ZFC Biomass Mapping Documentation

Release 0

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Contents

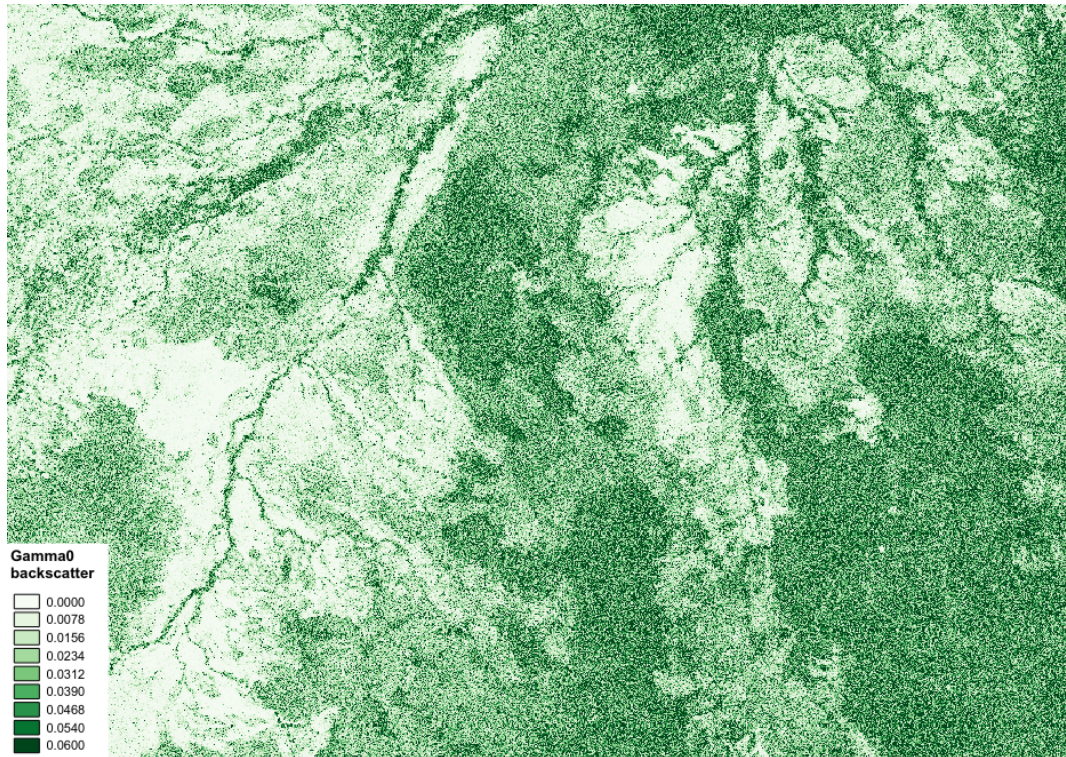Remote sensing in African woodlands is unusually difficult: woodlands and forest are very heterogeneous, trees and grasses have strong and unpredictable phenological effects, and fires occur frequently. Together these can render standard methods of land cover/use/change mapping with optical data ineffective. However, there are opportunities in freely available long-wavelength radar data for mapping forest properties, bypassing many of these obstacles.

Long wavelength radar data are a long-established method of generating maps of forest AGB in woodlands and dry forests. Until recently such data has been expensive, but free data are now available from JAXA's ALOS-1 and ALOS-2 L-band sensors (2007 – 2010, 2015 – onwards), which offer a relatively straightforward means to generate maps of AGB in woodlands and forests with AGB of up to around 150 tonnes per hectare.

In this tutorial we'll run through an example of using freely available L-band radar mosaics to produce biomass and biomass change maps in Zimbabwe.

Contents

1.1 Theoretical basis

1.1.1 What is radar?

RAdio Detection And Ranging (radar) operates by transmitting a microwave signal (with wavelength from 1 centimetre to several meters) towards a target and measuring the returned radiation (backscatter). Synthetic aperture radar (SAR) instruments use a satellite to generate images of large areas at high resolution. Radar imaging is not affected by cloud cover, and as radar instruments provide their own energy source they can operate at day or night. The magnitude of backscatter recorded by a SAR instrument is influenced by properties of the transmitted radiation, such as its wavelength, polarisation (orientation), and incidence angle, and the properties of the reflecting surface, such as its geometric structure, surface roughness and water content, and the interaction between the transmitted radiation and surface properties.

For example, this is a radar image from the Sentinel-1 satellite of Harare:

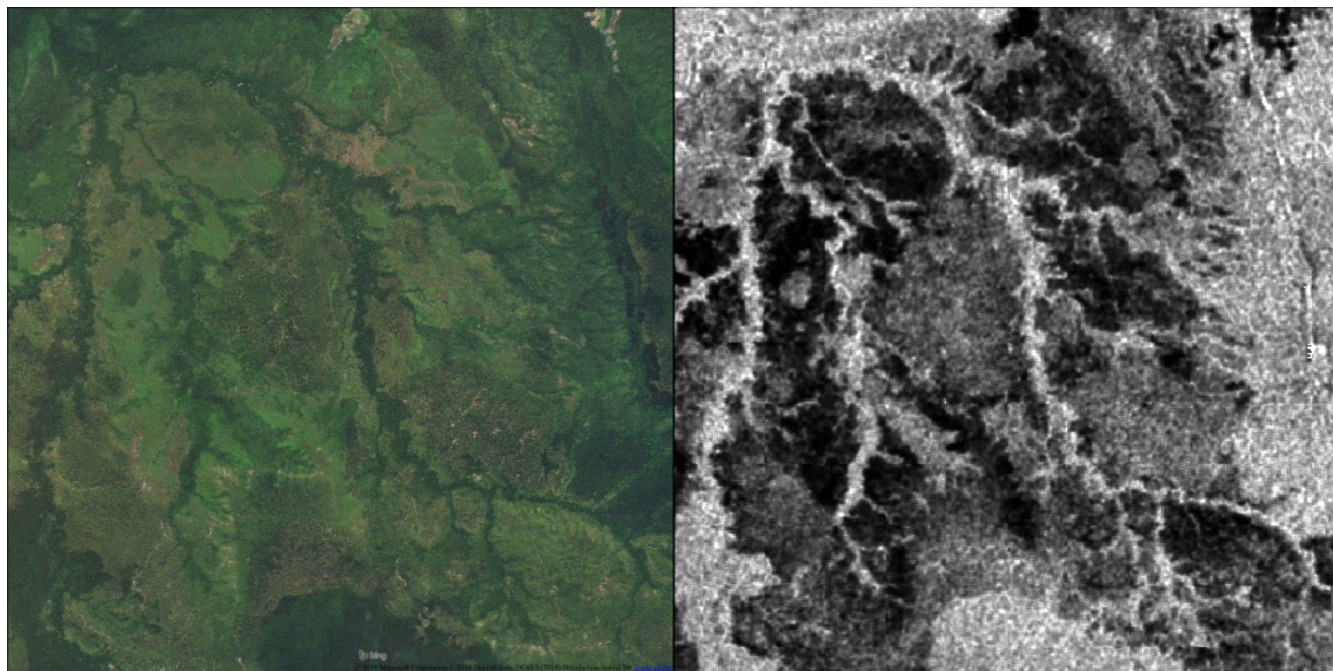### 1.1.2 Mapping biomass with L-band radar

Radar satellites are active sensors that look obliquely at the Earth's surface using microwave data (in the mm –cm wavelength range). The microwave radiation generated by radar instruments can penetrate through the forest canopy to obtain information on forest structure, with the amount of radiation scattered back to theinstrument ('backscatter') increasing as the number and/or size of trees present in an area increases. Therefore radar satellites have been used to map aboveground biomass, and to map changes in biomass.

Measurement of aboveground biomass with radar is limited by a saturation point, typically round 150 tonnes per hectare aboveground biomass for L-band (the longest, and therefore most sensitive, wavelength currently available), and ~50 tonnes per hectare for C-band (which is more widely available). The saturation point of L-band radar is higher than is typically reached by vegetation in southern Africa (including Zimbabwe), making it a powerful means of quantifying aboveground biomass.

The relationship between L-band backscatter and aboveground biomass can be determined by calibrating radar backscatter using points of known aboveground biomass, such as forest inventory plots. For example, the following calibration function was generated using plot inventory data and backscatter from L-band radar in southeastern Tanzania:
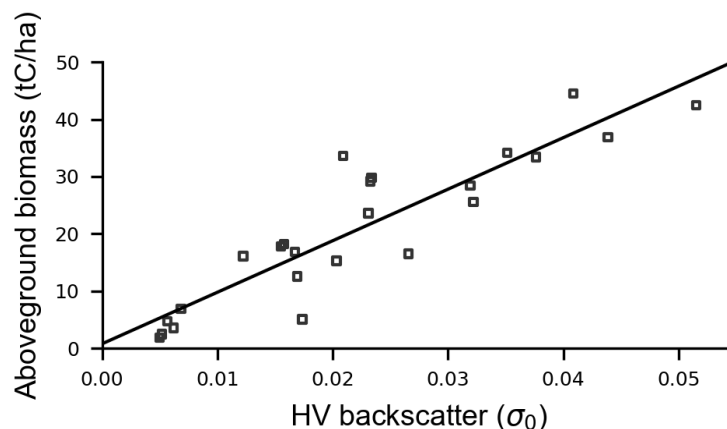
To see what this means in in practice, it helps to consider the problem visually. In the left image we see a high resolution image of an area of diverse vegetation cover in the same regon of southeastern Tanzania, and on the right the same area as measured with a radar instrument known as ALOS PALSAR. Greater backscatter is indicated by whiter colours, showing a clear distinction between open grasslands and agriculture, woodlands, and denser forests:

1.1.3 Change detection with L-band radar

By comparing biomass maps from two time periods, it's possible to use repeated radar data to detect changes. For instance, it has been used to map changes in biomass over miombo woodland in Mozambique, showing areas of increasing (blue) and decreasing (red) biomass with high accuracy:
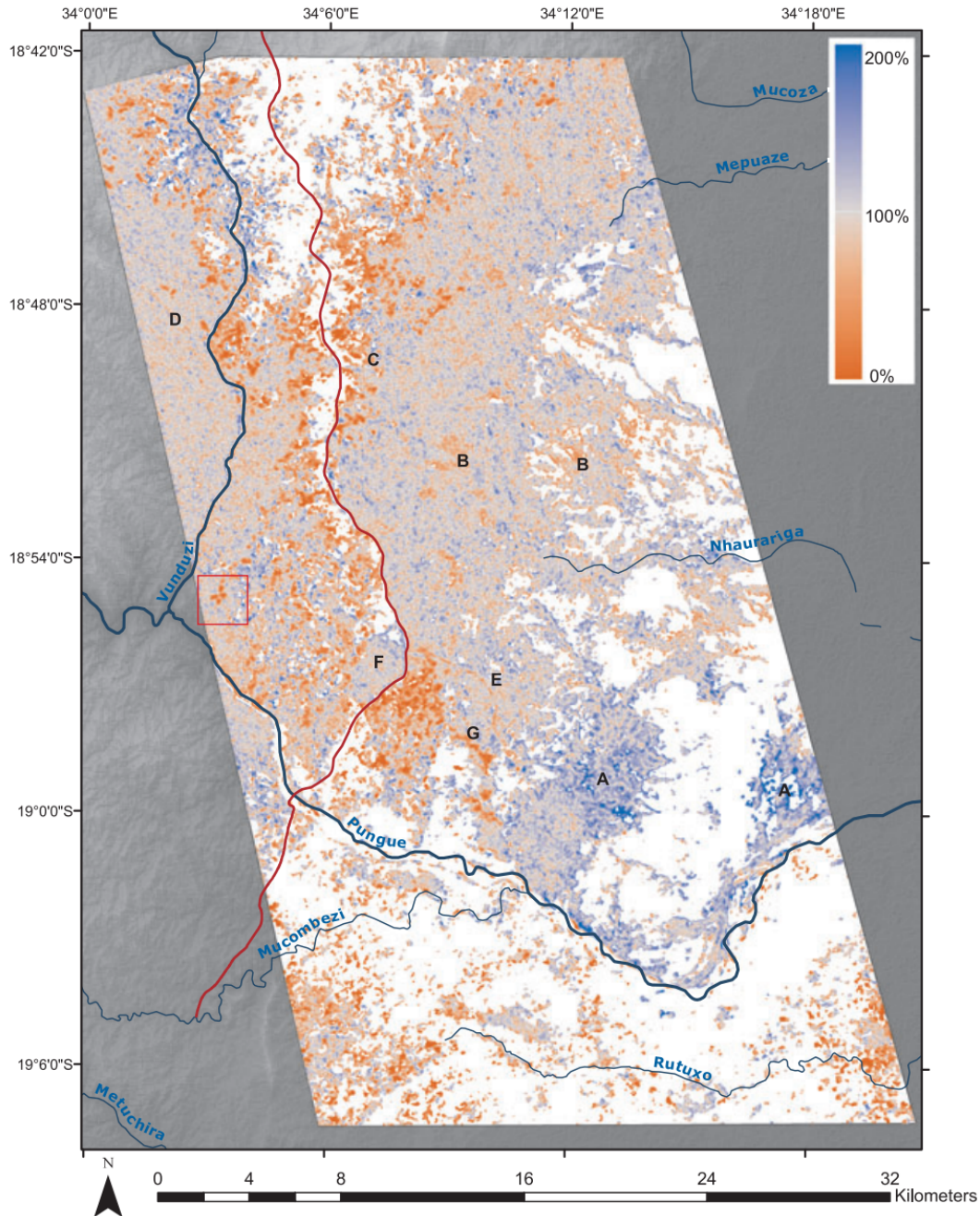
Change detection in this manner is not problem-free. Radar backscatter is also sensitive to vegetation and soil moisture changes, so a change in radar backscatter can also result from rainfall or flooding. Further to this, radar data usually appear very noisy (due an affect known as radar speckle), which results in random increases or decreases in radar backscatter that are unrelated to changes in vegetation structure. Together, this means that radar imagery need to be carefully processed in order to produce reliable change maps.

