WCMC) is the specialist biodiversity assessment centre of UN Environment, the world’s foremost intergovernmental environmental organisation. The Centre has been in operation for over 35 years, combining scientific research with practical policy advice.

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We welcome comments on any errors or issues. Should readers wish to comment on this document, they are encouraged to get in touch via: ccb@unep-wcmc.org.

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Contents

Acronyms and abbreviations

AGB	Above-Ground Biomass
ALOS	Advanced Land Observing Satellite
ASAR	Advanced Synthetic Aperture Radar
AVHRR	Advanced Very High Resolution Radiometer
BCEF	Biomass Expansion and Conversion Factors
BGB	Below-Ground Biomass
BRDF	Bi-directional Reflectance Distribution Function
CEOS	Committee on Earth Observation Satellites
DBH	Diameter at Breast Height
Envisat	European Space Agency Environmental Satellite
ESA CCI	European Space Agency Climate Change Initiative
FAO	United Nations Food and Agriculture Organization
FRA	Forest Resource Assessment
GHG-AFOLU	Greenhouse Gas emissions in Agriculture, Forestry and Other Land Use
GLAS	Geoscience Laser Altimeter System
GLC2000	Global Land Cover 2000
GPCP	Global Precipitation Climatology Project
GSV	Growing stock volume
HOME	Height of Median Energy
HPDI	Highest Posterior Density Interval
ICESAT	The Ice, Clouds, and Land Elevation Satellite
JAXA	The Japan Aerospace Exploration Agency
JRC	Joint Research Centre
LAI	Leaf Area Index
Landsat 7 ETM +	Landsat 7 Enhanced Thematic Mapper Plus (ETM+)
LiDAR	Light Detection and Ranging (named for ‘light’ and ‘radar’)
MERRA	Modern-Era Retrospective analysis for Research and Applications
MODIS	Moderate Resolution Imaging Spectroradiometer
MODIS LST	MODIS Land Surface Temperature Products
MODIS NBAR	MODIS Nadir Bidirectional reflectance distribution function Adjusted Reflectance
MVC	Maximum value composite
NDVI	Normalized difference vegetation index
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
PALSAR	Phased Array type L-band Synthetic Aperture Radar
QSCAT	Quick Scatterometer
SAR	Synthetic aperture radar data
SOC	Soil Organic Carbon
SRTM	Shuttle Radar Topography Mission

(See glossary in Appendix 2 for more information on terms)

1. Introduction

REDD+ is a voluntary climate change mitigation approach that has been developed by Parties to the UNFCCC. It aims to incentivize developing countries to reduce emissions from deforestation and forest degradation, conserve forest carbon stocks, sustainably manage forests and enhance forest carbon stocks. This will involve changing the ways in which forests are used and managed, and may require many different actions, such as protecting forests from fire or illegal logging, or rehabilitating degraded forest areas.

REDD+ has the potential to deliver multiple benefits beyond carbon. For example, it can promote biodiversity conservation and secure ecosystem services from forests such as water regulation, erosion control and non-timber forest products (NTFPs). Some of the potential benefits from REDD+, such as biodiversity conservation, can be enhanced through identifying areas where REDD+ actions might have the greatest impact using spatial analysis and other approaches.

The purpose of this tutorial series is to help participants in technical working sessions, who are already skilled in GIS, to undertake analyses that are relevant to REDD+. The tutorials have been used to build capacity in a number of countries to produce datasets and maps relevant to their spatial planning for REDD+, and to develop such map products. Maps developed using these approaches appear in a number of publications whose aim is to support planning of strategy options that enhance biodiversity and ecosystem services as well as delivering climate change mitigation (see http://bit.ly/mbs-redd for country materials). There is of course no requirement for countries to use the approaches described in these tutorials.

Where countries have identified biodiversity conservation as a goal for REDD+, and to be consistent with the Cancun safeguards for REDD+ on protecting biodiversity, it is useful to identify areas where specific REDD+ actions are feasible and can protect threatened species. It may also be useful to identify areas outside forest where threatened species may be vulnerable to the displacement of land-use change pressures or to afforestation.

Open-source GIS software can be used to undertake spatial analysis of datasets of relevance to multiple benefits and environmental safeguards for REDD+. Open-source software is released under a license that allows software to be freely used, modified, and shared (http://opensource.org/licenses). Therefore, the use of open-source software has great potential in building sustainable capacity and critical mass of experts with limited financial resources.

This tutorial is designed to help the user to compare and contrast carbon datasets and understand the differences in the estimates provided, and the reasons behind this. A country's forest inventory may already include forest carbon estimates and a national level carbon map may have been produced. However, when a country lacks the necessary data or resources to gather it, it may be useful to test global or regional products for suitability of use for REDD+ planning, using available national information to validate.

The tutorial provides technical instructions for using QGIS software to compare carbon values between datasets for potential use in spatial planning for REDD+ and an annex providing a summary of different publicly available datasets highlighting how they differ in resolution, time period, methodology and carbon pools covered. Although the tutorial uses global and regional products as example data, the same techniques can be used with national data.

This tutorial is intended for use in identifying suitable carbon data for use in REDD+ planning in the absence of available high-quality national datasets. It does not provide guidance on how to create a national level carbon map for use in reference level development or advocate the use of global or regional products for this purpose. Information on the potential added value and/or limitations of the use of spatial modelling techniques for Forest Reference Emission Level (FREL) and/or Forest Reference Level (FRL) can be found in the UN-REDD Programme Info Brief "Considering the use of spatial modelling in Forest Reference Emission Level and/or Forest Reference Level construction for REDD+" http://www.fao.org/3/a-i5721e.pdf.

2. Mapping carbon stocks for REDD+ planning

Through retaining threatened forest, REDD+ can prevent carbon dioxide emissions and promote carbon sequestration. Forests have much more to offer the world than their carbon stores, but their carbon can be easily estimated, and doing so provides a part of the case for their restoration, conservation and sustainable management. Mapped estimates of the total carbon locked in forest biomass can be used together with information on deforestation and forest degradation drivers for REDD+ planning. Carbon mapping can allow efforts at carbon protection to be targeted, for example to the higher carbon areas, and may be able to highlight areas that are already subject to degradation. Areas where significant additional benefits could also be gained through REDD+ activities can be identified by combining carbon maps with other spatial datasets showing forest ecosystem services, biodiversity or other forest values. MRV will also require baseline estimates of carbon stocks, which may need to be more precise.

Carbon in terrestrial ecosystems can be distributed into several different pools (Willcock et al. 2012):

- Aboveground biomass
- Belowground biomass
- Coarse woody debris
- Litter
- Soil

Certain pools are more difficult to assess than others and the type of pools considered by different maps vary.

Currently, sampling effort is largely focused on aboveground live carbon pools. However, the quantity of carbon in the remaining pools is being increasingly recognised. The soil carbon pool is typically estimated based on soil type, and the size of other pools is often estimated from ratios relating each pool to aboveground carbon stock.

The approaches to gathering spatial data on carbon stocks are broadly:

- **Field inventories -** these are the most accurate way to estimate biomass carbon of a forest, but are costly.
- **Remote sensing -** allows the whole landscape to be sampled equally, with little cost to the user, but only provide indirect estimates. Remote-sensing measurements need to be calibrated with some field data.

Even with remote sensing approaches, field data remains essential to convert estimates of vegetation cover to values of biomass or carbon. Many countries lack the necessary data or resources to gather it.

When working as part of a REDD+ programme, a nationally produced or -validated carbon map should ideally be used, for example, one which has drawn on data from the country’s National Forest Inventory. If point data from an inventory are available, statistical techniques can be used to develop a map from the raw point data, preferably in conjunction with remote sensing or other complementary spatial data.

A number of regional and global biomass carbon density maps have been produced in recent years, using various methods and sources. The carbon estimations vary greatly between the maps in certain areas. They also represent different time periods. If adopting one of these maps for REDD+ planning purposes, it is important to assess that these estimates are more or less accurate for the area of interest and understand which time period they reflect, as forests are dynamic.

In the absence of suitable data from national, regional or global sources, an alternative solution can be to build a map by assigning carbon values to the different land-cover classes (a so-called 'paint by numbers' approach). As well as a reliable land-cover map, an adequate number of estimates of the biomass of each class is required. These may be available in existing literature or obtained from field data (assessing as many field plots as available within each class, and considering how to represent the range as well as the average). As biomass is only partially related to land cover, there will be variability within each class. Such maps are not as accurate as remotely sensed derived maps but be useful when no other data is available.

An example of how such data have been used in supporting REDD+ planning can be seen in a report developed by the Ministry of Environment and Natural Resources in Kenya and UNEP-WCMC (Maukonen *et al.* 2016). In this report, the Baccini *et al.* 2012 data was used as an interim dataset for decision making as a national map of carbon stocks was not yet available. Expert knowledge of carbon stock distribution in the country was used to determine the most suitable dataset from those regional and global products that were available. The purpose of the report was to support REDD+ planning in Kenya through the development of maps on the distribution of drivers of deforestation and forest degradation, potential additional benefits of implementing REDD+ activities, and different implementation possibilities for REDD+ strategy options.

Please refer to Annex 1 for more information on understanding, comparing and selecting from existing carbon datasets.

2.1 Comparing carbon datasets using QGIS

When more than one carbon dataset is available it is useful to compare them to identify both differences in pattern and values. However, it is important to also bear in mind when comparing datasets that there may be differences in what is actually mapped in terms of the carbon (please refer to Table 3 in annex 1). One may represent just above-ground biomass for example where as another may represent above and below ground biomass. This means that there may be some preparatory work prior to doing the comparisons. The tutorial “Step-by-step tutorial v1.1: Adding below-ground biomass to a dataset of above-ground biomass and converting to carbon using QGIS 2.18” provides guidance on the specific example just mentioned. These pre-processing steps are not covered in this current tutorial.

There is a tool available online for comparing carbon datasets at https://carbonmaps.ourecosystem.com/interface/, however there may be times when you need to make comparisons yourself for datasets not included in this tool.

The following instruction will demonstrate, using as an example two datasets from Avitabile *et al.,* 2016 and Santoro *et al.* 2018, how to undertake a comparison of two datasets using QGIS software.

For this tutorial we will use as an example Liberia, but the same instructions can be used for any other country or region.
You may want to follow these instructions exactly by downloading the two datasets from:

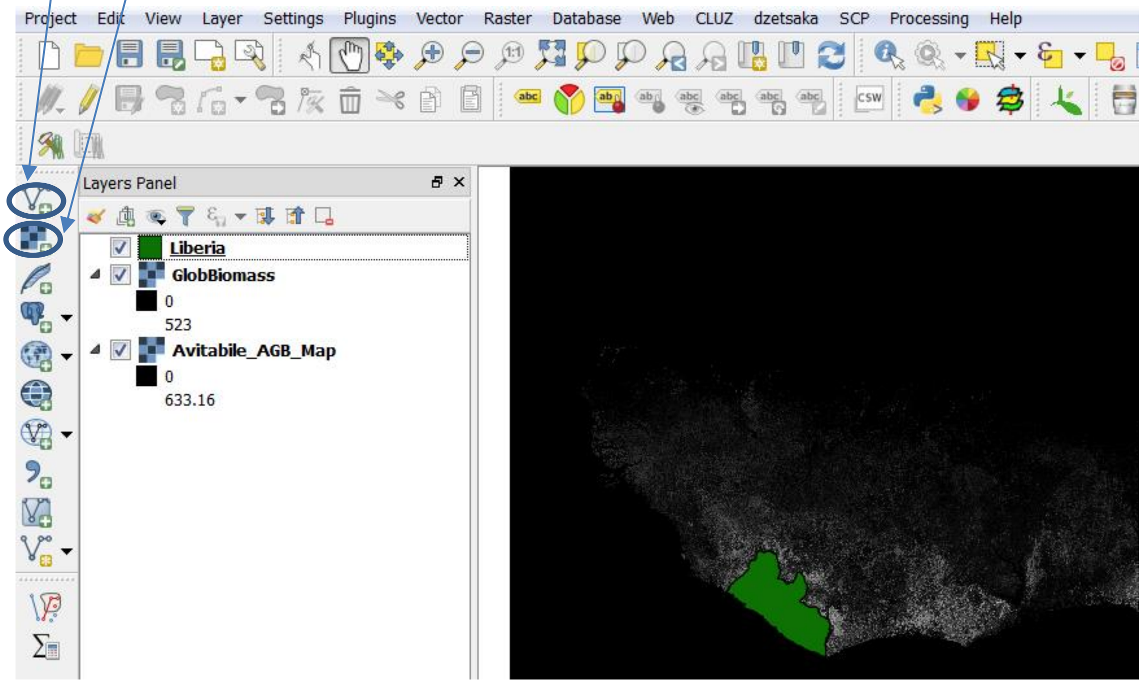
- Pan-Tropical Biomass Map (Avitabile et al., 2016). Accessible at: https://www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Laboratory-of-Geo-information-Science-and-Remote-Sensing/Research/Integrated-land-monitoring/Forest_Biomass.htm (In order to download the data you have to register. The file that has to be downloaded is called: "Pan-Tropical Biomass Map")
- GlobBiomass (Santoro et al., 2018). Accessible at: http://globbiomass.org/products/global-mapping/

2.1.1 Clip the two datasets to your area of interest

a. Add datasets to QGIS

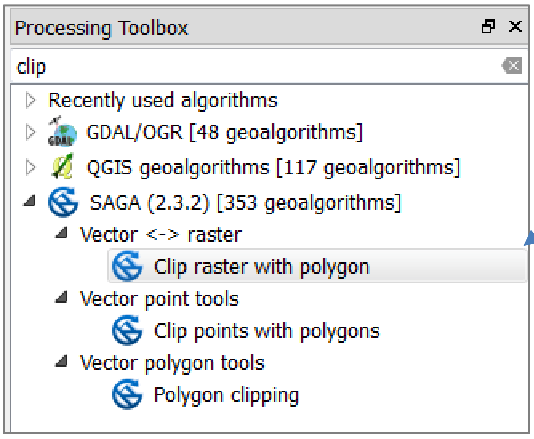
Click on the **Add Raster Layer** button to add the two raster datasets to QGIS. Click on the **Add Vector Layer** button to add the Shapefile of your area of interest – in this case Liberia.