1.1.4 Further reading

For further reading, see the following scientific publications:

1. Ryan, Casey M., et al. "Quantifying small-scale deforestation and forest degradation in African woodlands

using radar imagery." Global Change Biology 18.1 (2012): 243-257.

2. McNicol, Iain M., Casey M. Ryan, and Edward TA Mitchard. "Carbon losses from deforestation and widespread degradation offset by extensive growth in African Woodlands." Nature communications 9.1 (2018): 3045.

3. Mitchard, Edward TA, et al. "Using satellite radar backscatter to predict above-ground woody biomass: A consistent relationship across four different African landscapes." Geophysical Research Letters 36.23 (2009).

4. Bouvet, Alexandre, et al. "An above-ground biomass map of African savannahs and woodlands at 25 m resolution derived from ALOS PALSAR." Remote sensing of environment 206 (2018): 156-173.

1.2 QGIS Setup

Note: If you have already installed QGIS, you can skip this section.

1.2.1 What is QGIS

QGIS is a desktop Geographic Information System (GIS) application that supports viewing, editing and analysis of geospatial data. QGIS is free and open source, and offers a viable alternative to commercial software such as ArcGIS.

We'll be using QGIS to visualise and manipulate radar data from ALOS-1.

1.2.2 Downloading QGIS

You can download QGIS from the QGIS website. Make sure you choose the correct version, which is **Long term release, QGIS Standalone Installer** for Windows. Most users will require the 64-bit version, but if you're have an older laptop you might need to download the 32-bit version.

If you're struggling to find the correct version, you can also download it (Windows, 64-bit) directly here (392 MB).

Note: Are you using Linux or Mac, you may need to download a different version to that above. If accessing this large volume of data is a problem, we'll bring along copies of QGIS to the workshop for you to install.
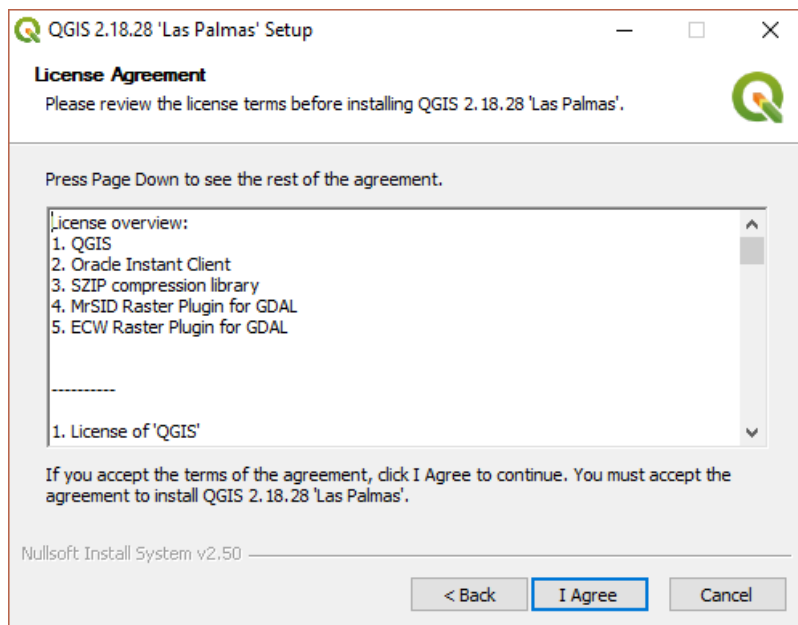
1.2.3 Installing QGIS

Once the download is complete, navigate to your `Downloads` folder, and run the executable named `QGIS-OSGeo4W-2.18.28-1-Setup-x86_64.exe` (or similar).
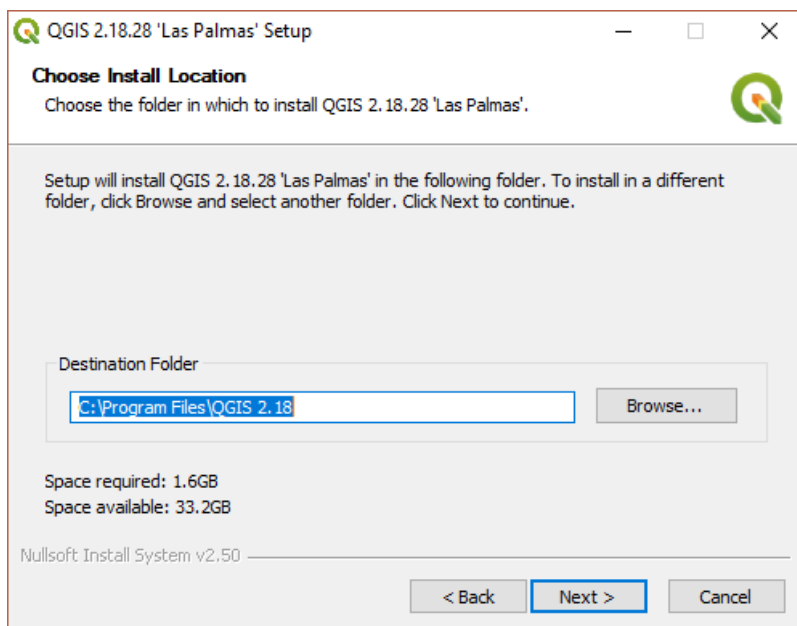
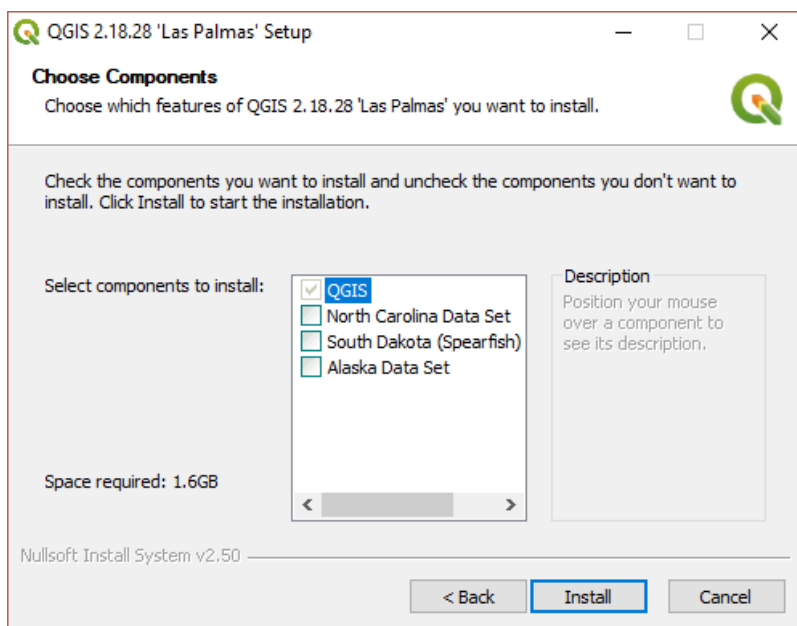This will open the QGIS installer. You can accept all default settings. Click Next:
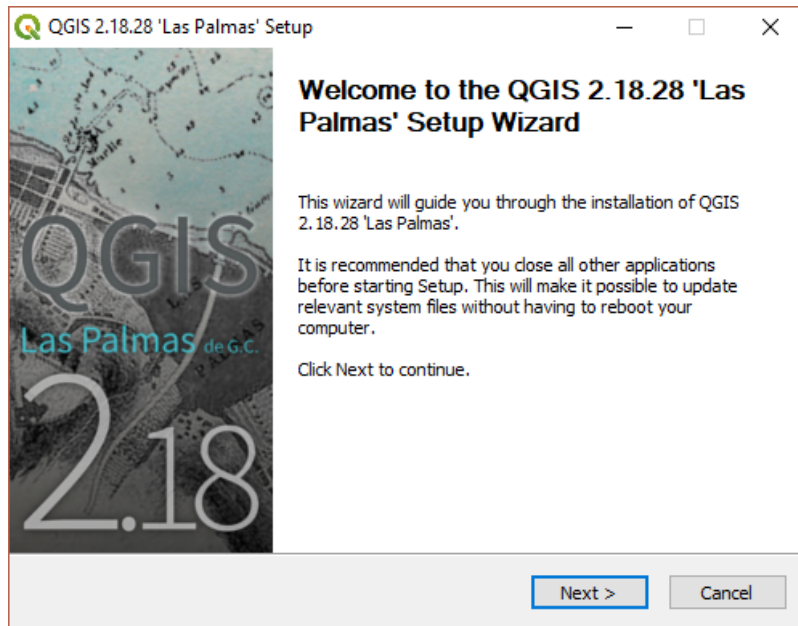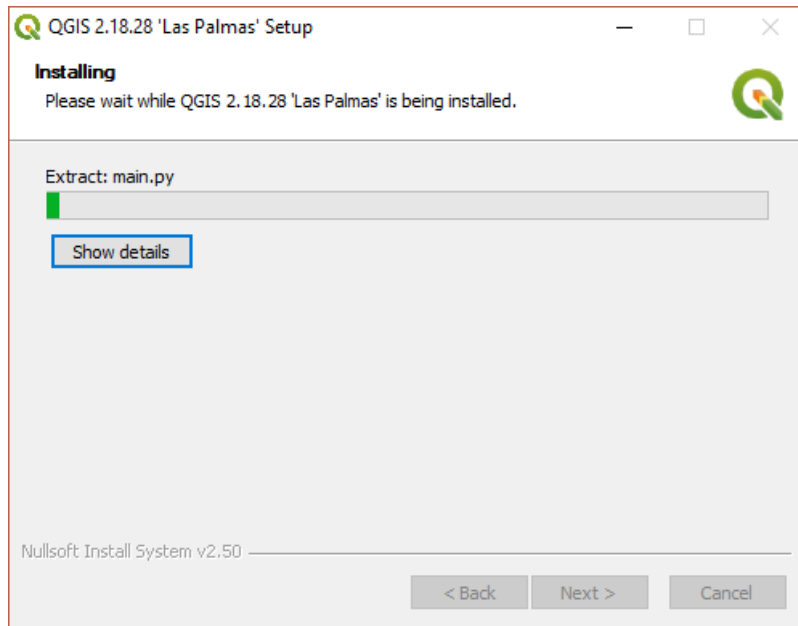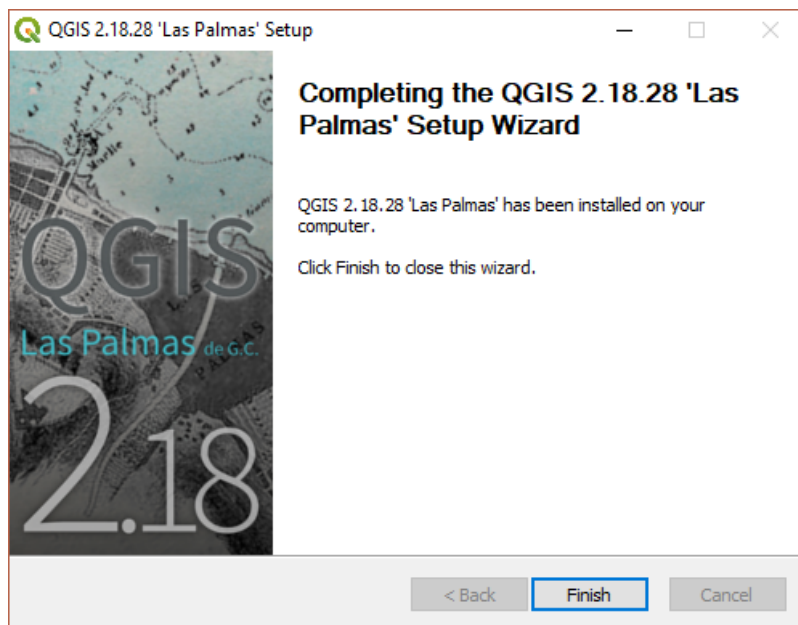
Then 'I Agree':