*In this example, both rasters are in WGS84 coordinate system, it is important to make sure the shapefiles are in the same projection. To check the coordinate system, right-click on each dataset, select **Properties** and click on the **General** tab.*



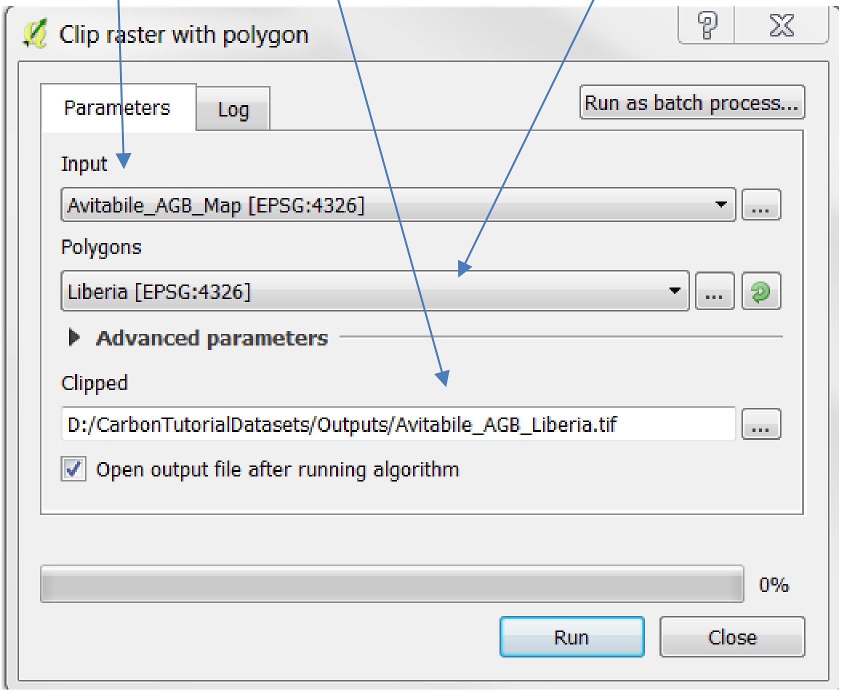
b. Clip both rasters to the area of interest

In the Processing Toolbox search box type **Clip** and select the tool **Clip raster with polygon**.



clip

For **Input** select one of the carbon datasets and for **Polygons** select the shapefile of the region of interest. For the **Clipped** output dataset navigate to an output folder and give the new dataset a name. Then click **Run**.



Input: Avitabile_AGB_Map [EPSG:4326]

Polygons: Liberia [EPSG:4326]

Clipped: D:/CarbonTutorialDatasets/Outputs/Avitabile_AGB_Liberia.tif

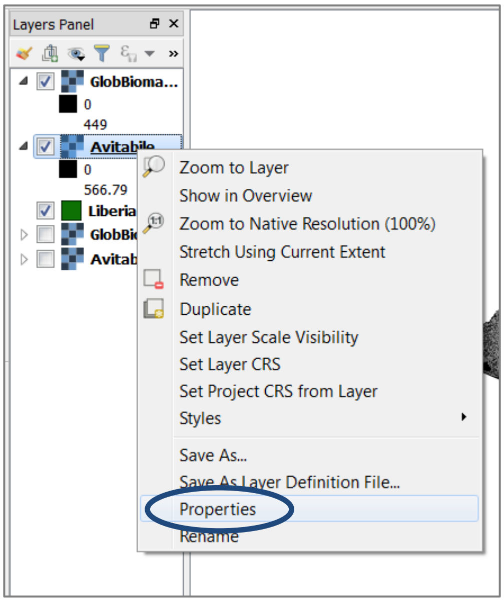
☑ Open output file after running algorithm

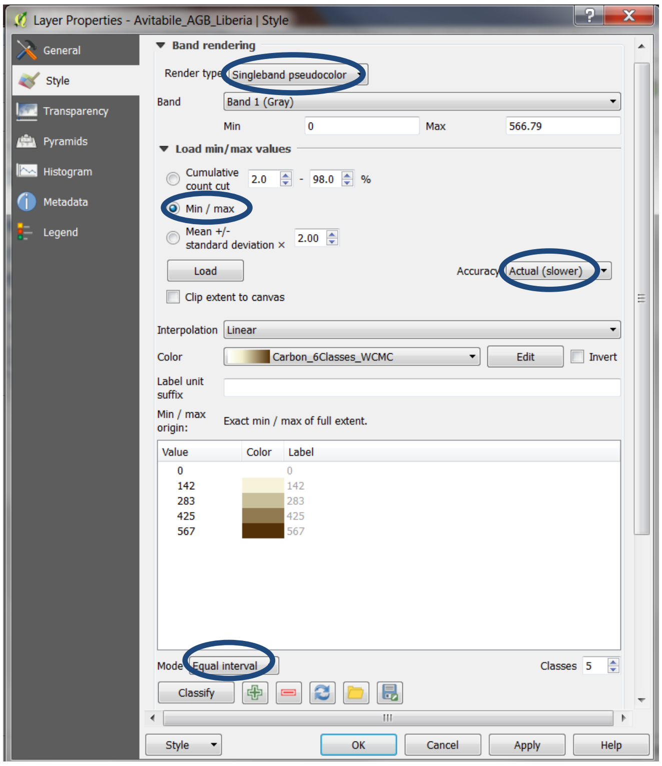
Repeat the steps in 2.1.1. **b** for the second carbon dataset.

2.1.2 Symbolising the raster datasets for comparison

Note that QGIS does not automatically symbolise and scale raster data to display the min-max values unless you have set your QGIS preferences to do so. Will assume that this has not been set.

a. The next step is to change the symbology of the layers to allow an easier interpretation of the data. Right-click on the dataset with the highest maximum value and click **properties** to open the layer properties window





Layer Properties - Avitabile_AGB_Liberia | Style

Render type: Singleband pseudocolor
Band: Band 1 (Gray)
Min: 0 Max: 566.79
Cumulative count cut: 2.0 - 98.0 %
● Min / max
Mean +/- standard deviation × 2.00
Accuracy: Actual (slower)
Interpolation: Linear
Color: Carbon_6Classes_WCMC
Min / max origin: Exact min / max of full extent.

Value	Color	Label
0		0
142		142
283		283
425		425
567		567

Mode: Equal interval
Classes: 5

b. Change the **Render type** to **Singleband pseudocolor**

c. Change **Mode** to **Equal interval**

d. Click on **Min / Max,** click on **Actual (slower)** and click **Load**

e. Click **Classify**

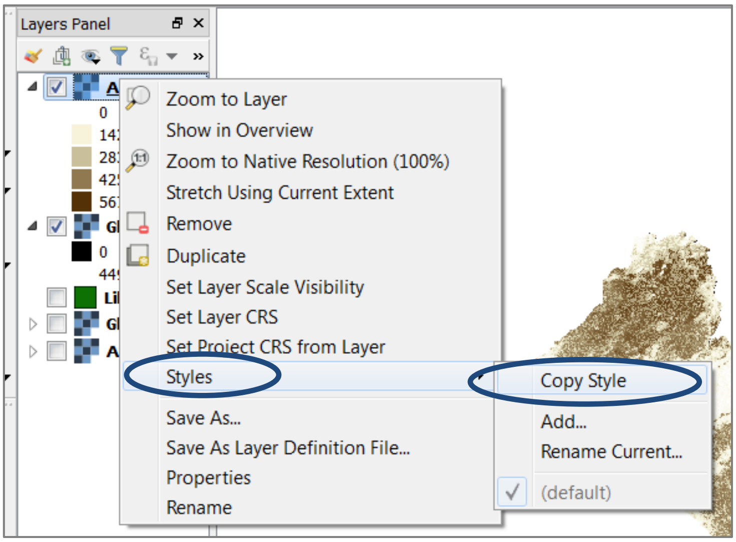
You can manually change the Class breaks if you do not want equal interval classes.

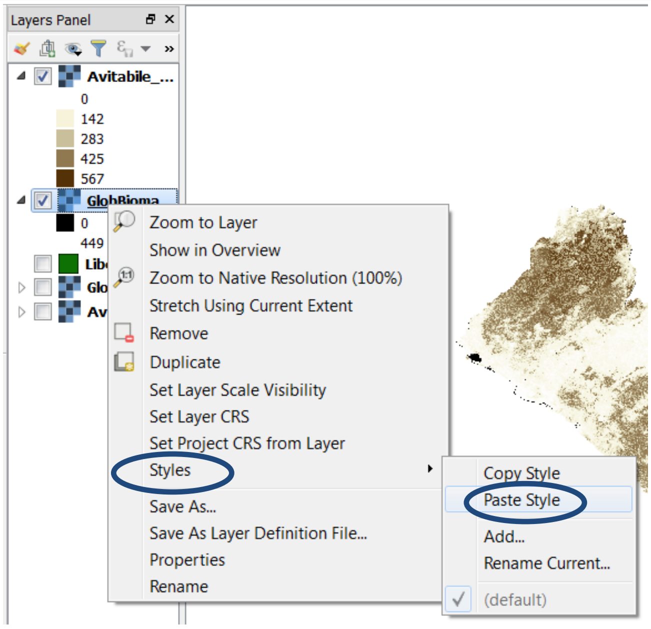
f. Click **OK**

The next step is to copy the symbology across to the second dataset in order to visually compare the datasets with the same class breaks.

g. Right-click on the **same** dataset and click **Styles>>Copy Style**

h. Right-click on the **second** dataset and click **Styles>> Paste Styles**





Visually review the distribution of carbon/biomass values in the different layers. Does it makes sense according to your knowledge of the landcover and carbon distribution?

2.1.3 Preparing raster datasets for comparison

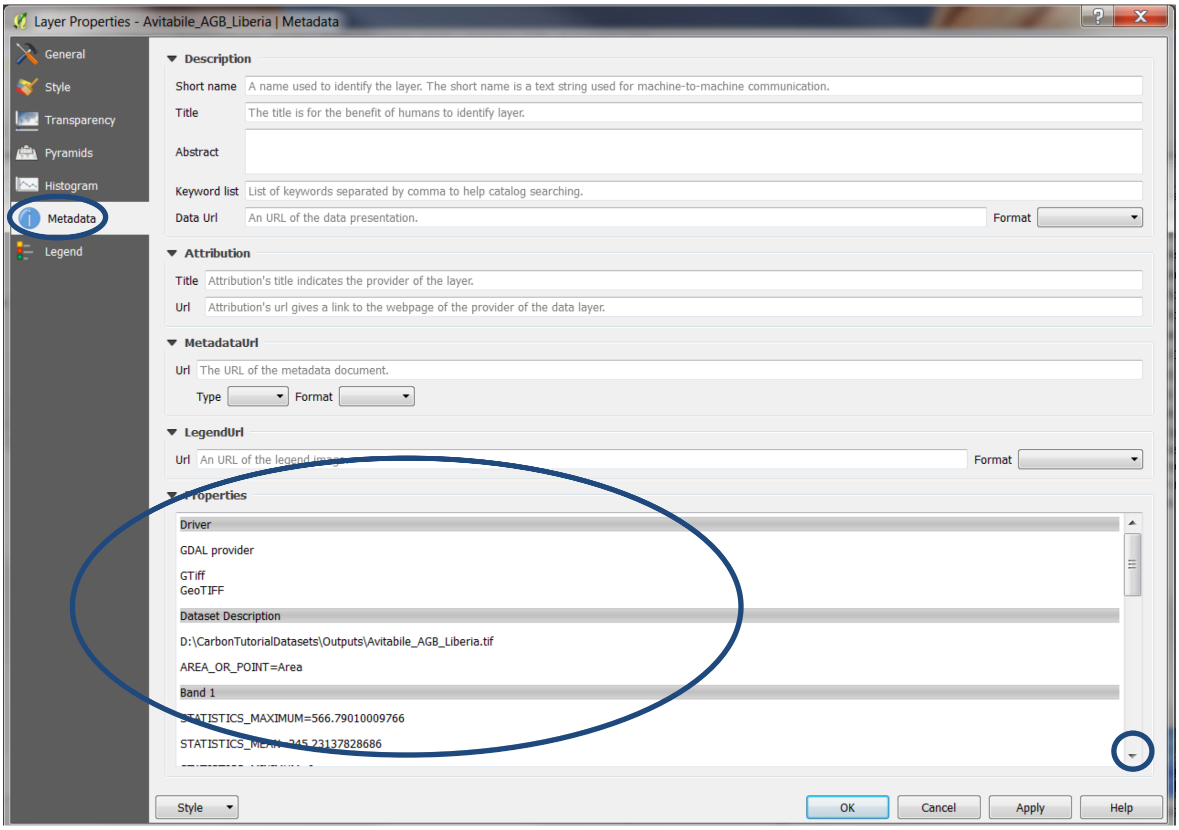
The next steps apply different techniques to compare, both visually and quantitatively, the values estimated in the two datasets.