Then Next:

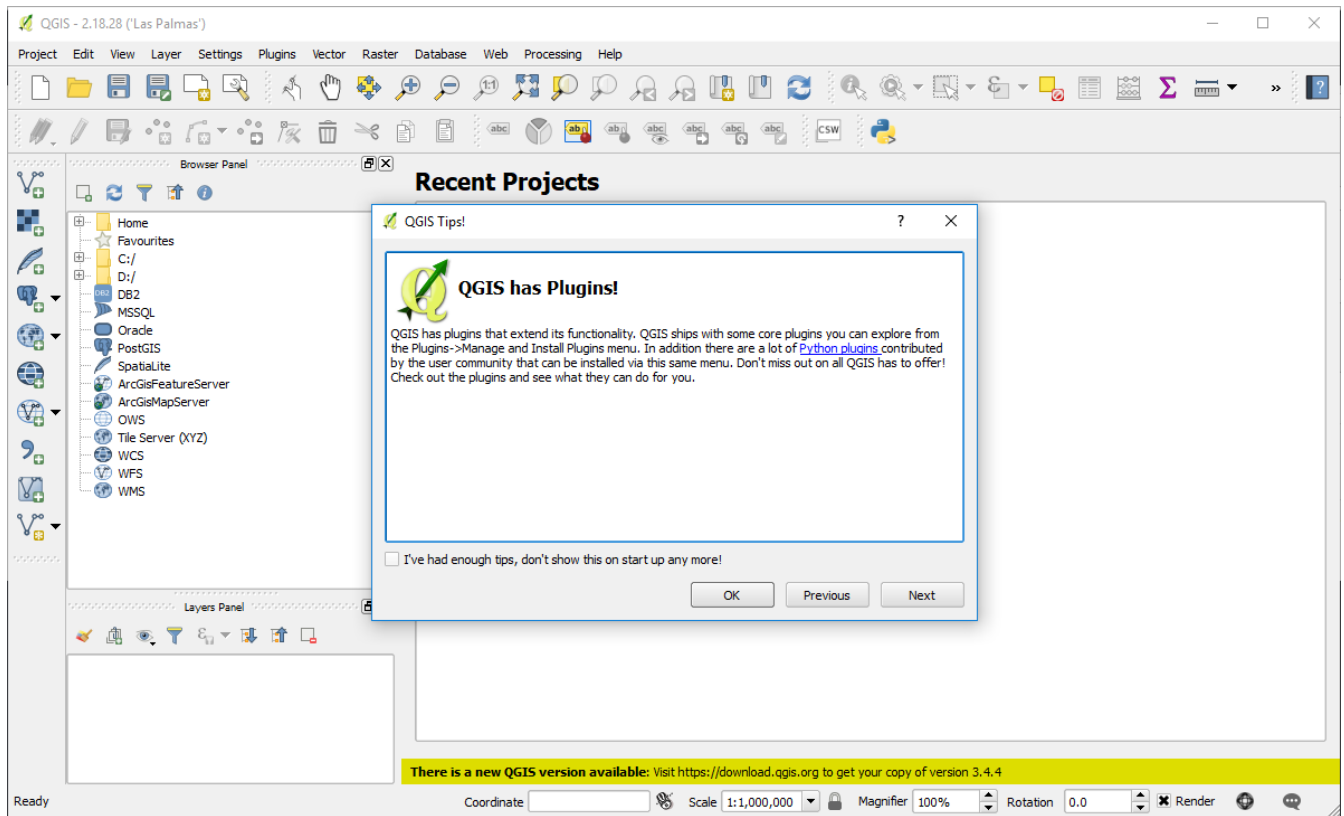Then Install:

...and wait until the installation is complete:

Press Finish to complete the installation.

1.2.4 Running QGIS

To run QGIS, navigate to your install through the start menu, and Run `QGIS Desktop 2.18.28` or similar.

If your installation is successful, you should see an interface that looks something like the following:

1.2.5 Installation problems?

If something isn't working for you, please feel free to get in touch with sam.bowers@ed.ac.uk.

1.3 Mapping aboveground biomass

Here we'll load data from ALOS PALSAR from the year 2007 from near the town of Kadoma in Zimbabwe to show the approach required to make a biomass and a biomass change map.

1.3.1 Downloading data

Data from the ALOS mosaic are freely available (for non-commercial use) in 1x1 degree tiles. For the purposes of this tutorial, we'll use the tile at -18 degrees latitude, 29 degrees longitude.

Download the tile here: `S18E029.zip` (142 MB).

Once the download is complete, unzip and put them in a memorable location (e.g. `Desktop`).

1.3.2 Loading data in QGIS

To add data to QGIS, first click the 'Add Raster Layer' button:

Navigate to the unzipped `S18E029` folder, where you'll find two further folders. The folder `S18E029_07_MOS` contains data from 2007, `S18E029_10_MOS` contains data from 2010. We'll start with 2007.
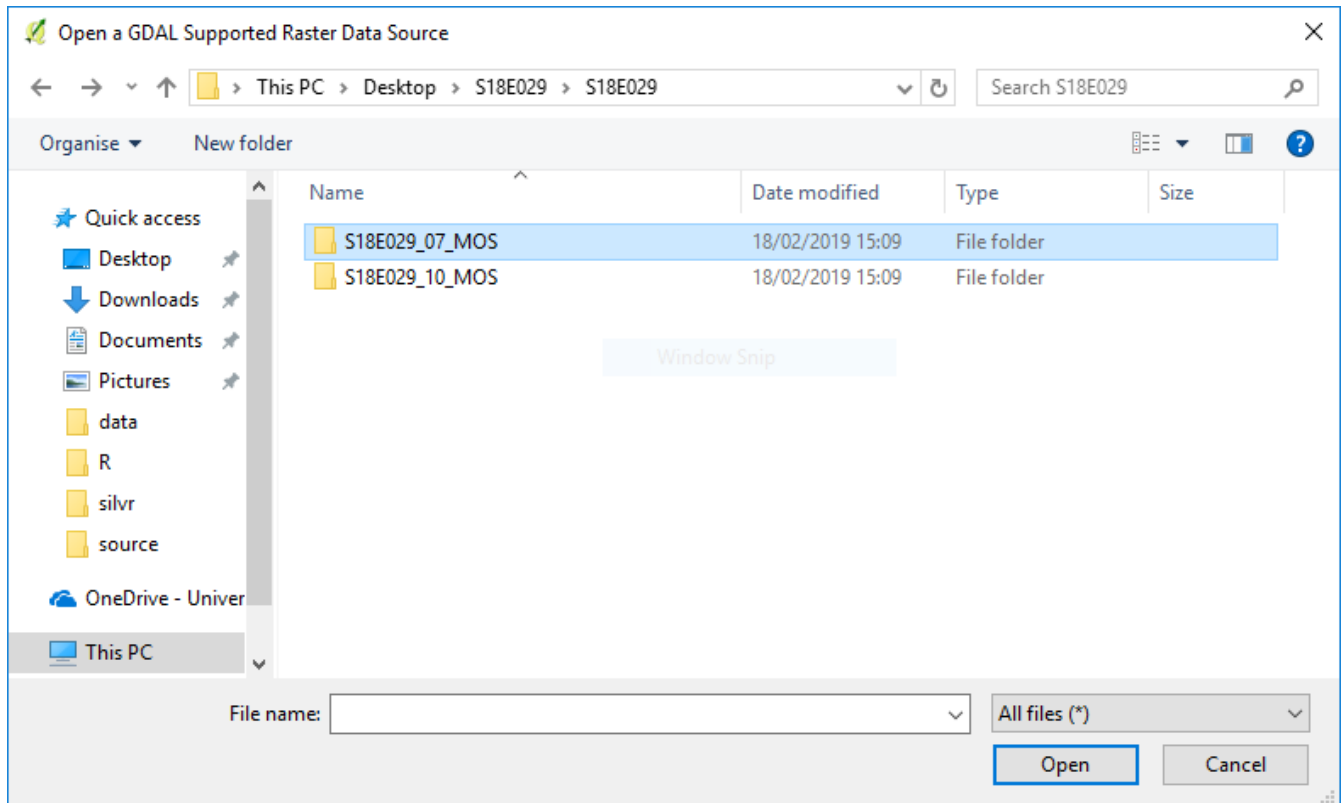

Inside `S18E029_07_MOS` you'll find multiple raster files. These describe:

Filename	What does it show?
S18E029_07_date	Image acquisition date
S18E029_07_linci	Local incidence angle
S18E029_07_mask	Masked values (e.g. water, mountainous terrain)
S18E029_07_HH	HH backscatter
S18E029_07_HV	HV backscatter (best for biomass mapping)

See https://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/fnf_index.htm for more details.

We'll be using `S18E029_07_HV`, which contains what's known as cross-polarised backscatter values, which are generally the most sensitive to differences in aboveground biomass.
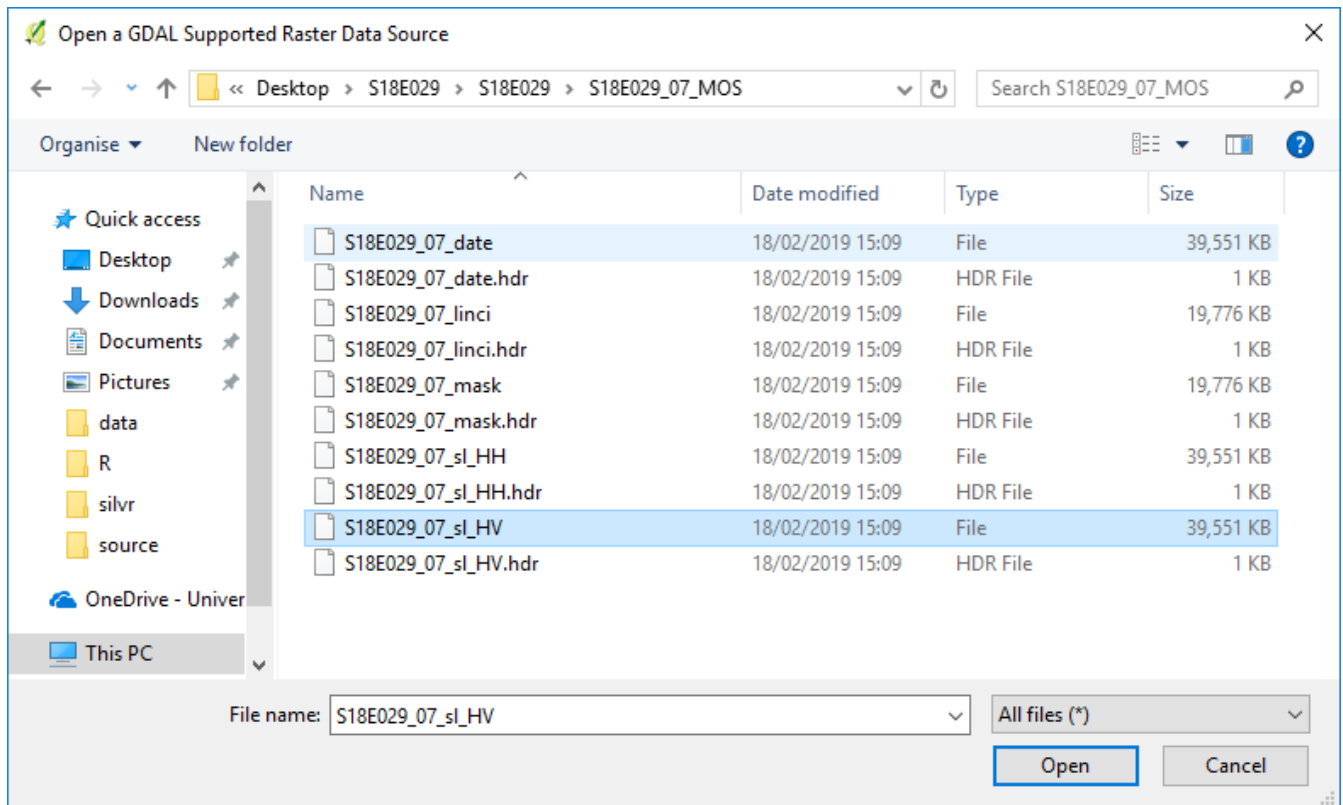
Click Open, and the image show show on the map canvas.
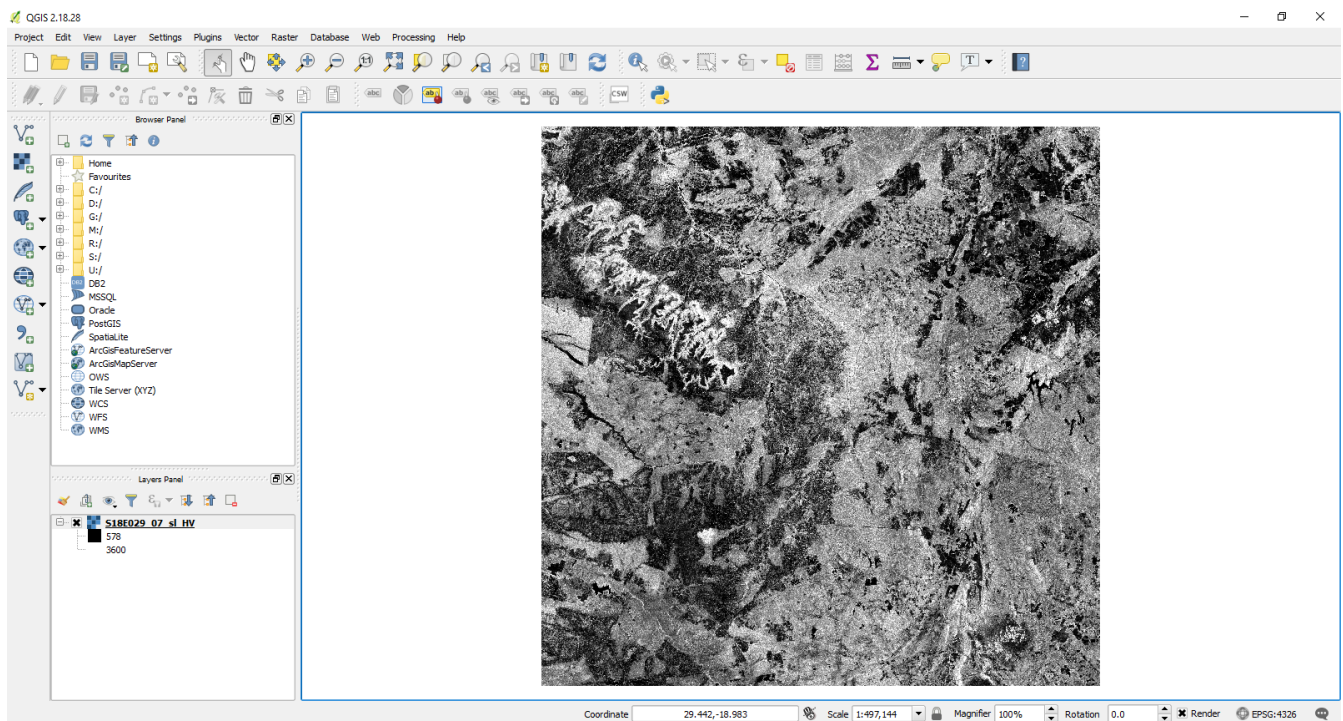
Take some time to explore the image. Can you recognise any features? What land cover types are associated with high backscatter values?
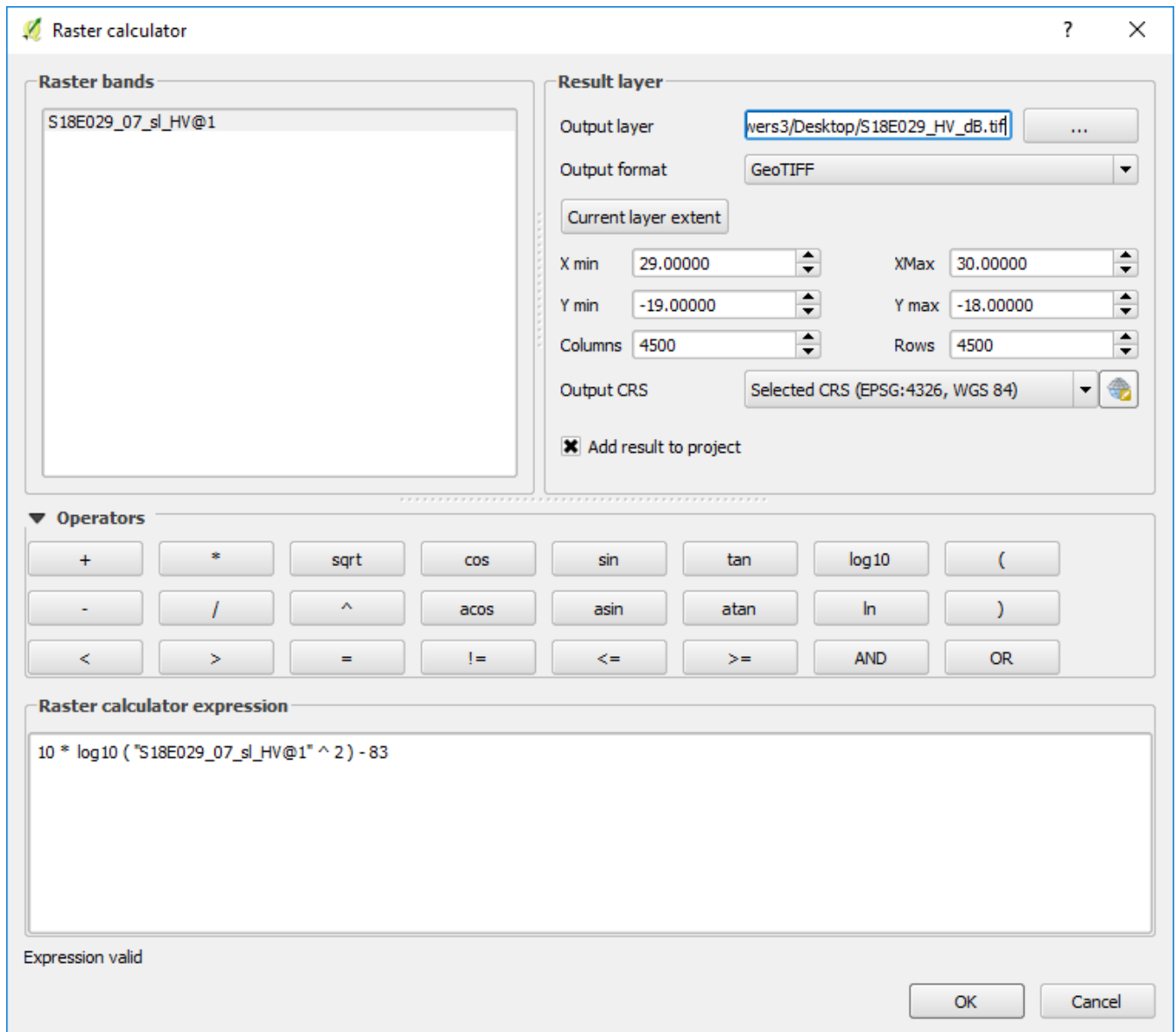
1.3.3 Calibration of radar backscatter

Data from the ALOS mosaic are provided as integers (whole numbers) for efficient storage. The first step of calibration requires converting these values to standard units of radar backscatter, which are decibels. This is done with the following equation:

$$\gamma_{0(decibels)} = 10log_{10}(DN^2) - 83.0dB$$

To perform this operation in QGIS, go to the `Raster` menu and select `Raster calculator`. In this interface you can slect mathematical operators and rater layers by clicking them. Input the equation as follows, and specify an appropriate output name (e.g. `S18E029_HV_dB.tif`):

Click `OK` when ready, and after processing is complete the image will be loaded into the canvas:


The units of this image are decibels, which is a logarithmic measure of radar backscatter. For our purposes here we've calibrated a biomass backscatter relationship in linear units, To convert to linear units (or 'natural' units), open the

raster calculator once again and perform the following operation:

$$\gamma_{0(natural)} = 10^{(\gamma_{0(decibels)}/10)}$$

which can be input with the raster calculator as follows. Give the output image a sensible name (e.g. `S18E029_HV_natural.tif`):
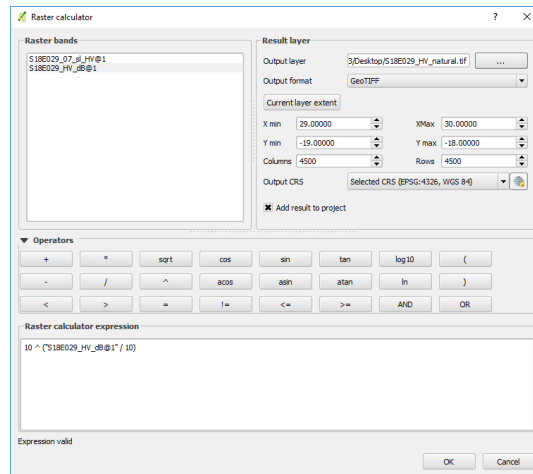
This will produce an image with values between 0 and ~0.06. If your image has a different range, carefully check your previous steps.