The first step is to ensure that the projection, resolution (size of the cells) and extent (geographic boundaries) are the same in both layers.

a. Right-click on each layer, click **Properties**

b. Click on the **Metadata** tab

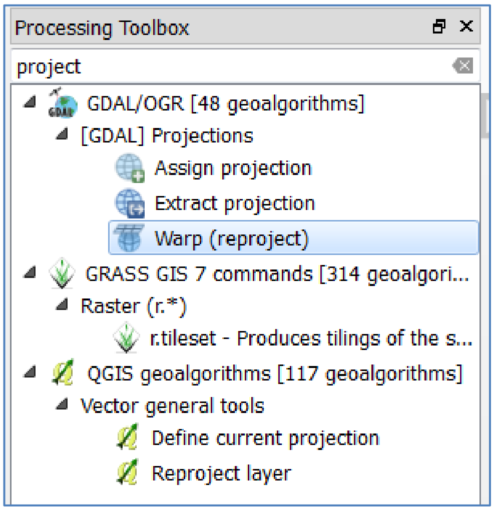
c. The **Properties** section at the bottom of the layer properties window provides information about the dataset. Scroll down to see the resolution and extent



```
Driver
GDAL provider
GTiff
GeoTIFF
Dataset Description
D:\CarbonTutorialDatasets\Outputs\Avitabile_AGB_Liberia.tif
AREA_OR_POINT=Area
Band 1
STATISTICS_MAXIMUM=566.79010009766
STATISTICS_MEAN=245.23137828686
```

In this example both the datasets are in Geographic coordinate system with a cell size of approximately 0.00833333. The datasets have to be re-projected to an equal-area projection, in this case UTM, in order to be able to generate areas or stock statistics later. For UTM projections, you need to know in which UTM zone your region of interest is in. In the case of Liberia it falls within UTM 29 N. If your region of interest falls across multiple UTM zones it is better to use a Lambert-azimuthal equal area projection to ensure areas are represented accurately.

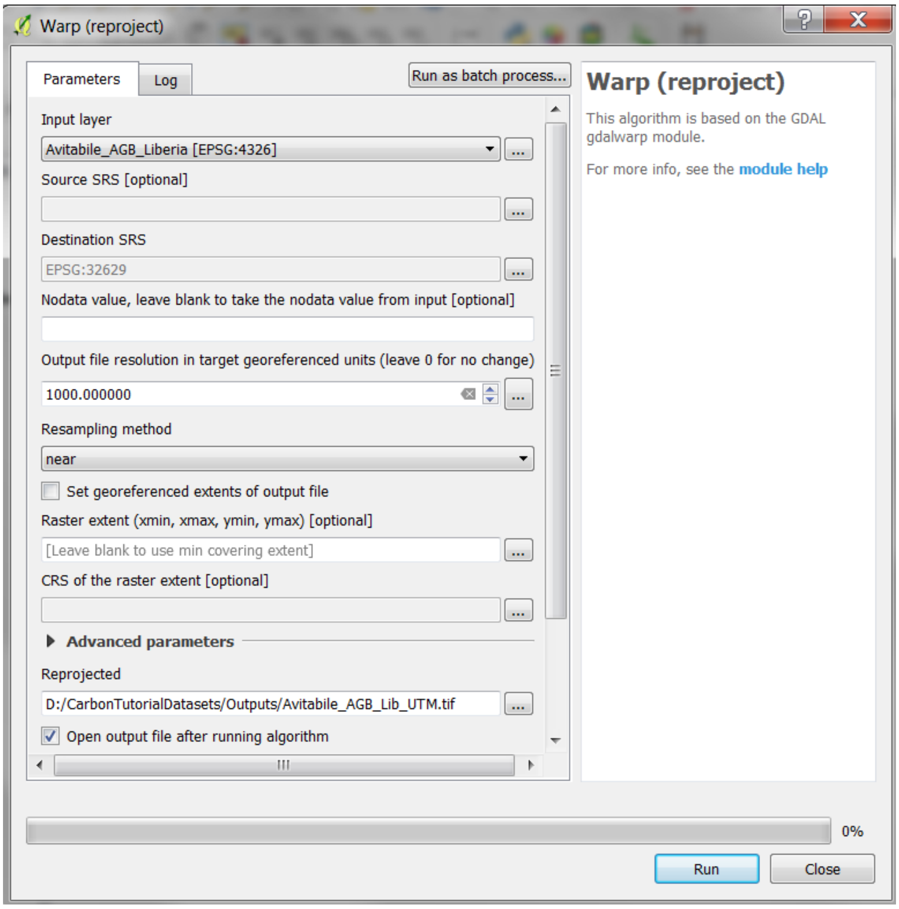
d. Search for **project** in the Processing toolbox and double-click on the tool **Warp (reproject)**



Processing Toolbox

project

e. Re-project the Avitabile to UTM projection. Select in the Destination SRS box the right UTM coordinate references for your zone and in the output file resolution 1000. Give a name to the re-projected file and click Run.



Input layer: Avitabile_AGB_Liberia [EPSG:4326]

Source SRS [optional]:

Destination SRS: EPSG:32629

Nodata value, leave blank to take the nodata value from input [optional]:

Output file resolution in target georeferenced units (leave 0 for no change): 1000.000000

Resampling method: near

☐ Set georeferenced extents of output file

Raster extent (xmin, xmax, ymin, ymax) [optional]: [Leave blank to use min covering extent]

CRS of the raster extent [optional]:

Advanced parameters

Reprojected: D:/CarbonTutorialDatasets/Outputs/Avitabile_AGB_Lib_UTM.tif

☑ Open output file after running algorithm

0%

Warp (reproject)

This algorithm is based on the GDAL gdalwarp module.

For more info, see the **module help**

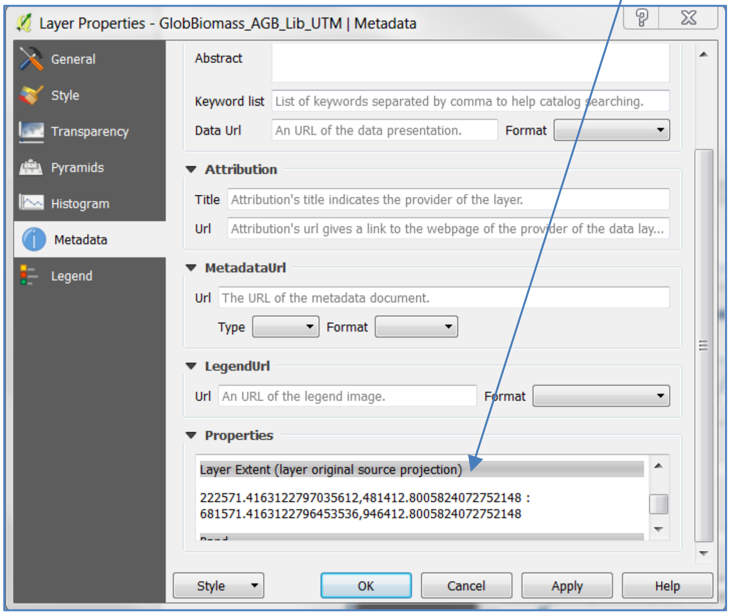
f. Repeat the same steps for the second database.

g. Copy the symbology across to the new projected datasets (as in previous steps g-h in section 2.1.2)

The next step is to ensure that both datasets have the same extent.

h. Right-click on the dataset to match to (i.e. in this example the re-projected GlobBiomass dataset) and click **properties>>Metadata**

i. Scroll down in the properties window and **copy and paste** the **Layer Extent** into a text editor (such as notepad)

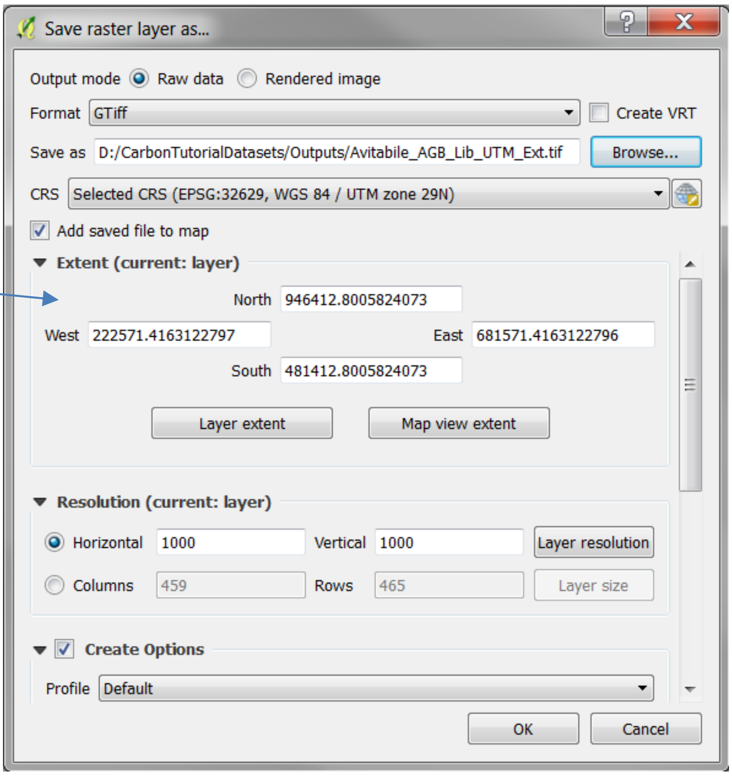


Layer Properties - GlobBiomass_AGB_Lib_UTM | Metadata

Layer Extent (layer original source projection)

222571.4163122797035612,481412.8005824072752148 :
681571.4163122796453536,946412.8005824072752148

j. Right-click on the Avitabile dataset, click **Save as** and copy and paste the correct extent from the text editor into the North, South, East and West extent boxes.



Save raster layer as...

Output mode ● Raw data ○ Rendered image

Format GTiff ☐ Create VRT

Save as D:/CarbonTutorialDatasets/Outputs/Avitabile_AGB_Lib_UTM_Ext.tif

CRS Selected CRS (EPSG:32629, WGS 84 / UTM zone 29N)

☑ Add saved file to map

North 946412.8005824073

West 222571.4163122797

East 681571.4163122796

South 481412.8005824073

● Horizontal 1000 Vertical 1000

○ Columns 459 Rows 465

☑ Create Options

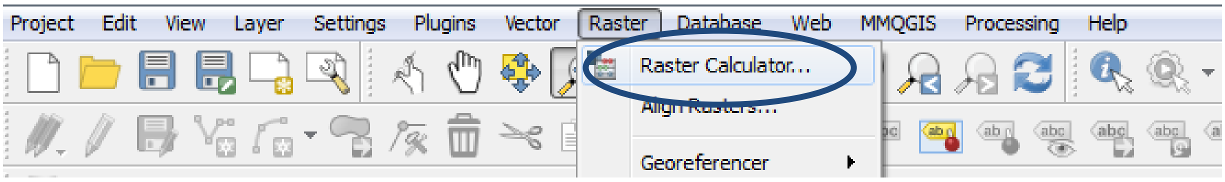
Profile Default

k. When finished, click **properties>>Metadata** on both datasets and check that the dimensions of each raster layer (number of rows and columns) are exactly the same.