1.3.4 Calibration to aboveground biomass

The final step is to convert these radar backscatter values to units of aboveground biomass. The best way to do this is to produce a local calibration equation based on large (> 0.5 ha) forest inventory plots that cover a wide range of biomass, but it's also possible to use a generic equation where local data aren't available

Here we'll use a generic equation from McNicol et al. (2018) applicable to southern Africa, which is:

$$AGB = 715.667 * \gamma_{0(natural)} - 5.967$$

Using the raster calculator and with an appropriate output name (e.g. `S18E029_AGB_2007.tif`), produce a map of aboveground biomass:
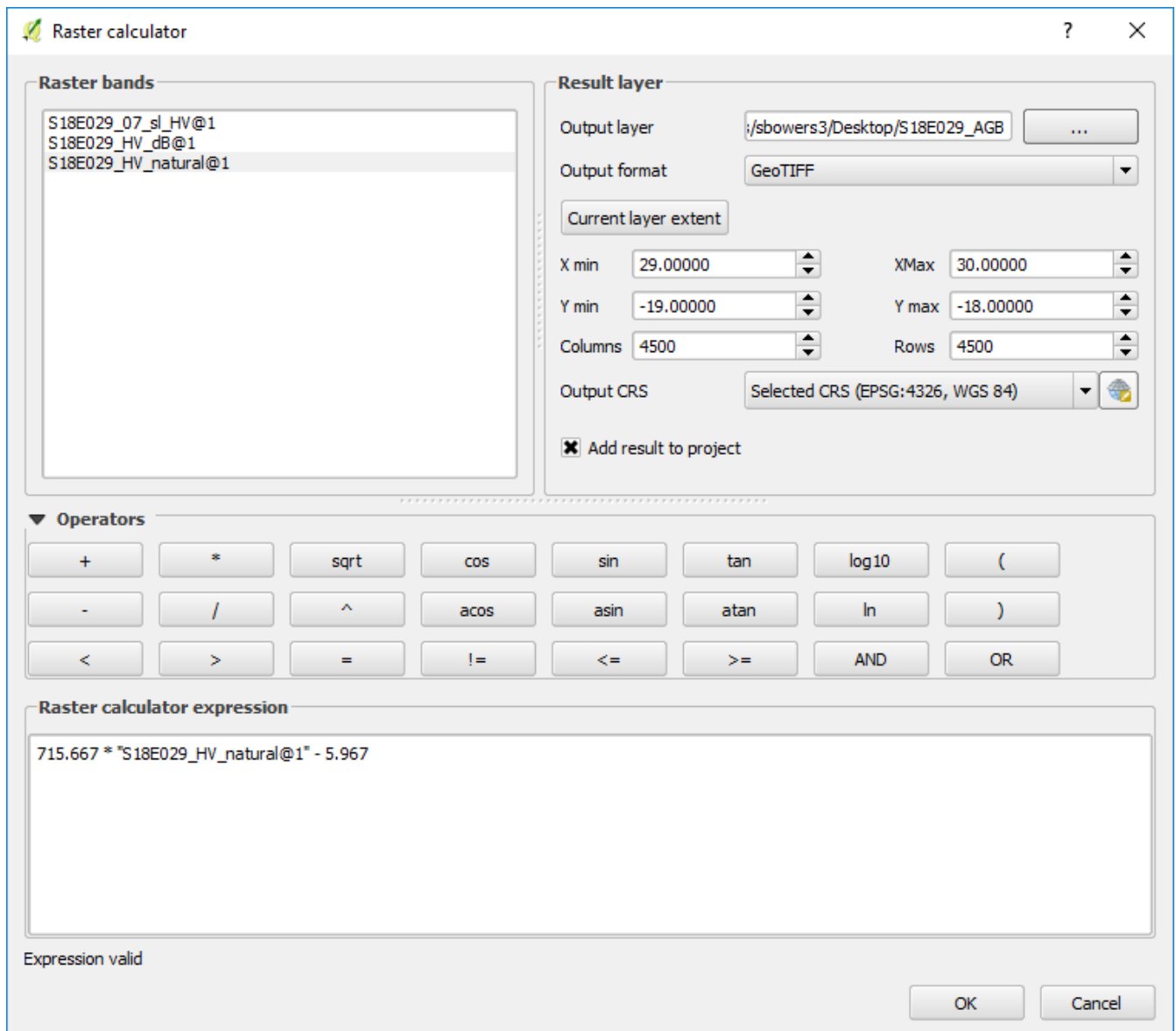
Your output image should have values from around 0 - 40 tC/ha.

1.3.5 Visualisation

At present the image you've produced shows in black and white, which can be difficult to interpret. Double-click on your AGB layer in the `Layers Panel`, and change `Render type` to `Singleband pseudocolor`. Choose an appropriate colour range from the `Color` pull-down menu (e.g . `YlGn`), and press `OK` to apply:
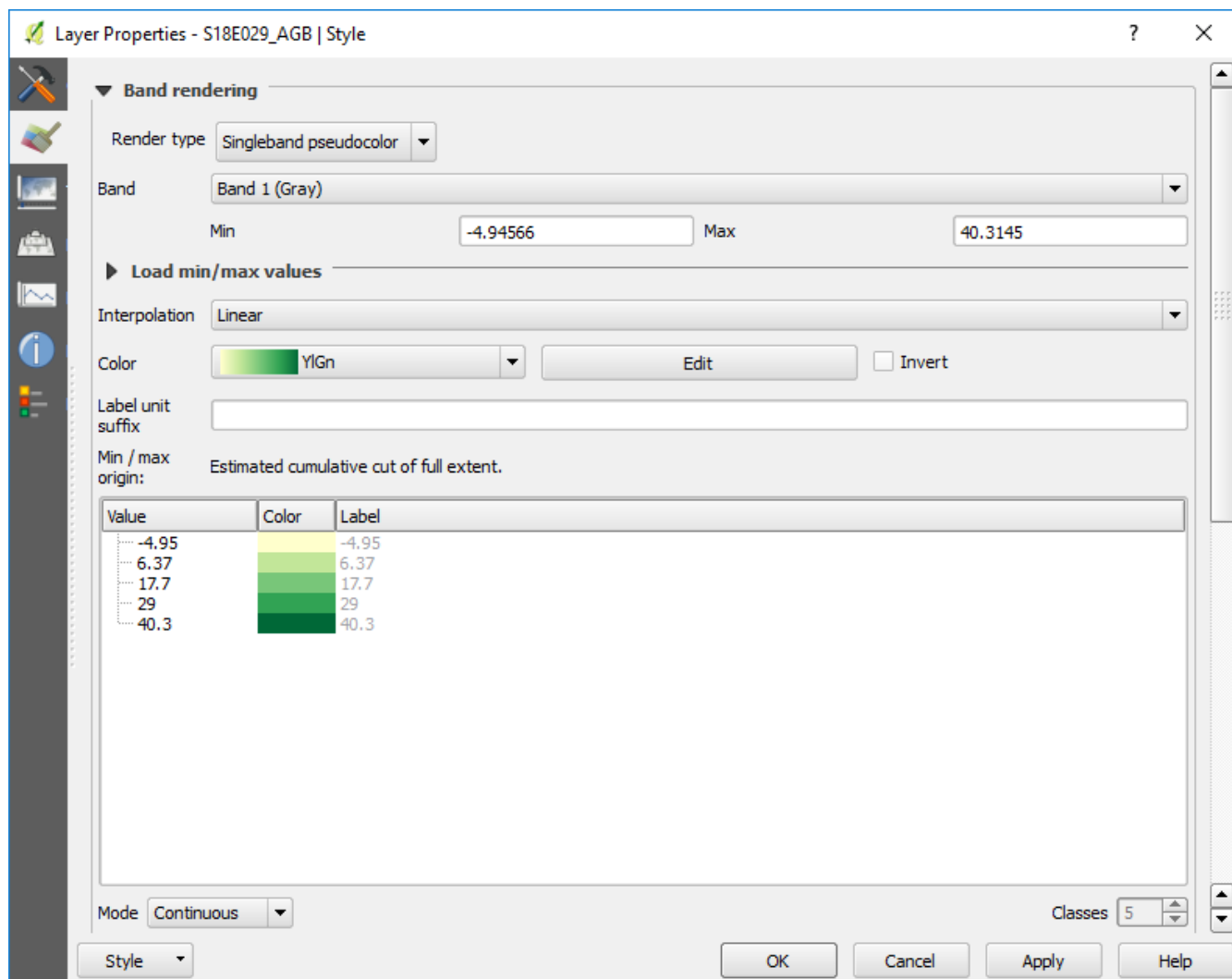
This will change the colours of the image to make it clearer how forest biomass varies across the image:
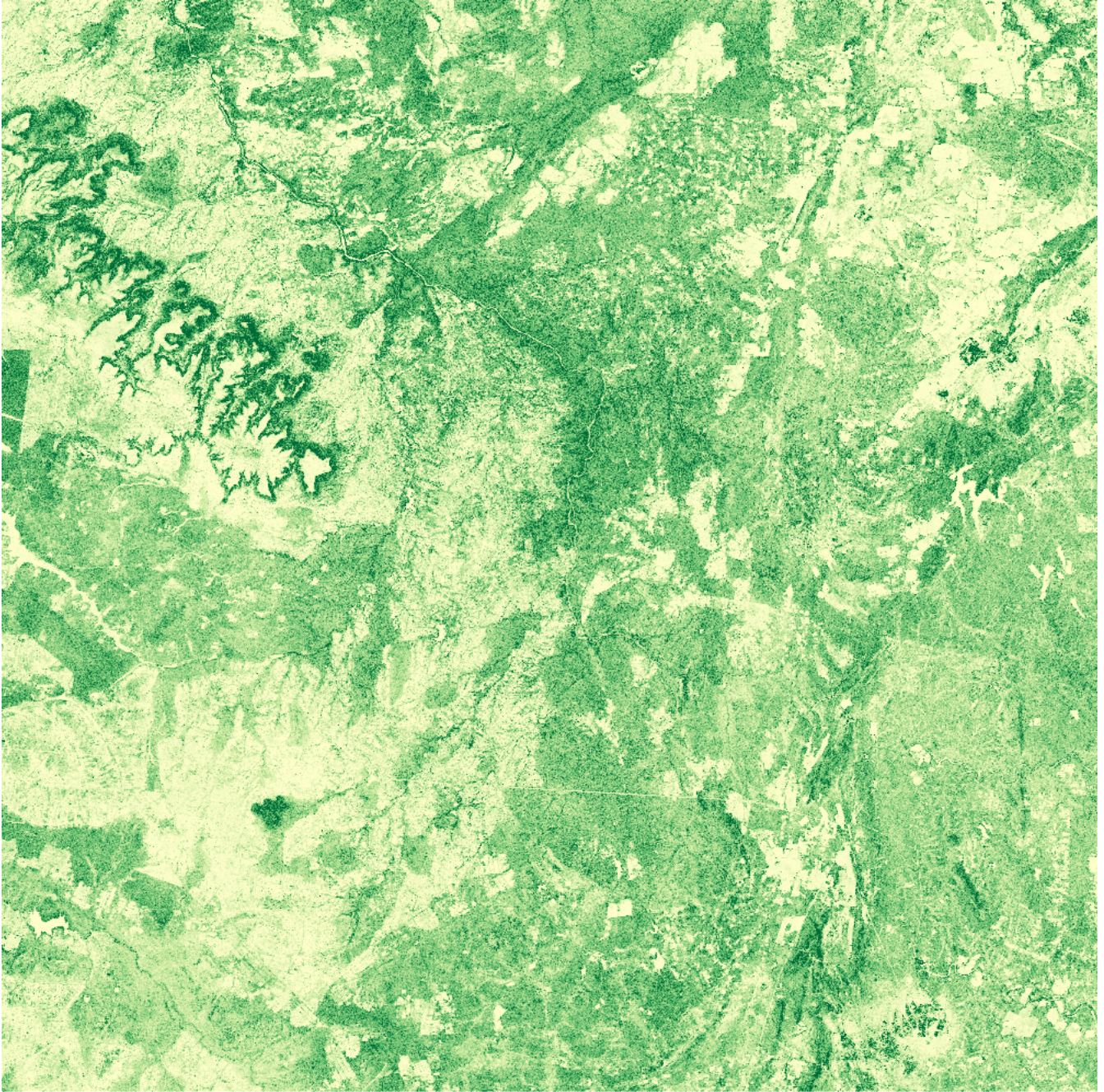
Congratulations, you've created a map of aboveground biomass!

Take some time to explore the image. What factors do you think are impacting the distribution of aboveground biomass?

1.4 Identifying change

As well as producing static biomass maps, we can use L-band radar backscatter data to produce estimates of biomass change. We do this using multiple snapshots of the same location, and taking a difference image.

1.4.1 Loading data from 2010

Return to the `S18E029` directory and repeat the procedure for 'Mapping aboveground biomass', but this time using the data from 2010.