2.1.4 Creating a difference map

To compare the carbon values estimated by the two datasets, we can now make a difference map and graphically see where these estimations agree and disagree.

a. Go to Raster >> Raster Calculator



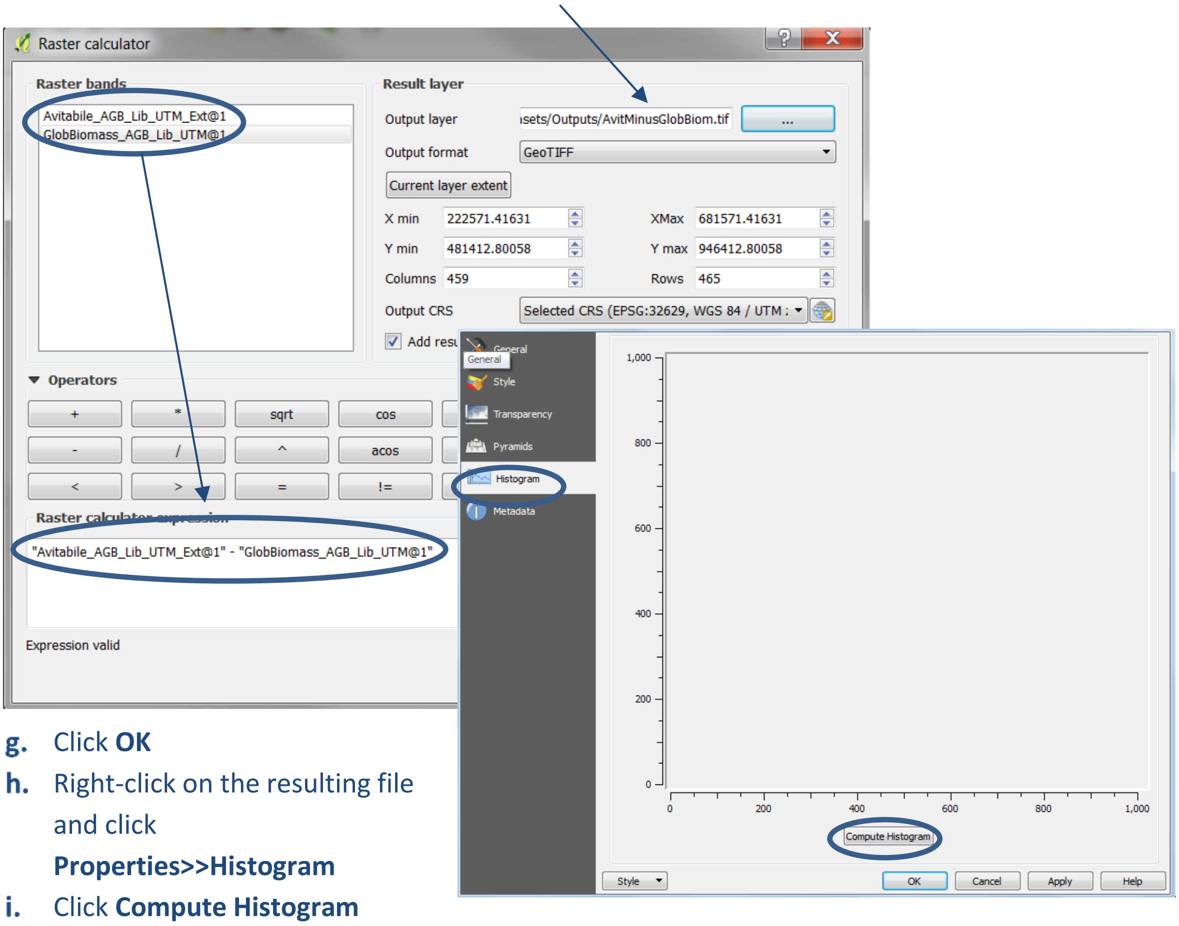
b. Then subtract one dataset from another to find the difference. In this example, we will subtract Avitabile from GlobBiomass.

c. Double-click on the dataset to subtract from to send it down to the **Raster calculator expression panel**.

d. Click on the **minus** sign to send it down to the **Raster calculator expression panel**.

e. Double-click on the dataset to subtract to send it down to the **Raster calculator expression panel**.

f. Navigate to an output folder and give the new file a name



Raster bands:
Avitabile_AGB_Lib_UTM_Ext@1
GlobBiomass_AGB_Lib_UTM@1

Output layer: ısets/Outputs/AvitMinusGlobBiom.tif
Output format: GeoTIFF
X min: 222571.41631
XMax: 681571.41631
Y min: 481412.80058
Y max: 946412.80058
Columns: 459
Rows: 465
Output CRS: Selected CRS (EPSG:32629, WGS 84 / UTM ;
☑ Add resu

Raster calculator expression:

```
"Avitabile_AGB_Lib_UTM_Ext@1" - "GlobBiomass_AGB_Lib_UTM@1"
```

Expression valid

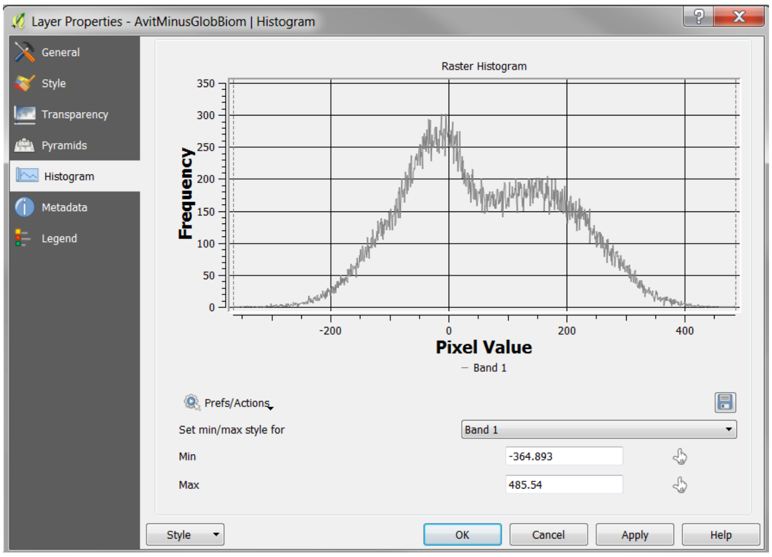
g. Click **OK**

h. Right-click on the resulting file and click **Properties>>Histogram**

i. Click **Compute Histogram**

QGIS will compute a graphical representation of the distribution of the values.

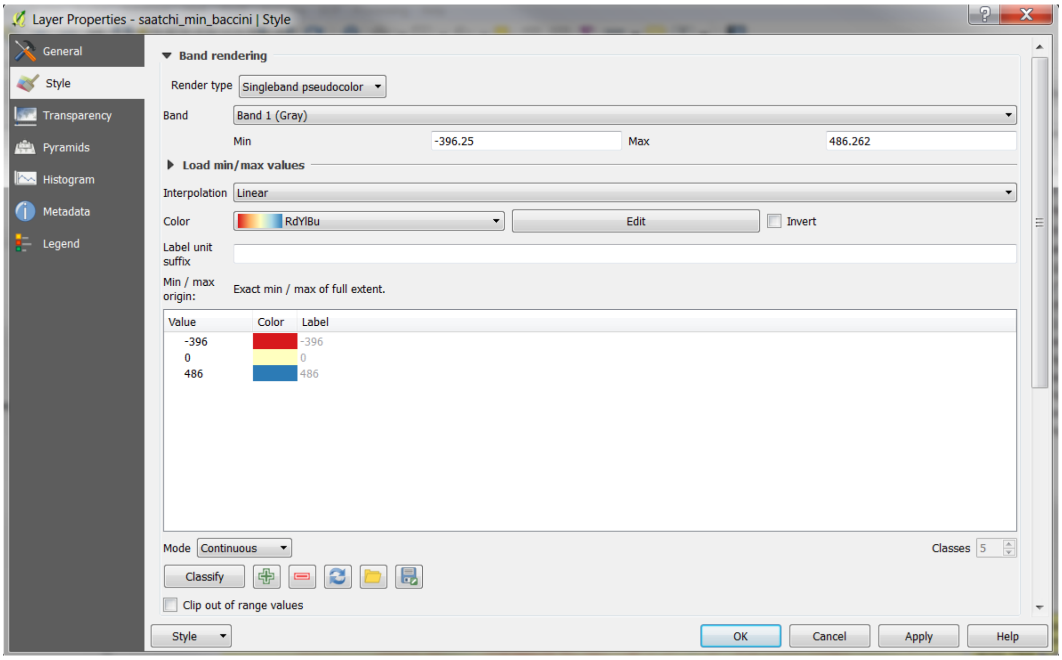
For two identical datasets the values would be zero. In this example we see that there are values either side of 0. This means that in some locations the GlobBiomass data are higher (positive values in the histogram) and in some others the Avitabile data are higher (negative values in the histogram).



Set min/max style for: Band 1
Min: -364.893
Max: 485.54

To represent this graphically: change the symbology of the layer to represent negative values in red, neutral in yellow, and positive, in blue. In this way, you are able to see where are the areas have differences in values and whether they are higher or lower.

j. Right-click on the layer and click on **Properties>>Style**



Render type: Singleband pseudocolor
Band: Band 1 (Gray)
Min: -396.25
Max: 486.262
Interpolation: Linear
Color: RdYlBu
Min / max origin: Exact min / max of full extent.

Value	Color	Label
-396	🟥	-396
0	🟨	0
486	🟦	486

Mode: Continuous
Classes: 5

k. Set **render type** to **Singleband pseudocolor**

l. Click **on min/max,** click on **Actual** and then click **Load**

m. Set **Color Interpolation** to **Linear**

n. Set **Mode** to **EQUAL INTERVAL**

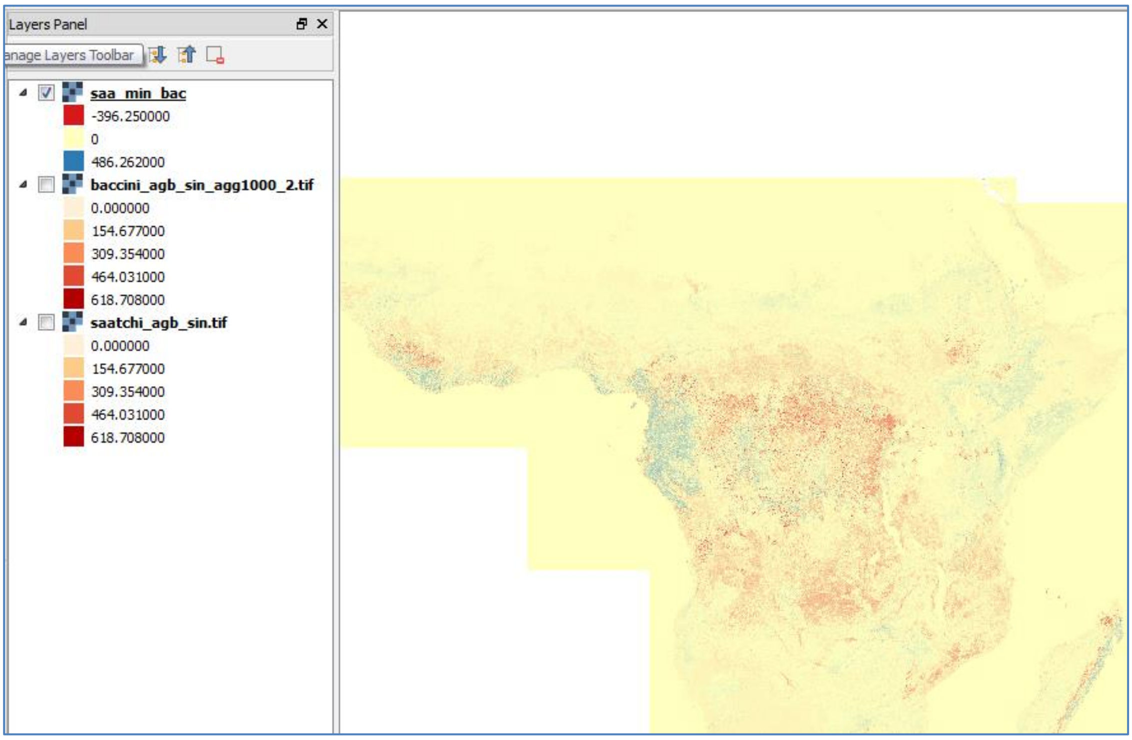
o. Set **classes** to **3**

p. Choose the **Red- yellow-blue** colour ramp

q. Click **Classify**

r. Change the **middle value** to **0**

s. Click **Apply** then **OK**



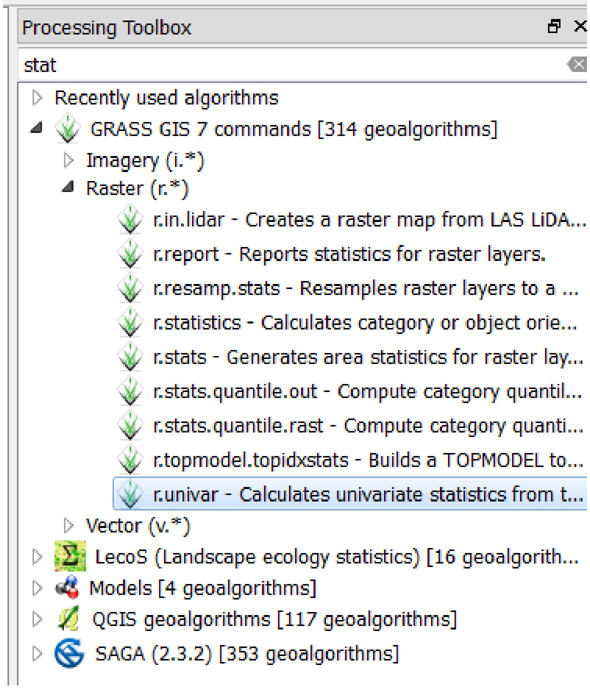
2.1.5 Comparing AGB values by land cover type

To compare the carbon values estimated by the two datasets by land cover type and to identify for which types they agree and disagree, we have to:

a. Add the land cover to your QGIS project and ensure that extent and cell size are the same as the carbon layers. If extent and cell size are different repeat steps I and J in section 2.1.3.

b. Type **Stat** in the search box of the processing toolbox.

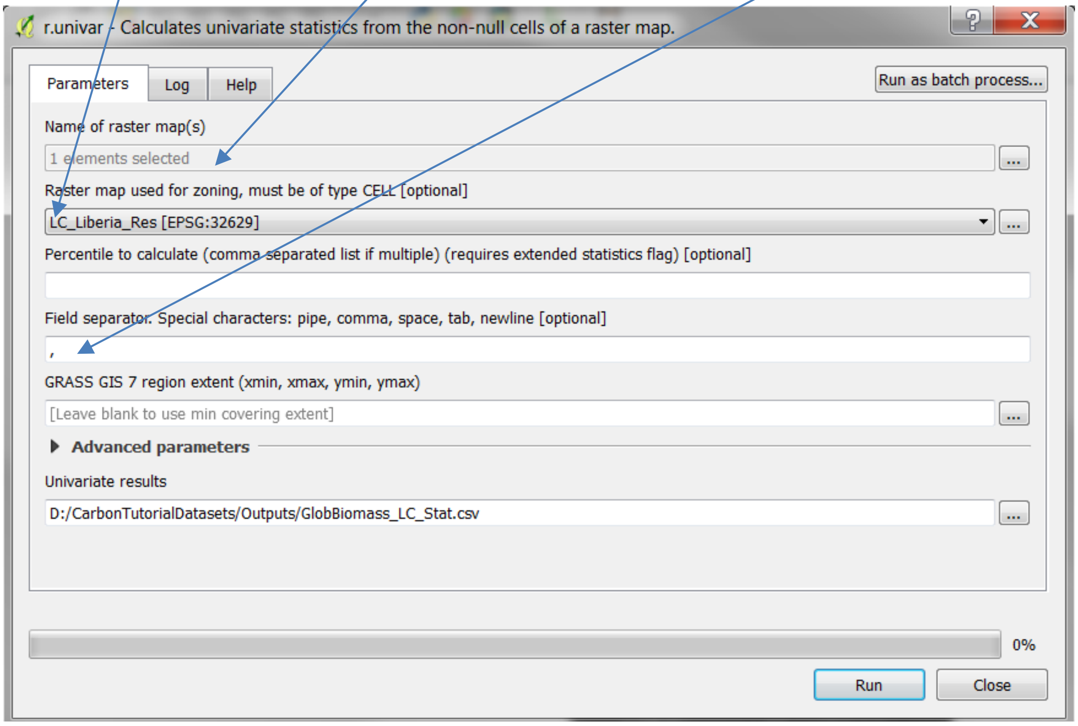
c. To calculate the amount of carbon in each land cover type we will use the tool **r.univar**. Double click on the tool.


Processing Toolbox

stat

- Recently used algorithms
- GRASS GIS 7 commands [314 geoalgorithms]
  - Imagery (i.*)
  - Raster (r.*)
    - r.in.lidar - Creates a raster map from LAS LiDA...
    - r.report - Reports statistics for raster layers.
    - r.resamp.stats - Resamples raster layers to a ...
    - r.statistics - Calculates category or object orie...
    - r.stats - Generates area statistics for raster lay...
    - r.stats.quantile.out - Compute category quantil...
    - r.stats.quantile.rast - Compute category quanti...
    - r.topmodel.topidxstats - Builds a TOPMODEL to...
    - r.univar - Calculates univariate statistics from t...
  - Vector (v.*)
- LecoS (Landscape ecology statistics) [16 geoalgorith...
- Models [4 geoalgorithms]
- QGIS geoalgorithms [117 geoalgorithms]
- SAGA (2.3.2) [353 geoalgorithms]

d. Select one of the carbon datasets under **Name of raster map(s)** and the resamples land cover raster under **Raster map used for zoning**. In the field separator include a comma (,) navigate to an output folder and give a name to the output dataset including the format of the file (csv), in this case **GlobBiomass_LC_Stata.csv.** Click **Run.**



Name of raster map(s)
1 elements selected

Raster map used for zoning, must be of type CELL [optional]
LC_Liberia_Res [EPSG:32629]

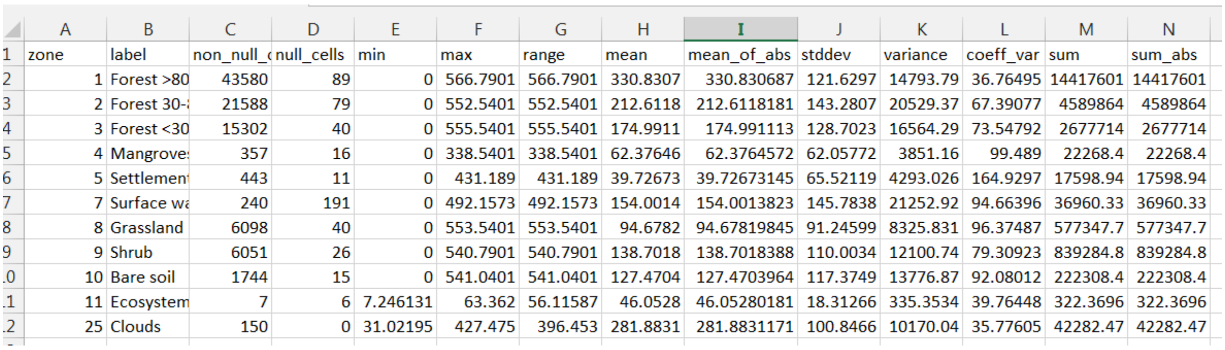
Percentile to calculate (comma separated list if multiple) (requires extended statistics flag) [optional]

Field separator. Special characters: pipe, comma, space, tab, newline [optional]
,

GRASS GIS 7 region extent (xmin, xmax, ymin, ymax)
[Leave blank to use min covering extent]

Univariate results
D:/CarbonTutorialDatasets/Outputs/GlobBiomass_LC_Stat.csv

The output file, containing the summary of above ground biomass (AGB) values by landcover type will look like the one shown below:



zone	label	non_null_c	null_cells	min	max	range	mean	mean_of_abs	stddev	variance	coeff_var	sum	sum_abs
1	Forest >80	43580	89	0	566.7901	566.7901	330.8307	330.830687	121.6297	14793.79	36.76495	14417601	14417601
2	Forest 30-	21588	79	0	552.5401	552.5401	212.6118	212.6118181	143.2807	20529.37	67.39077	4589864	4589864
3	Forest <30	15302	40	0	555.5401	555.5401	174.9911	174.991113	128.7023	16564.29	73.54792	2677714	2677714
4	Mangrove	357	16	0	338.5401	338.5401	62.37646	62.3764572	62.05772	3851.16	99.489	22268.4	22268.4
5	Settlement	443	11	0	431.189	431.189	39.72673	39.72673145	65.52119	4293.026	164.9297	17598.94	17598.94
7	Surface wa	240	191	0	492.1573	492.1573	154.0014	154.0013823	145.7838	21252.92	94.66396	36960.33	36960.33
8	Grassland	6098	40	0	553.5401	553.5401	94.6782	94.67819845	91.24599	8325.831	96.37487	577347.7	577347.7
9	Shrub	6051	26	0	540.7901	540.7901	138.7018	138.7018388	110.0034	12100.74	79.30923	839284.8	839284.8
10	Bare soil	1744	15	0	541.0401	541.0401	127.4704	127.4703964	117.3749	13776.87	92.08012	222308.4	222308.4
11	Ecosystem	7	6	7.246131	63.362	56.11587	46.0528	46.05280181	18.31266	335.3534	39.76448	322.3696	322.3696
25	Clouds	150	0	31.02195	427.475	396.453	281.8831	281.8831171	100.8466	10170.04	35.77605	42282.47	42282.47

e. Repeat the steps for the second carbon datasets.

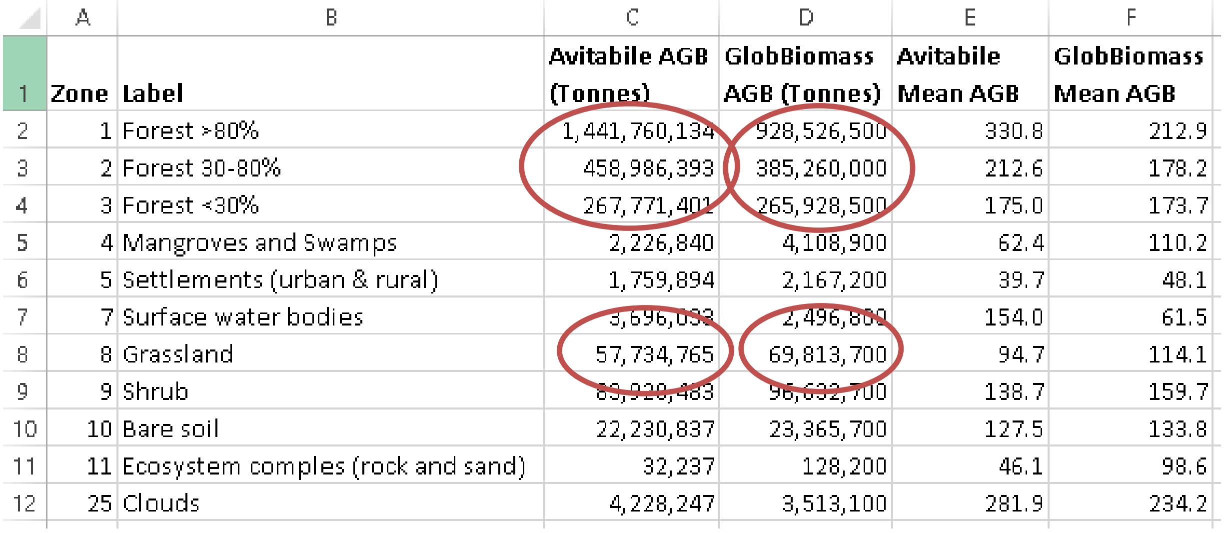
f. Once you have csv files for both carbon datasets, open them in **Microsoft Excel.**

We will need to calculate the area in tonnes/ha for each land cover type. Since the area of each cell in the raster dataset used to generate these summary statistics is 1x1 Km, in order to do make the calculation the following equation can be used for each land cover type:

Tonnes of AGB = Number of cells * (1*1 Km)*100ha*mean AGB value (tonnes/ha)

Where the number of cells is contained in Column C (non_null_cells) i.e. number of 1km x1km cells containing data with that landcover type and the mean (AGB value) is contained in Column H (mean).

g. Copy the zone, label and mean fields from the two excel tables into a new excel sheet. Label the mean columns **Avitabile Mean AGB** and **GlobBiomass Mean AGB**. Add two new columns **Avitabile AGB (Tonnes) and GlobBiomass AGB (Tonnes)**. Use the above formula to calculate in these new columns the amount of AGB in each landcover type for the Avitabile and GlobBiomass datasets. Now you can compare the amount of AGB for each land cover type in the two carbon datasets.



	A	B	C	D	E	F
1	**Zone**	**Label**	**Avitabile AGB (Tonnes)**	**GlobBiomass AGB (Tonnes)**	**Avitabile Mean AGB**	**GlobBiomass Mean AGB**
2	1	Forest >80%	1,441,760,134	928,526,500	330.8	212.9
3	2	Forest 30-80%	458,986,393	385,260,000	212.6	178.2
4	3	Forest <30%	267,771,401	265,928,500	175.0	173.7
5	4	Mangroves and Swamps	2,226,840	4,108,900	62.4	110.2
6	5	Settlements (urban & rural)	1,759,894	2,167,200	39.7	48.1
7	7	Surface water bodies	3,696,033	2,496,800	154.0	61.5
8	8	Grassland	57,734,765	69,813,700	94.7	114.1
9	9	Shrub	83,920,483	96,632,700	138.7	159.7
10	10	Bare soil	22,230,837	23,365,700	127.5	133.8
11	11	Ecosystem comples (rock and sand)	32,237	128,200	46.1	98.6
12	25	Clouds	4,228,247	3,513,100	281.9	234.2

As you can see Avitabile's AGB is higher for forest ecosystems, for the other ecosystems (Grasslands and Shrub) GlobBiomass gives higher estimates.

Annex 1: Understanding and comparing carbon datasets

The terrestrial carbon pools that are most often included in available maps are above-ground biomass (AGB), below-ground biomass (BGB) and soil organic carbon (SOC). Although SOC can be a substantial pool, which can be affected by land-use change, there is more limited spatial data available than for vegetation carbon[2]. For biomass carbon, a number of globally consistent AGB maps are now available, either for the world as a whole or for the tropics (Kindermann *et al.*, 2008; Ruesch & Gibbs 2008; Saatchi *et al.* 2011; Baccini *et al.* 2012; Thurner *et al.* 2014; Avitable *et al.* 2014 and 2016, Spawn *et al.* 2017; Xia *et al.* 2014; Bouvet *et al.* 2018; Santoro *et al.* 2018; Baccini 2018; Hu *et al.* 2016). BGB is often derived from the AGB using conversion factors , termed 'root to shoot' ratios, such as those used by the IPCC Tier 1 methodology. The quality of AGB data has progressed markedly in recent years, however, the existing products do not provide a consensus on the total amount of biomass carbon or its spatial distribution pattern, and in some cases show strong disagreement. Furthermore, recent comparative studies have shown disagreement between remotely-sensed datasets and plot-based estimates (Mitchard *et al.*, 2013, 2014). Within the scientific community, no single method is considered definitive; some approaches may have advantages or disadvantages in particular areas or ecosystems, and a number of issues influence data quality.

Data on the quantity and spatial distribution patterns of AGB is crucial for well-informed REDD+ planning and implementation. This annex is designed to assist in selecting between publicly available biomass carbon datasets, especially for use by an individual country. It compares the different existing datasets (henceforth referred to by the codes in Table 1) and presents the main issues to consider when selecting a dataset for use.