Save the resultant image as something readily identifiable (e.g. `S18E029_AGB_2007.tif`).

Once you're done, you should have two biomass maps, one for 2007 and one for 2010. Set an identical colour map and scale for these two images and flip between them.

1. Can you spot any locations where aboveground biomass has changed?

2. What are the likely causes of these changes?

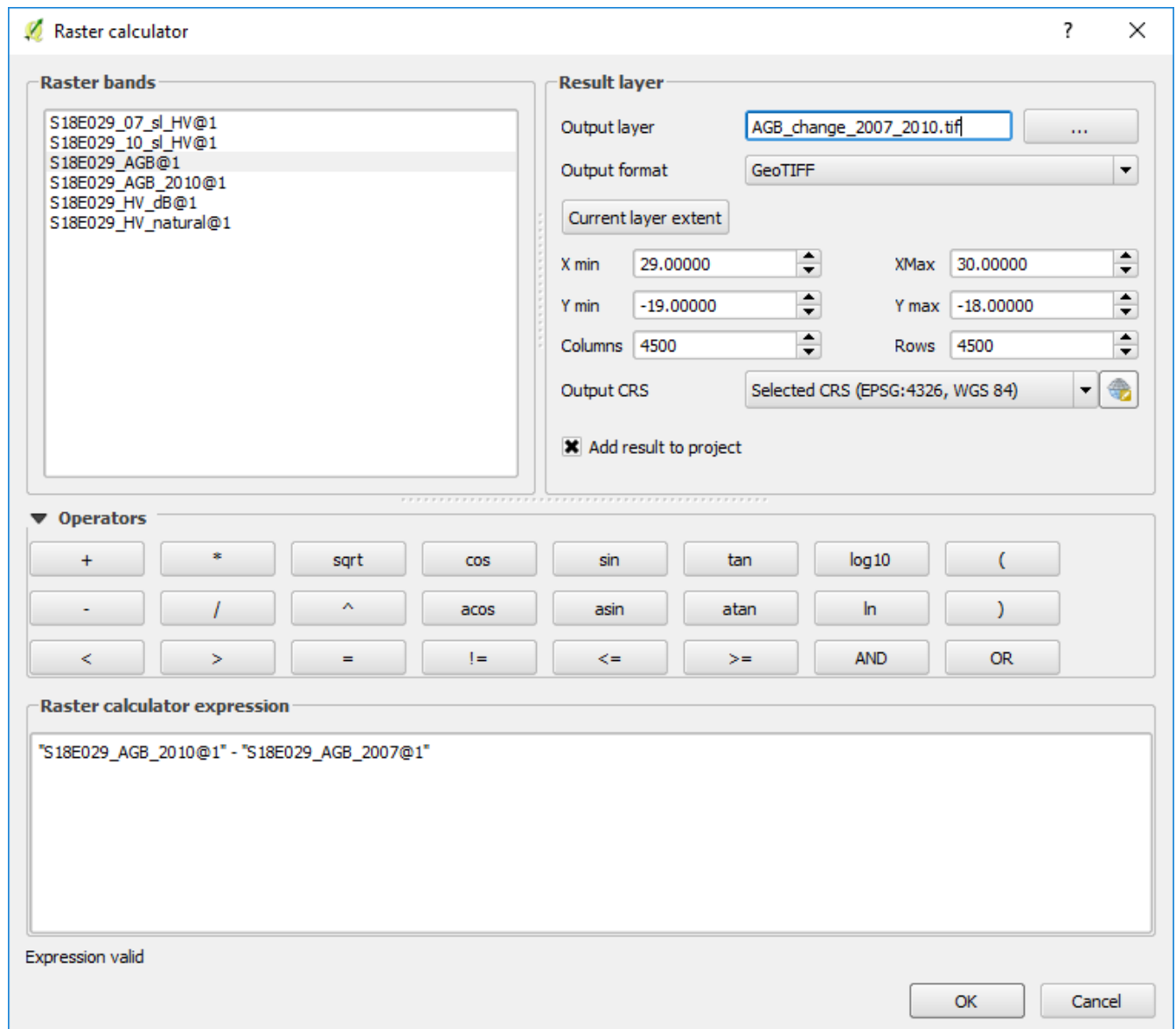3. Can you spot any changes that probably aren't related to forest loss?

1.4.2 Calculating a difference image

Another way to consider change is to subtract one image from the other. Where values are negative, biomass has been lost, and where positive, biomass has been gained.
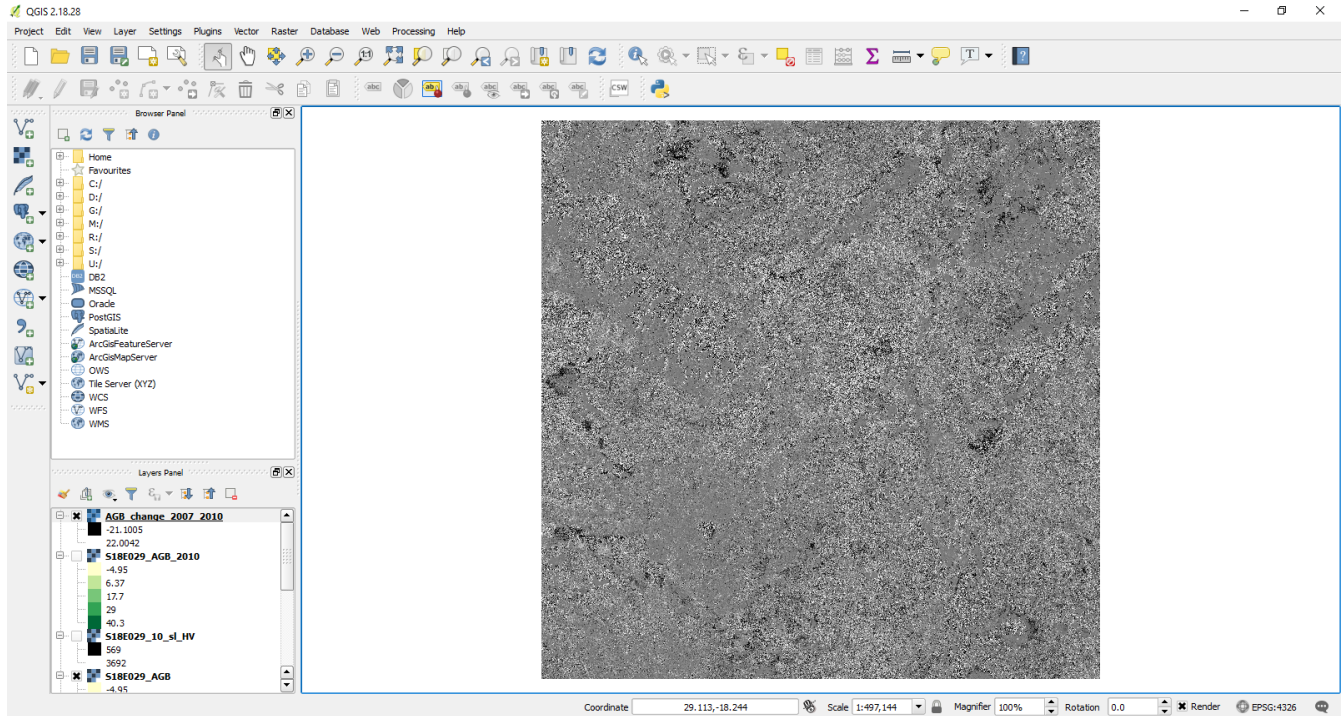
Perform the following operation:

$$AGB_{change} = AGB_{2010} - AGB2007$$

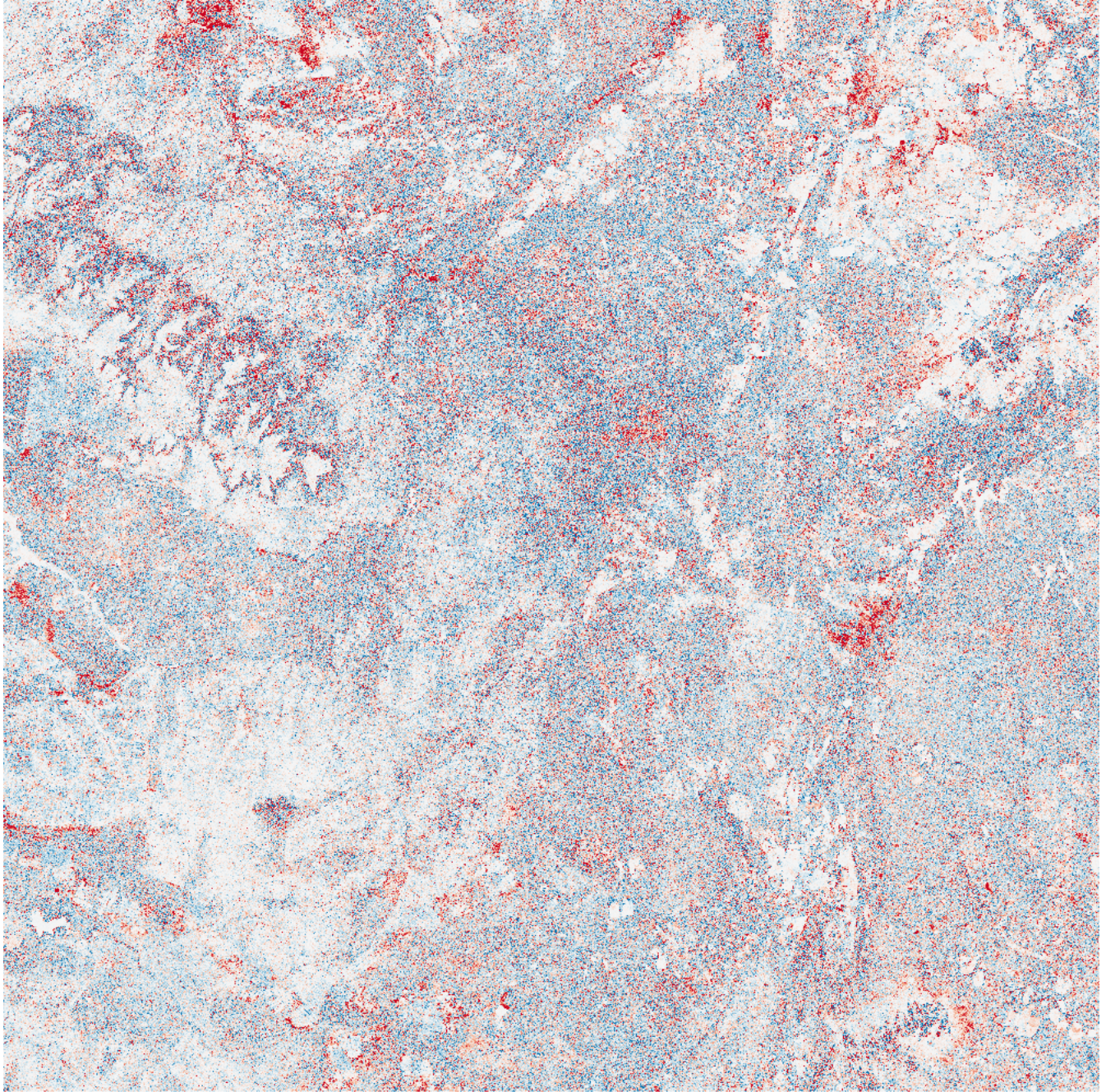. . . using the raster calculator:

The resulting image shows areas of biomass loss in black, and areas of gain in white.

1.4.3 Visualisation

We can improve visualisation of this image using different color maps and limits. Here's my effort, which shows biomass losses in red and biomass gains in blue:

Try and experiment to find the best combination.

Advanced: Try to mask out areas of low biomass (e.g. < 10 tC/ha), which can improve the interpretabiltiy of the image.