Table 1 - Codes used in this Annex to refer to the datasets

Kindermann *et al*. 2008	K
Ruesch and Gibbs 2008	R
Saatchi *et al.* 2011	S
Baccini *et al.* 2012	B
Thurner *et al*. 2014	T
Avitabile *et al.* 2014 (**GEOCARBON**)	A
Xia *et al.* 2014	X
Avitabile *et al.* 2016	V
Hu *et al.* 2016	H
Spawn *et al.* 2017	P
Bouvet *et al.* 2018	O
Santoro *et al.* 2018 (GlobBiomass)	N
Baccini 2018[1]	C

Comparing biomass carbon datasets

The datasets show differences in terms of total carbon estimates, carbon density estimates and spatial distribution patterns of carbon stocks in different ecosystems, forest areas, woody biomass in non-forest areas, grassland ecosystems, and other ecosystems.

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[1] unpublished

[2] Even at national scales there are rarely datasets available that contain the soil chemical properties required for soil carbon estimates.

Unsurprisingly, there are markedly different estimates for total carbon between K and R; because K focuses only on forest whilst R tackle all ecosystems. K report 296 GtC for forests whilst R report 502 GtC for vegetation a whole. At the regional level, Table 2 shows regional and pan-tropical differences between S and B datasets for woody biomass. The S and B datasets also disagreed strongly at the national level with the FAO Forest Resources Assessment (2010) (Mitchard, *et al*., 2013), though differences in forest definition will account for some of the differences, and many of the nationally-reported figures from the FRA rely on best estimates rather than recent measurements. There are also differences between S and B in the spatial distribution of carbon, with the direction of the difference varying between locations (Mitchard *et al*. 2014).

Table 2: Mean carbon density (averaged across the continent) and total aboveground biomass for the tropical terrestrial continental regions (not including Australia, southern Latin America, and southern Africa), Source: Mitchard *et al*., 2013.

Continent	Area Compared (km^2)	S		B	
		Mean Density (Mg ha^{-1})	Total AGB (PgC)	Mean Density (Mg ha-1)	Total AGB (PgC)
Africa	22,105,436	50.8	56.2	58.4	64.5
Americas	14,713,658	129.8	95.5	158.1	116.3
Asia	6,457,241	160.2	51.7	144.9	46.8
Pan-Tropics	43,276,334	94.0	203.4	105.2	227.6

A comparison between biomass estimates within forest areas, in two more recent datasets, N and C (Figure 1), shows that for most UN Environment sub-regions, C provides higher estimates of AGB than N, especially for the South Pacific, Southeast Asia and Central Africa. In contrast N's estimate for Australia + New Zealand and Mashriq are notably higher than C's and for Western, Central and Eastern Europe are marginally higher. These differences are likely due to several factors, including the different distribution of field data and the approach for estimating AGB in the two studies.

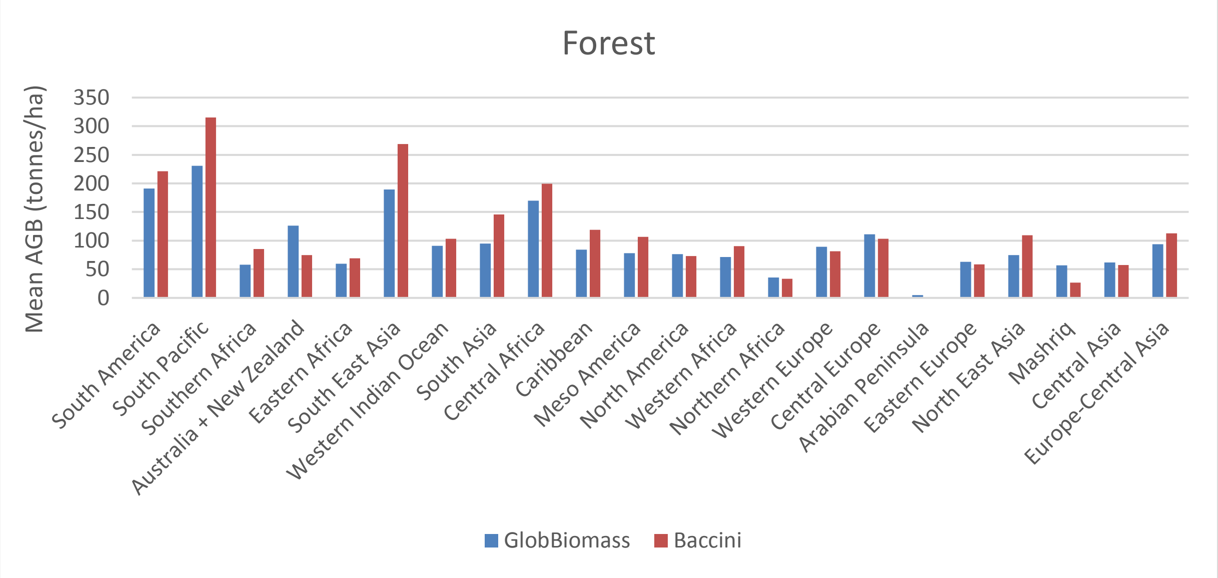

Figure 1 Comparison of biomass estimates within forest areas (according to the forest classes of the 2010 Land Cover CCI product) from GlobBiomass (Santoro et al. 2018) and Baccini (2018), by UN Environment sub-region.

When looking at woody biomass in non-forest areas, C provides higher estimates of AGB than N, in particular for the South Pacific, Southeast Asia and Central Africa. In contrast, N's estimates are higher for Australia + New Zealand, South Asia, North Africa and Mashriq (Figure 2).

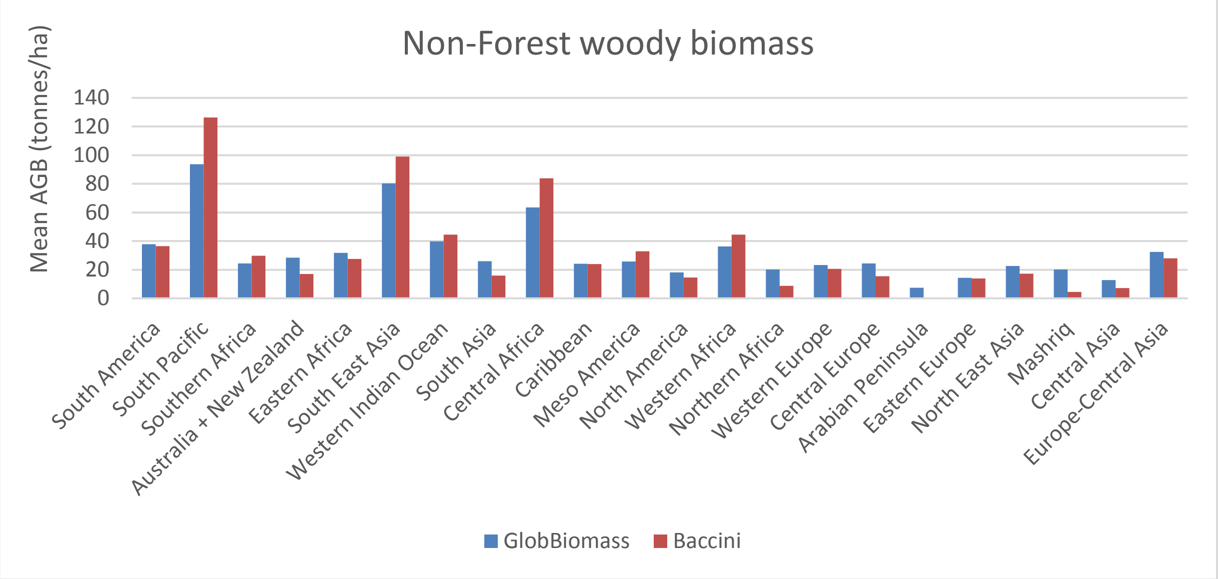

Figure 2 Comparison of GlobBiomass (Santoro *et al.* 2018) and Baccini (2018) within non-forest areas (according to the forest classes within the 200 Land Cover CCI product), by UN Environment sub-region.

O is a high resolution dataset for woodland and savanna in Africa, and when compared to N and S, shows a higher agreement with N. This result indicates that for global woody formations, other than Africa for which O should be used, N is the most reliable dataset currently available.

P, is the best available dataset to be used for all other ecosystems, including grassland, cropland, sparse vegetation and any areas of shrubland not covered by O and N.

These analyses highlight the need to evaluate any given map against what is known for the country in question, whether that's through expert assessment, comparison with available data for part of the region or both.

Table 3 shows the main differences in coverage and methods of the various datasets. For example, for Carbon pools it highlights whether the data are AGB only or AGB and BGB, only forest biomass or other biomass, and if they only include trees above a certain diameter. S for example, includes woody biomass (both inside and outside forests) for trees that are >10cm diameter at breast height (DBH), whilst B includes all trees >5cm DBH.

Table 3: Spatial coverage and design of the datasets; including spatial resolution, time period, carbon pools covered, overall methodology, the use and comprehensiveness of field inventories, allometric and statistical equations used, and uncertainty estimates.

	K	R	S	B	V	T	A	P	X	O	N	C	H
Scope	Global	Global	Pan-tropical	Pan-tropical[23]	Pan-tropical	Temperate and boreal	Global	Global	Global	Africa	Global	Global	Global
Data Year(s)	2005	2000	2000	2007-2010	2000 +	2010	Various 2000s	circa 2010	1982 to 2006	2010	2010	2000	2004
Spatial Resolution	60km	1km	1km	463m	1km	1km	300m	300m	8km	25m	100m	30m	1km
Biomass	AGB &BGB	AGB &BGB	AGB &BGB	AGB	AGB	AGB&BGB	AGB	AGB+BGB	AGB	AGB	AGB	AGB	AGB
Biomass Definition	In woody biomass in forests only + some in litter and soil. Non-harmonised DBH thresholds	All living vegetation using globally consistent default values. (IPCC 2006)	Woody biomass inside and outside forest for trees that are > 10cm DBH	Woody biomass inside and outside forest for trees that are > 5cm DBH	AGB for all living trees with diameter at breast height ≥ 5-10cm.	Living biomass (stem, branches, roots, foliage) in forests. Forest GSV referring to volume of tree stems per unit area.	Biomass only in forest areas according to the GLC2000 map.	Synthetic, global above- and below-ground biomass maps that combine recently-released satellite based data of standing forest biomass with novel estimates for non-forest biomass stocks	Grassland biomass	Woodland and savannah. Low woody biomass areas, which therefore exclude dense forests and deserts	Woody biomass inside and outside forest for trees that are > 10cm DBH masked to Landsat canopy cover of 2010 (Hansen et al., 2013). The mass, expressed as oven-dry weight of the woody parts (stem, bark, branches and twigs) of all living trees excluding stump and roots.	Woody biomass inside and outside forest for trees that are > 10cm DBH	Biomass only in forest areas according to MODIS land cover map for 2004 from the Global Land Cover Facility.
Field Data	FRA 2005, plots and allometrics depends on data source.	No	4,079 plots spanning a variety of forest types. Varying in plot size, sampling scheme, allometric	Plots in 9 countries (3 African, 4 South American and 2 Asian); 283 field plots for calibration	18 ground datasets and yielding 4,283 field plot. Used in combination with AGB maps (below) - 10,741	Field measurements from Global Wood Density Database (Chave *et al.* 2009; Zanne *et al.*, 2009) and the JRC GHG-AFOLU Biomass	3 input datasets weighted with local reference datasets to minimize the impact of errors on the final biomass estimates in the tropics.	No	81 field plots of aboveground live biomass measurements totalling 158 site-years of field (some sites had multi-year observations). These were used for model	In total, 144 field plots were selected, located in 8 countries (Cameroon, Burkina Faso, Malawi, Mali, Ghana, Mozambique, Botswana and South Africa), with	Field data used in validation process only for which 56,345 forest inventory and forest plot data from research networks were used. Only plots with precise coordinates (from	field-based biomass measurements (as described in Baccini *et al*, 2012)	> 4000 plot measurement records collected from published literature.

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[3] Saatchi *et al*., 2011 includes Australia, Southern Latin America and Southern Africa which are not included in Baccini *et al*., 2012.