1.4.4 Building a simple deforestation map

By making some assumptions, we can produce a map of deforestation. For example, we could assume that all areas that lost more than 20 tC/ha over the period 2007 - 2010 were deforested. This can be programmed into the raster calculator as follows:
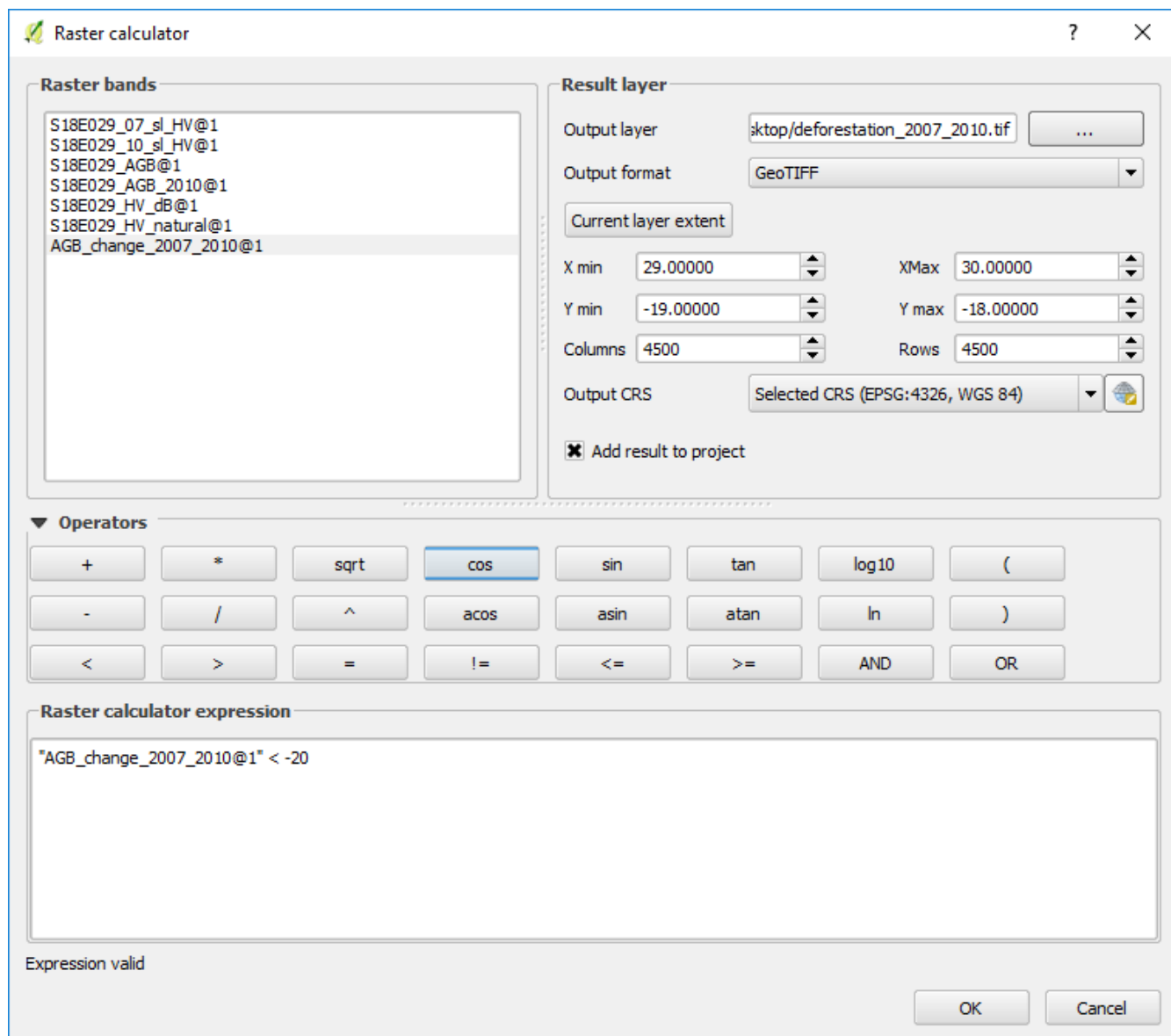
In this image, pixels with value 1 show deforestation, and pixels with value 0 show no change. If we give pixels of value 1 a red colour, set 0 to transparent, and overlay it on the 2007 biomass map, we can identify locations of forest loss. For example:
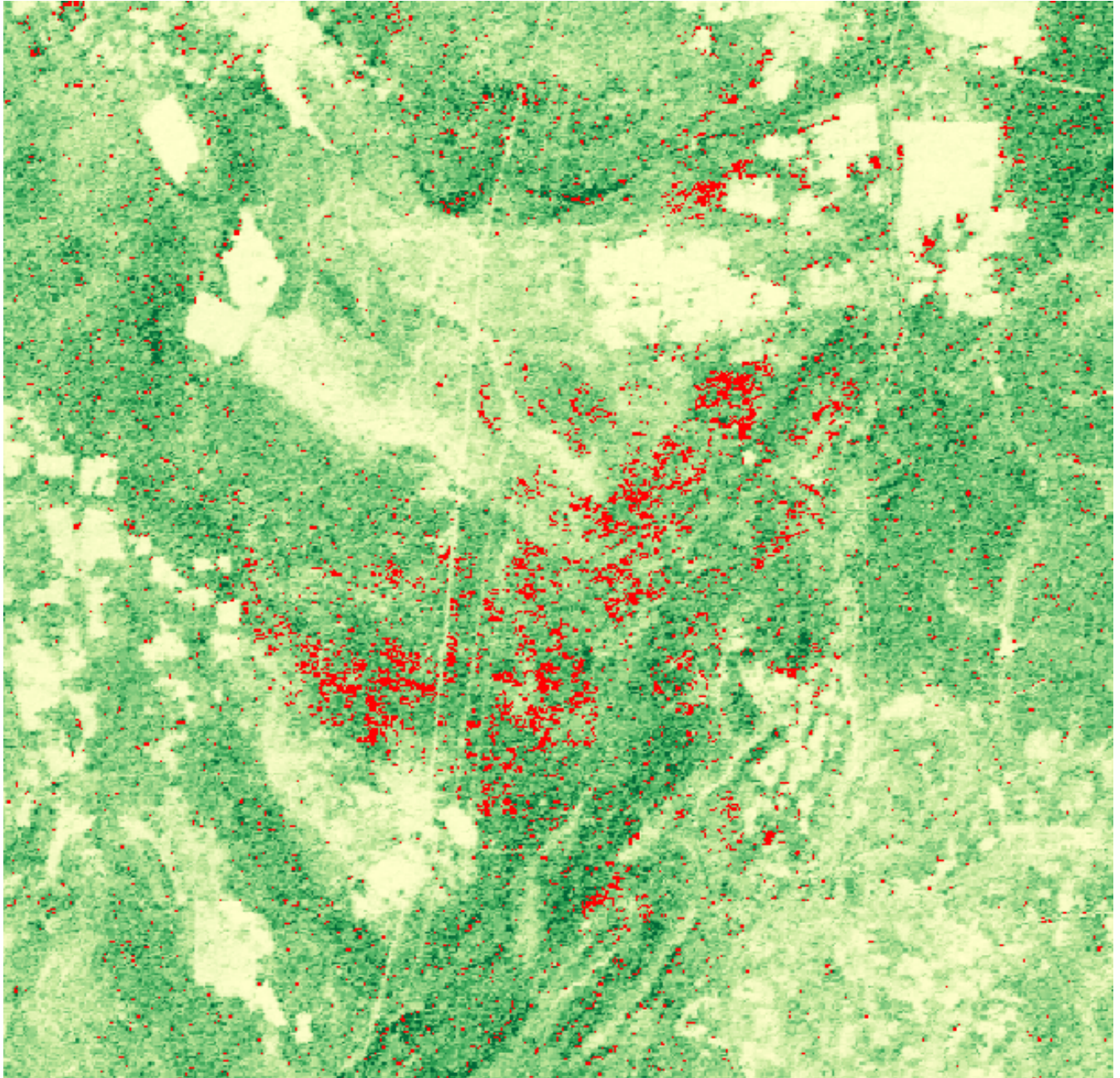
Try to build your own deforestation image, and see if you can improve on the assumptions we've made here.

Tip: You might improve on these assumptions with a different biomass loss value, or by taking into account a forest/nonforest threshold (e.g. 10 tC/ha).

1.5 Pre-processed change maps

As part of the Satellite Mapping for Forest Management (SMFM: https://www.smfm-project.org), The University of Edinburgh has produced a set of biomass change maps for southern Africa (see https://http://biota.rtfd.io for method).

We've used a range of techniques to suppress noise in the biomass change maps to generate high quality maps of biomass change, and classify these into different types of change (e.g. deforestation, degradation).

Here we'll load data outputs from the SMFM project to see what impact this pre-processing has on change map quality.

1.5.1 Data download

We've provided two files containing classes of forest change, one for the period 2007 - 2010, and another for the period 2007 - 2017.

The two files are available here:

`ChangeType_2007_2010_S18E029.tif` (2.4 MB).

`ChangeType_2007_2017_S18E029.tif` (2.7 MB).

Download these two files, and save them somwhere memorable (e.g. `Desktop`).

1.5.2 Loading data in QGIS

To add data to QGIS, first click the 'Add Raster Layer' button:

Navigate to `ChangeType_2007_2010_S18E028.tif` and add it to the map canvas:

1.5.3 Dataset description

This data was generated with the BIOmass Tool for Alos (biota), a module written in the Python programming language to simplify processing of the ALOS mosaic into biomass and biomass change maps.

The change map here was based on a very similar process to that which we've just run in QGIS, including the same calibration methods. However, it differs in that any changes identified in the image must be greater than a minimum area (`area threshold`: connected pixels in hectares), and have a minimum loss/gain intensity (`intensity threshold`: proportional biomass change in %). Additonally, forest losses can only occur over a previously forested area (greater than a `forest_threshold` in the first image), and forest gains over a previously non-forested area

(less than the `forest_threshold` in the first image). The images are also subjected to a speckle filter, which suppresses noise in the backscatter images.

For these change maps we set the `area threshold` to 1 hectare, the `intensity_threshold` to 25 %, and the `forest_threshold` to 10 tC/ha.

The resultant image contains 7 classes of data, numbered 0 to 6. These numbers represent:

Forest change type	Value	Definition
Defor-estation	1	AGB above forest threshold in image 1 and below forest threshold in image 2, with a loss of AGB greater than intensity threshold over an area greater than minimum area threshold.
Degrada-tion	2	AGB above forest threshold in image 1 and image 2, with a loss of AGB greater than intensity threshold over an area greater than minimum area threshold.
Minor loss	3	Any loss of AGB that doesn't meet conditions of deforestation or degradation.
Minor gain	4	Any increase of AGB that doesn't meet conditions of deforestation or degradation
Growth	5	AGB above forest threshold in image 1 and image 2, with an increase of AGB greater than intensity threshold over an area greater than minimum area threshold
Af-foresta-tion	6	AGB below forest threshold in image 1 and above forest threshold in image 2, with a increase of AGB greater than intensity threshold over an area greater than minimum area threshold.
Non-forest	0	AGB below forest threshold in image 1 and image 2.

The effect of this extra processing is to reduce noise, by suppressing changes of low intensity (likely the result of soil/vegetation moisture and calibration changes) and removing isolated pixels of change (which frequently result from noise).
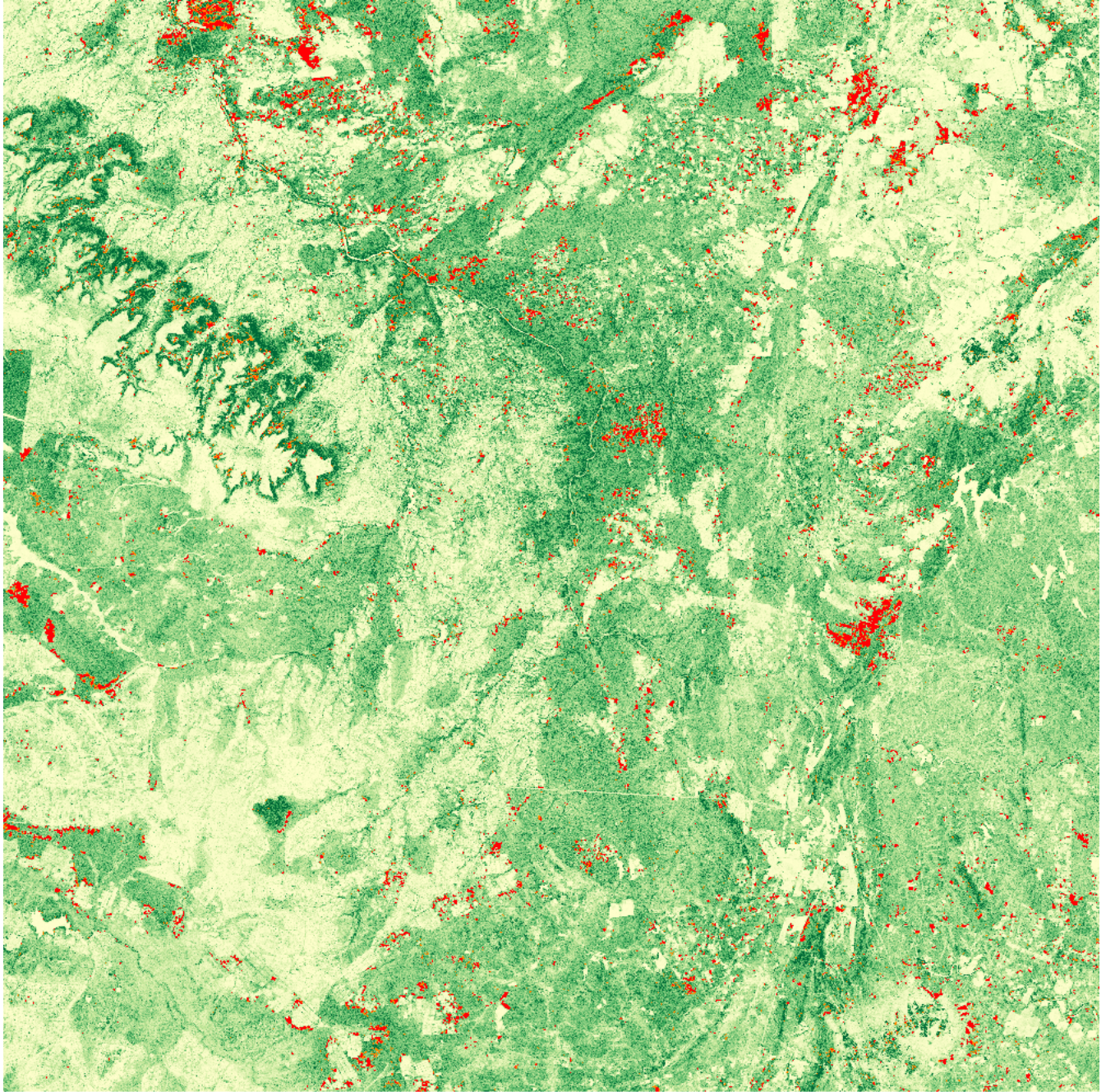
1.5.4 Visualisation

For now, we'll focus on showing only classes 1 and 2 (deforestation and degradation), which are most often the classes of interest. Double-click `ChangeType_2007_2010_S18E029` in the `Layers Panel`, and choose `Singleband pseudocolour` from the `Render type` pull down menu. Click the green + symbol 4 times to add four colours. Set these as follows:

Forest change type	Value	Colour
Non-forest	0	Transparent
Deforestation	1	Red
Degradation	2	Orange
Other	3	Transparent
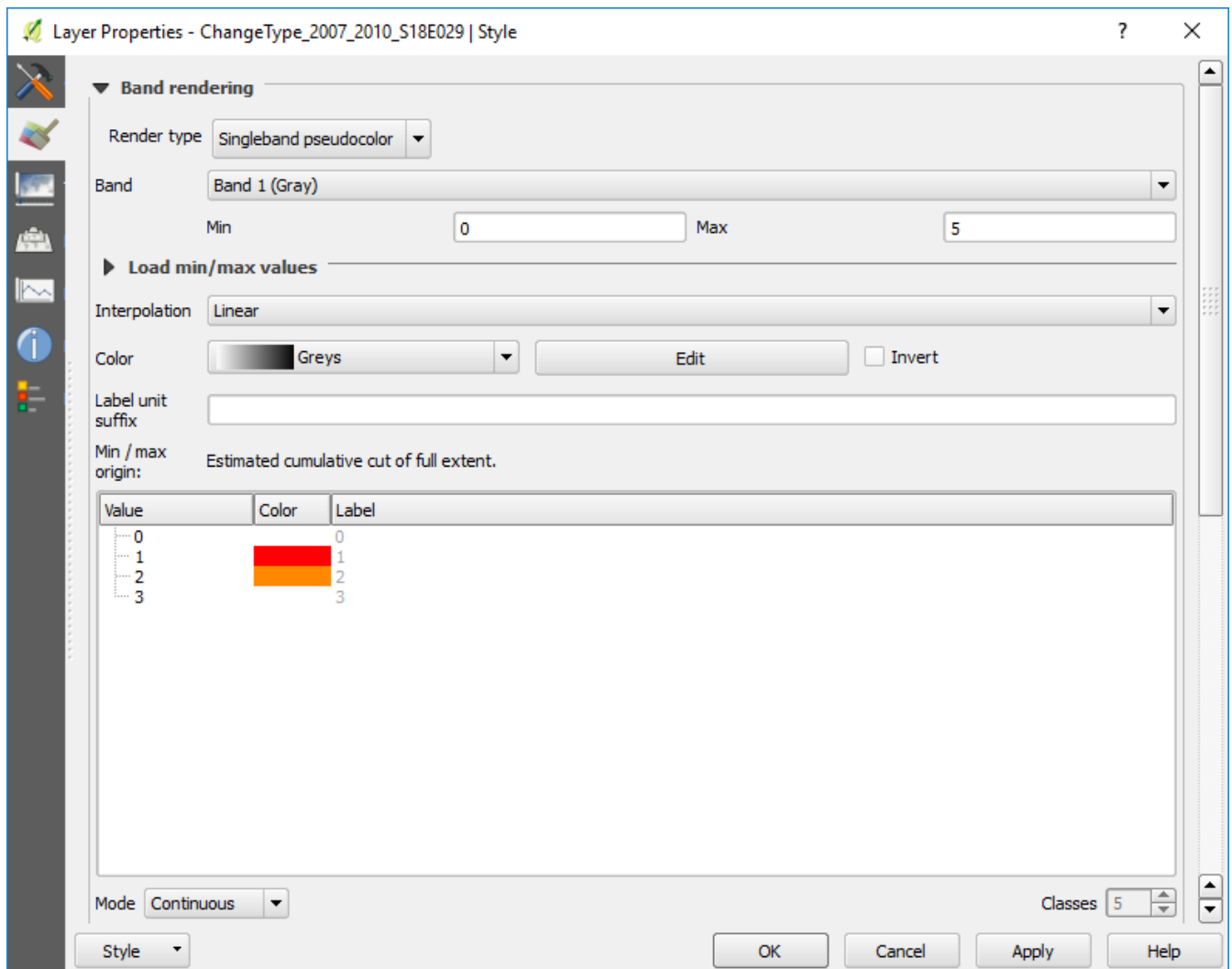
Display the output image on top of your previously created biomass map from 2007 to show areas of forest loss and their context.

1.5.5 Questions

1. How does this map compare to the one you generated? Do you agree with the assumptions we've made?

2. Try to load in the 2007 - 2017 change map. How does this compare to 2007 - 2010?

3. Build a visualisation of the growth and afforestation classes. Do you think these look realistic?

1.6 What next?

1.6.1 More data: option A

We've brought along radar data covering all of southern Africa. Find a location that you're familiar with, or an area in which you're interested in, and build a biomass and biomass change map.

1.6.2 More data: option B

We've also brought along pre-calibrated biomass, biomass change, and classified deforestation/degradation maps from across Zimbabwe. With this data you can visualise the forest cover changes that have occurred over the past decade in Zimbabwe. Again, if you have an area in mind that you'd like to look at, we have the data with us.
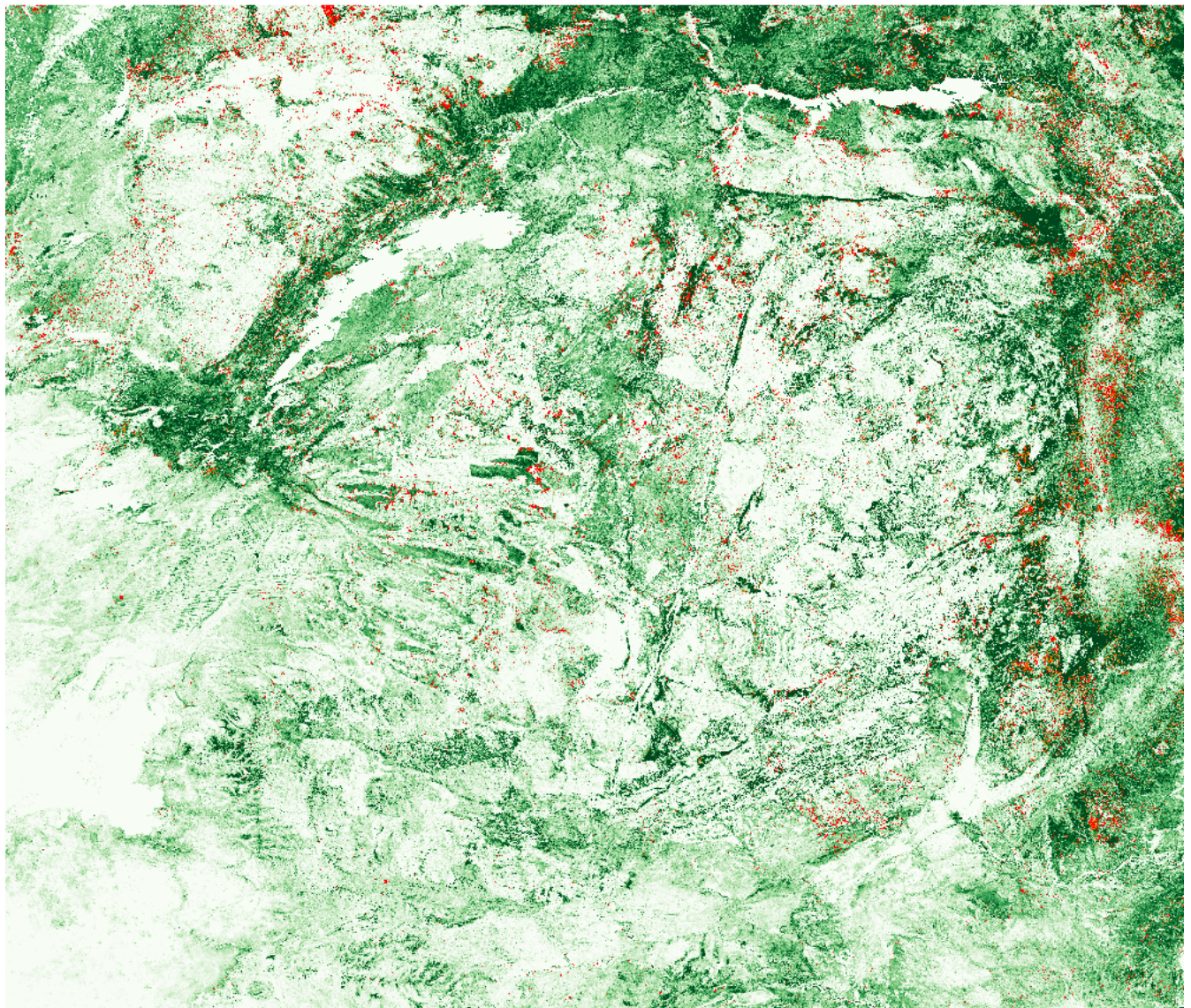
1.6.3 More data: option C (very advanced!)

Download a shapefile covering the regions and districts of Zimbabwe (http://www.diva-gis.org/gdata). Using the data from option B, try to caclulate the deforesation rate for some shapefile polygons. Which regions have experienced the fastest rate of deforestation?