	K	R	S	B	V	T	A	P	X	O	N	C	H
			equations, and number of structural components)	(23,881 trees)	reference pixels; and validation based on additional 2,118 pixels.	Compartment Database (JRC, 2009).			calibration and validation. These included 31 intensively studied grassland sites, spanning five ecoregions (cold desert steppe, temperate dry steppe, humid savanna, humid temperate, and savanna) and 22 sites of temperate grasslands in China.	a mean plot size of 0.89 ha used to train a model that relates PALSAR intensities to AGB. Data from different countries in Africa between 2000 and 2013, both from published literature and from original campaigns.	year 2000 onwards) for which trees of ≥ 10 cm diameter were included and with a minimum size of 0.04 ha (average 0.04-0.32ha). Most plots located in Europe although large part of the forested area worldwide covered.		
Other spatial data	FRA 2005, Human Influence (Ciesen 2002)	GLC2000, FAO ecofloristic zones, continental regions, and WRI frontier forests (level of human disturbance)	GLAS LIDAR, MODIS (LAI, NDVI), QSCAT, SRTM	MODIS (NBAR, BRDF, LST), SRTM, LIDAR	Saatchi (2011) and Baccini (2012) datasets. 9 high-resolution (<= 100m) AGB maps, derived from satellite data and validated using Field and LIDAR data. GLC2000, Global Ecological Zones (FAO, 2000), Intact forest landscapes for 2000	GLC2000 land-use/land-cover map (JRC, 2003) Multi-temporal Envisat ASAR. GSV estimates obtained with the BIOMASAR algorithm (Santoro *et al.*, 2011).	Combining and harmonizing pan-tropical biomass map by Avitabile et al. (2016) with the boreal forest biomass map by Santoro et al. (2015). The map covers only forest areas, where forest are defined as areas with dominance of tree cover in the GLC2000 map (Bartholomé and Belward, 2005). For a proper use and description of this dataset, please refer to the mentioned articles.	Represents an update for circa 2010 to the IPCC Tier-1 Global Biomass Carbon Map for the Year 2000 (Ruesch and Gibbs, 2008). Data inputs for ABG: Avitabile et al., 2016; Baccini et al., 2012; Jia et al., 2003; Monfreda et al., 2008; Xia et al., 2014) and interpolation where necessary. BGB was modeled from aboveground biomass carbon stocks using published empirical relationships (Mokany et al., 2006; Reich et al., 2014).	NDVI, Climate data included monthly Modern Era Retrospective-Analysis for Research and Applications (MERRA) temperature data and Global Precipitation Climatology Project (GPCP)	ESA CCI (2010) Landcover dataset	Spaceborne SAR (ALOS PALSAR, Envisat ASAR), optical (Landsat-7), LiDAR (ICESAT) and auxiliary datasets with multiple estimation procedures.	GLAS, LiDAR, SRTM, Landsat 7 ETM+, and ancillary bio/geophysical data	

	K	R	S	B	V	T	A	P	X	O	N	C	H
					(Potapov *et al.*, 2008).								
Approach to Estimating AGB	NPP and human impact w/ biomass	Biomass classification	Using field and LIDAR data, sampling forest structure and estimating biomass; relating Lidar-derived stand height and AGB, mapping AGB using satellite imagery to stratify forest types and structure and MaxEnt to spatially model AGB.	Using field and LIDAR data, sampling forest structure and estimating biomass; relating field biomass estimates to LIDAR waveform metrics and extrapolating to further GLAS footprints; combining with MODIS satellite and DEM data using the Random Forest model.	AGB maps and field plots used to calibrate fusion model to assess the accuracy of input data. Bias and weight parameters computed by stratum and continent. Criteria used to select reliable AGB estimates. Harmonized with the Saatchi (2011) and Baccini (2012) variables to 1km resolution.	Non-forested areas masked out according to the GLC2000 (JRC, 2003). GSV derived from SAR. Forest biomass derived from the GSV using existing databases and allometric relationships between AGB and BGB. Remote sensing GSV data obtained with the BIOMASAR algorithm.	The map is obtained by combining and harmonizing the pan-tropical biomass map by Avitabile et al. (2016) with the boreal forest biomass map by Santoro et al. (2015). The map covers only forest areas, where forest are defined as areas with dominance of tree cover in the GLC2000 map (Bartholomé and Belward, 2005). For a proper use and description of this dataset, please refer to the mentioned articles.	Harmonized global maps of biomass and soil organic carbon stocks created by overlaying a global landcover map for the year 2010 with satellite-based maps of landcover-specific aboveground biomass carbon and interpolation where necessary. Belowground biomass was modeled from aboveground biomass carbon stocks using published empirical relationships (Mokany et al., 2006; Reich et al., 2014).	-NDVI to develop global biomass model based on the bi-Bi-weekly NDVI derived from (NOAA/AVHRR) to develop model on relationship between aboveground live biomass measurements and their corresponding NDVI at sites - NDVI data used to calculate the spatial patterns and temporal changes. -Maximum value composite (MVC) to decrease the noise in NDVI data.	The map is built from the 2010 L-band PALSAR mosaic produced by JAXA, along the following steps: a) stratification into wet/dry season areas in order to account for seasonal effects, b) development of a direct model relating the PALSAR backscatter to AGB, with the help of in situ and ancillary data, c) Bayesian inversion of the direct model.	AGB was obtained from GSV with a set of Biomass Expansion and Conversion Factors (BCEF) following approaches to extend on ground estimates of wood density and stem-to-total biomass expansion factors to obtain a global raster dataset.	Allometric relationships were used to convert stem diameter measurements to biomass, yielding an estimate of the density of aboveground biomass for each sampled GLAS shot. By linking the field and LiDAR observations, Baccini et al.(2)developed a statistical relationship between field-measured biomass density and GLAS waveform metrics	based on the framework proposed by Su et al. (2016) to estimate global forest AGB using a combination of ground inventory data, spaceborne LiDAR, optical imagery, climate surfaces, and topographic data.
Uncertainty Assessments	Statistics and spatial analysis for countries where no data was available	No	Validating the results and propagating the errors through the methodol	Multiscale assessments for ABG distribution and total carbon estimates.	Uncertainty of the model for creation of fused map computed.	Uncertainty estimate derived for each pixel. The uncertainty from GLC2000 land cover could not be	According to the GlobBiomass project: - Errors and uncertainties in the tropics minimized only in areas where reference datasets	No. But observed anomalies in interpolation process reported by authors. In areas where the biomass map corresponding with a given landcover type	No estimate of error limits of estimates. General observations listed in paper: -uncertainties exist in field measurements mainly from	The overall uncertainties, taking into account both the accuracy and precision of the AGB estimates, can be calculated by running a Monte Carlo	Accuracy has been assessed over a significant set of locations with independent in situ reference data. This included significant efforts	Uncertainty layer for the pan-tropics (only). Takes into account the errors from allometric equations, the LiDAR based model, and the Random Forest	Uncertainty not fully quantified. -only uncertainty caused by the plot location analysed using the Monte Carlo simulation method - There are other

	K	R	S	B	V	T	A	P	X	O	N	C	H
	through FRA 2005.		ogy to estimate uncertainty at national scale			accounted for.	were available - Underestimation for latitudes > 30°N in dense mature forest and in patchy forest landscapes. - Large uncertainties reported in temperate and sub- tropical forest -Conversion from GSV to AGB based on simple, biome-specific BCEFs that do not take into account the complexity of the forest landscape in terms of genus and wood density (cf Thurner et al. 2014).	reports no data, pixels were filled with the "regional average" biomass value for that specific landcover. The regional average was calculated for each landcover type individually by overlaying a hexagonal-grid and taking the average of all pixels reporting biomass values for that type land cover within each hexagon. The interpolation procedure was most frequently used for the shrub class as primary maps were only available for the high arctic and pan tropical regions.	imbalanced geographic distribution of field sites. -An NDVI time series dataset may still contain errors from incomplete corrections of satellite drift and atmospheric effects. -The grassland distribution map was static, which might not be able to reflect the quick response of grassland to inter-annual change of precipitation as some research has indicated in the transition zones between deserts and dry grassland in Sahel, Africa.	simulation. This approach provides an extended 95% HPDI (Highest Posterior Density Interval, used in Bayesian statistics) that accounts for the uncertainties linked to both accuracy and precision.	to collect, and process a large reference database. The has achieved CEOS WGCV LPV stage 2 stage validation.	model. All the errors are propagated to the final biomass estimate.	sources from the uncertainty of each prediction variables. - to conduct this, thousands of RF runs need to be executed to estimate the uncertainty of the final forest AGB product.

The variation in carbon estimates between the datasets for any given pixel will result from differences in the information covered (e.g. year the data is from, or whether it covers forests or a broader set of terrestrial ecosystems, what carbon pools are included), differences in the methodologies used to create the datasets and error and uncertainty in the estimates.

A number of the datasets quantify the **uncertainties** within their estimates, and discuss this in their documentation. S notes that uncertainties in the distribution of AGB result from factors including: (1) Observation errors when calculating the AGB from observable parameters; (2) Sampling errors associated with the ability of the dataset to capture the spatial variability of AGB, and (3) Prediction errors associated with the extrapolation of AGB estimates across a whole area (Saatchi *et al*., 2011). V uses a fusion approach to combine the S and B datasets with field observation data to produce a new map, aiming to have greater accuracy than the two input datasets (S and B). They applied bias removal and weighted linear averaging techniques, using a reference dataset compiled from a mix of field observations and calibrated high-resolution biomass maps. The resulting output map has different spatial patterns to either the original S or B input datasets (Avitabile *et al*., 2016).

The 13 datasets used different overall approaches for estimating AGB. The pan-tropical maps (B, S and V), temperate/boreal map (T) and O, were all developed using remote-sensing information calibrated with field information, typically combining high-resolution LIDAR or RADAR data with wall-to-wall MODIS data. Models are then used to relate the satellite and field data to variation in biomass carbon.

The global datasets use different approaches. K and R make some assumptions on reduced biomass in areas subject to human impact, with K using a ‘human footprint’ map, and R using a ‘frontier forests’ map. K has the starting point of national estimates that countries had submitted to the FRA 2005, downscaling these using datasets of Net Primary Production (NPP), land cover and human impact. Countries used a range of approaches to generate these national estimates, and their national forest definitions do vary. R used an approach based on IPCC Tier-1 methods, assigning biome-average default values to land-cover maps. Both K and R used the same land-cover map, Global Land Cover 2000 (GLC2000). K used it to define the proportion of forest in a cell, and R combined it with maps of ecofloristic zones, continental regions, and frontier forests (level of human disturbance) to assign grid cells to one of 124 ‘carbon zones’, or categories, with different carbon stock values. Each of these zones contains significant variation in reality. As a result of the approaches used, both global maps contain some abrupt gradients, for R between groups of cells assigned to the different zones, and for K across country boundaries, which aren’t seen in the pantropical datasets.

A and P combine and harmonize previous global datasets with land cover maps. A includes just forested areas, defined as areas with dominance of tree cover in the GLC2000 and P, which also includes soil organic carbon stocks, uses a global land cover map for 2010 with satellite based maps of land cover-specific AGB. X uses NDVI from NOAA/AVHRR to model the relationship between AGB and the corresponding NDVI. N uses the Growing Stocks value (GSV) to obtain AGB with a set of Biomass expansion and Conversion Factors (BCEF). C and H, use different approaches to combine ground truth data with LiDAR observations.

Allometric equations are used to estimate above-ground biomass (AGB) from measurements of forest tree attributes such as diameter at breast height (DBH), tree height and/or wood-specific gravity[4]. The equations are used with field plot data that is then used to contribute to estimating average carbon density for an ecosystem type or in calibrating satellite-based biomass maps (see below). Therefore, the differences in the allometric equations used contribute to the variations in the carbon estimates of different datasets.

Forest inventory field data is extremely important for estimating AGB, including for estimating average biomass for different vegetation types and calibrating remote sensing models. The quality, quantity and source of the field data will influence the carbon estimates of a dataset. This includes the size of plots used; the sampling strategy; the spatial distribution of plots; the ability of surveyors to identify the range of tree species present; the representativeness of the plots' biomass compared to surrounding forest (e.g. field plots chosen to be undisturbed may be less representative of the forest as a whole); and the period when field data has been collected relative to the timing of the remote-sensing data (i.e. accounting for any potential land change that has occurred).

For pan-tropical carbon biomass map B, the field data had a standardized sampling methodology. For S, field data were collated from various sources including scientific studies and forest inventories. Whilst this does not provide a uniform or scientific sampling approach (in terms of plot size, number, allometrics used etc.), it does provide the largest dataset of field plots and covers the widest number of countries. The methods by which field data are used to calibrate remote-sensing data will also influence the results. B and S use similar approaches with different intermediate parameters.

Soil carbon datasets

Soil organic carbon data at global to regional scale are available from:

- FAO's Global Soil Organic Carbon (GSOC; FAO and ITPS. 2018) dataset. This is based on the soil carbon data provided by each country following GSOC guidelines: http://www.fao.org/global-soil-partnership/pillars-action/4-information-and-data-new/global-soil-organic-carbon-gsoc-map/en/
- Soil organic carbon at global (JRC data) and European (various sources) scale (Hiederer and Köchy (2011) dataset): http://esdac.jrc.ec.europa.eu/themes/soil-organic-carbon-content
- Soilgrids at ISRIC (global, aiming to crowdsource additional data): http://soilgrids1km.isric.org/
- Africa Soil Information Service: http://africasoils.net/

The FAO dataset shows often marked differences between countries (e.g. across the Chilean-Argentinian, Norwegian-Swedish, PNG-Indonesian border areas) and this makes it less appropriate for global mapping. In contrast, the ISRIC Soilgrids by being fitted at the global scale, is a better product to be used for global analyses.

The ISRIC Soilgrids is a better product to be used for global analyses, for several reasons:

- The model on which is based was fitted at the global scale
- It is based in >150,000 soil profiles compared to the Hiederer and Köchy (2011) map, which used 9,607 WISE 2.1 soil profiles + 16,107 national SOTER soil profiles.

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[4] The inclusion of wood-specific gravity (the density of wood compared to water) can improve the estimates of AGB (Chave *et al*., 2014), however, wood density can have larger variation within landscapes than between regions (Saatchi et al. 2014).

- When the ISRIC SoilGrids dataset was compared with a mangrove-specific soil carbon dataset (Sanderman *et al.* 2018), it showed that the carbon values were adequately covered.

This has been supported by a recent comparative analysis between these latter two datasets (Tifafi et al. 2018) which indicated that the value of the total carbon stock provided by SoilGrids may be the closest one to reality. It provides information to 2m depth, which may allow a better assessment of carbon in peats. Although the ISRIC SoilGrids provide information to 2m depth, which may allow a better assessment of carbon in peats, compared to the Hiederer & Köchy map's assessment to 1m depth. It is important to consider whether including soil data to 2m data is appropriate as it is not relevant to climate change mitigation in all soil types.

Guidance on selecting between datasets

The variability observed between the different datasets both in carbon estimates and in the methods used highlight that careful consideration needs to be given to selecting between the datasets. The most appropriate dataset is likely to depend on both the intended use and location. These steps can help in selection:

1) Identify any national constraints on acceptable data for use in REDD+ planning (as distinct from MRV). For example, can datasets from public domain sources be used, in combination with national definitions for forest or are only nationally derived datasets acceptable? Where national data do not exist or are still in development, can public domain data be validated for use in planning?
2) Evaluate methods associated with data; referring to this brief as appropriate, including:
    a. What is the resolution of the map, and does this provide enough detail for intended use?
    b. What period does the data relate to, i.e. is it the most recent data available?
    c. Does the dataset provide full coverage of the study area? (e.g. Baccini 2012 is delimited by the lines of the tropics and is therefore incomplete for countries that span the tropics).
    d. What carbon pools does the data cover and does it cover the most relevant ones?
    e. Does it cover biomass inside and outside forest and how does this correspond to the national definition of forests?
    f. Are the assumptions in the methodology appropriate to the proposed analysis and study area? (i.e. appropriate allometric equations and spatial modelling?)
    g. Do the data persuasively take into account human activities that could impact carbon stock estimates?
3) Compare spatial data using GIS overlay (i.e. producing maps using the spatial data from the shortlisted datasets)
    a. Do the pattern of distribution and/or values appear reasonable for the area of interest? (do the patterns correspond to general ecosystem patterns and patterns of human influence?).
    b. Seek expert opinion both on quantity and distribution of carbon stocks
4) Compare with other relevant data

    a. How does the dataset compare with available aspatial data (for example information in national reports, from national forest inventories or FRA reports)?

5) Compare with field values
    a. if field plot information not already used in the formulation of the dataset is available for the country, this can help in assessing accuracy
6) Select or Combine data as necessary (only where scale and data are appropriate to do so).

Selecting the most appropriate dataset will reduce the uncertainty in analyses derived from it. **Even where the most appropriate map has been selected uncertainties in the estimate will remain.** Globally, the uncertainty assessments provided by each dataset are generally smaller than the differences between datasets suggesting that the uncertainties may be higher. However, **uncertainty assessments** provide the user with information on the accuracy of the data and how that varies through space, and can allow for more informed decisions.

In summary:

- Evaluate methods associated with data
  (using this brief and perhaps referring back to the original papers)
- Compare spatial data using GIS overlay
  (i.e. producing maps using the spatial data from the shortlisted datasets)
- Compare with other relevant data
  (perhaps from country-assessments or recent FRA data)
- Compare with field values
  (if plot-based assessments are available. Provided methods for assessing field values are standardised and rigorous, this can be a key tool for assessing accuracy)
- Seek expert opinion
- Select or Combine data as necessary (only where scale and data are appropriate to do so).

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Annex 2 : Glossary of terms

Acronymn	definition	Description	Source
AGB	Above ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.	Terms and Definitions - FRA 2020, FAO, 2018 (http://www.fao.org/3/I8661EN/i8661en.pdf).
ALOS	Advanced Land Observing Satellite	The Japanese Earth observing satellite used mainly for land observation. The Advanced Land Observing Satellite (ALOS) follows the Japanese Earth Resources Satellite-1 (JERS-1). ALOS will be used for cartography, regional observation, disaster monitoring, and resource surveying.	https://www.eorc.jaxa.jp/ALOS/en/about/about_index.htm
ASAR	Advanced Synthetic Aperture Radar	The Advanced Synthetic Aperture Radar (ASAR) was an active radar sensor on-board the European Space Agency (ESA) satellite ENVISAT, operational from March 2002 to April 2012. Applications for this sensor are many and include the study of ocean waves, sea ice extent and motion, and land surface studies, such as deforestation and ground movement.	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/asar/sensor-description
AVHRR	Advanced Very High Resolution Radiometer	The AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and the surface temperature	https://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
BCEF	Biomass Expansion and Conversion Factors	Is a multiplication factor that expands growing stock, or commercial round-wood harvest volume, or growing stock volume increment data, to account for non-merchantable biomass compon-ents such as branches, foliage, and non-commercial trees.	(IPCC. 2003. Good Practice Guidance for LULUCF - Glossary), FRA2005. ; http://www.fao.org/faoterm/en/?defaultCollId=1

BGB	Below ground biomass	All biomass of live roots. Fine roots of less than 2 mm diameter are excluded because these often cannot be disting-uished empirically from soil organic matter or litter.	Terms and Definitions - FRA 2015, Forest Resources Assessment Working Paper 180, FAO, 2015 (http://www.fao.org/docrep/017/ap862e/ap862e00.pdf).
BIOMASAR algorithm		An approach for retrieval of forest growing stock volume using stacks of multi-temporal SAR data	https://www.researchgate.net/publication/230662433_The_BIOMASAR_algorithm_An_approach_for_retrieval_of_forest_growing_stock_volume_using_stacks_of_multi-temporal_SAR_data
BRDF	Bi-directional Reflectance Distribution Function	The bidirectional reflectance distribution function is a function of four real variables that defines how light is reflected at an opaque surface.	https://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function
CEOS WGCV LPV	Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) Land Product Validation (LPV)	The Committee on Earth Observation Satellites (CEOS), defines validation as the process of assessing, by independent means, the quality of the data products derived from the system outputs.	https://landval.gsfc.nasa.gov/
DBH	Diameter at breast height	The stem diameter of a tree measured at breast height.	FAO Language Resources Project, 2005; IUFRO, Vienna, 2005; IUFRO World Series Vol.9-en, 2000. http://www.fao.org/faoterm/en/?defaultCollId=1
Envisat	European Space Agency Environmental Satellite	The European Space Agency's Envisat satellite was operational from March 2002 to April 2012. It superceded the ESR satellites, having more advanced imaging radar, radar altimeter and temperature-measuring radiometer instruments, supplemented by new instruments including a medium-resolution spectrometer sensitive to both land features and ocean colour. Envisat also carried two atmospheric sensors monitoring trace gases.	https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat
ESA CCI	European Space Agency Climate Change Initiative		
FAO	The Food and Agriculture Organization of the United Nations		

FRA	Forest Resources Assessments	The Global Forest Resources Assessments (FRA) are now produced every five years in an attempt to provide a consistent approach to describing the world's forests and how they are changing.	http://www.fao.org/forest-resources-assessment/background/en/
GHG-AFOLU	Greenhouse Gas emissions in Agriculture, Forestry and Other Land Use		https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf
GLAS	The Geoscience Laser Altimeter System	GLAS (the Geoscience Laser Altimeter System) is the first laser-ranging (lidar) instrument for continuous global observations of Earth. GLAS is the primary instrument aboard the ICESat spacecraft.	https://www.nasa.gov/mission_pages/icesat/
GLC2000	Global Land Cover 2000	The JRC coordinated and implemented the Global Land Cover 2000 Project (GLC 2000) in collaboration with a network of partners around the world. The general objective to provide for the year 2000 a harmonised land cover database over the whole globe.	https://ec.europa.eu/jrc/en/scientific-tool/global-land-cover
GPCP	Global Precipitation Climatology Project		https://climatedataguide.ucar.edu/climate-data/gpcp-monthly-global-precipitation-climatology-project
GSV	Growing Stock Volume	volume of all living trees more than 10 cm in diameter at breast height measured over bark from ground or stump height to a top stem diameter of 0 cm. Excludes: smaller branches, twigs, foliage, flowers, seeds, stump and roots	https://doi.pangaea.de/10.1594/PANGAEA.894711
HPDI	Highest Posterior Density Interval	Interval used in Bayesian statistics. Choosing the narrowest interval, which for a unimodal distribution will involve choosing those values of highest probability density including the mode. This is sometimes called the highest posterior density interval.	https://en.wikipedia.org/wiki/Credible_interval
ICESAT	The Ice, Clouds, and Land Elevation Satellite	Ppart of NASA' Earth Observing System (EOS)	https://www.nasa.gov/mission_pages/icesat/
IPCC	Intergovernmental Panel on Climate Change	The international body for assessing the science related to climate change	http://www.ipcc.ch/

JAXA	The Japan Aerospace Exploration Agency		http://global.jaxa.jp/about/jaxa/index.html
JRC	Joint Research Centre	European Commission's science and knowledge service	https://ec.europa.eu/jrc/en/about/jrc-in-brief
LAI	Leaf Area Index	The total area of green leaves per unit area of ground covered. Usually expressed as a ratio. (Terminology for integrated resource planning and management, 1999 - X2079E)	http://www.fao.org/faoterm/en/?defaultCollId=1
Landsat 7 ETM +	Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	The Landsat Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat 7 satellite has acquired images of the Earth nearly continuously since July 1999, with a 16-day repeat cycle.	https://lta.cr.usgs.gov/LETMP
LIDAR	Light Detection And Ranging	A surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target.	https://en.wikipedia.org/wiki/Lidar
MaxEnt		Maxent software for modeling species niches and distributions by applying a machine-learning technique called maximum entropy modeling.	https://biodiversityinformatics.amnh.org/open_source/maxent/
MERRA	Modern-Era Retrospective analysis for Research and Applications	The Modern-Era Retrospective analysis for Research and Applications (MERRA) dataset was released in 2009. It is based on a version of the GEOS-5 atmospheric data assimilation system that was frozen in 2008. MERRA data span the period 1979 through February 2016 and were produced on a 0.5° × 0.66° grid with 72 layers. MERRA was used to drive stand-alone reanalyses of the land surface (MERRA-Land) and atmospheric aerosols (MERRAero).	https://gmao.gsfc.nasa.gov/reanalysis/MERRA/

MODIS	Moderate Resolution Imaging Spectroradiometer	MODIS is ideal for monitoring large-scale changes in the biosphere that are yielding new insights into the workings of the global carbon cycle. MODIS measures the photosynthetic activity of land and marine plants (phytoplankton) to yield better estimates of how much of the greenhouse gas is being absorbed and used in plant productivity. Coupled with the sensor's surface temperature measurements, MODIS' measurements of the biosphere are helping scientists track the sources and sinks of carbon dioxide in response to climate changes.	https://terra.nasa.gov/about/terra-instruments/modis
MODIS LST	MODIS Land Surface Temperature Products		https://lpdaac.usgs.gov/sites/default/files/public/product_documentation/mod11_user_guide.pdf
MODIS NBAR	MODIS Nadir BRDFAdjusted Reflectance	The MODIS MCD43A4 Version 6 Nadir Bidirectional reflectance distribution function Adjusted Reflectance (NBAR) data set is a daily 16-day product. The MCD43A4 provides the 500 meter reflectance data of the MODIS "land" bands 1-7 adjusted using the bidirectional reflectance distribution function to model the values.	https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mcd43a4_v006
MVC	Maximum value composite	A maximum-value composite procedure (or MVC) is a procedure used in satellite imaging, which is applied to vegetation studies. It requires that a series of multi-temporal geo-referenced satellite data be processed into NDVI images. On a pixel-by-pixel basis, each NDVI value is examined, and only the highest value is retained for each pixel location. After all pixels have been evaluated, the result is known as an MVC image.[1]	https://en.wikipedia.org/wiki/Maximum-value_composite_procedure
NDVI	Normalized difference vegetation index	The normalized difference vegetation index (NDVI) is a simple graphical indicator that can be used to analyze remote sensing measurements, typically, but not necessarily, from a space platform, and assess whether the target being observed contains live green vegetation or not.	https://en.wikipedia.org/wiki/Normalized_difference_vegetation_index

NOAA	National Oceanic and Atmospheric Administration		
NPP	Net Primary Productivity	How much carbon dioxide vegetation takes in during photosynthesis minus how much carbon dioxide the plants release during respiration (metabolizing sugars and starches for energy).	https://earthobservatory.nasa.gov/global-maps/MOD17A2_M_PSN
PALSAR	Phased Array type L-band Synthetic Aperture Radar	An active microwave sensor using L-band frequency to achieve cloud-free and day-and-night land observation. It provides higher performance than the JERS-1's synthetic aperture radar (SAR).	https://www.eorc.jaxa.jp/ALOS/en/about/palsar.htm
QSCAT	Quick Scatterometer	A SeaWinds instrument placed in orbit quickly was launched in June 1999 and operated until November 2009. SeaWinds scatterometers are essentially radars that transmit microwave pulses down to the Earth's surface and then measure the power that is returned back to the instrument. This "backscattered" power is related to surface roughness. For water surfaces, the surface roughness is highly correlated with the near-surface wind speed and direction. Hence, wind speed and direction at a height of 10 meters over the ocean surface are retrieved from measurements of the scatterometer's backscattered power.	http://www.remss.com/missions/qscat/
SAR	Synthetic Aperture Radar	Synthetic Aperture Radar (SAR) refers to a technique for producing fine resolution images from an intrinsically resolution-limited radar system.	https://nisar.jpl.nasa.gov/technology/sar/
Soil organic carbon		Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series.	Terms and Definitions - FRA 2020, FAO, 2018 (http://www.fao.org/3/I8661EN/i8661en.pdf).
SRTM	Shuttle Radar Topography Mission	High resolution topographic data generated from NASA's Shuttle Radar Topography Mission.	https://www2.jpl.nasa.gov/srtm/