Combining satellite imagery and shaded relief: the free way

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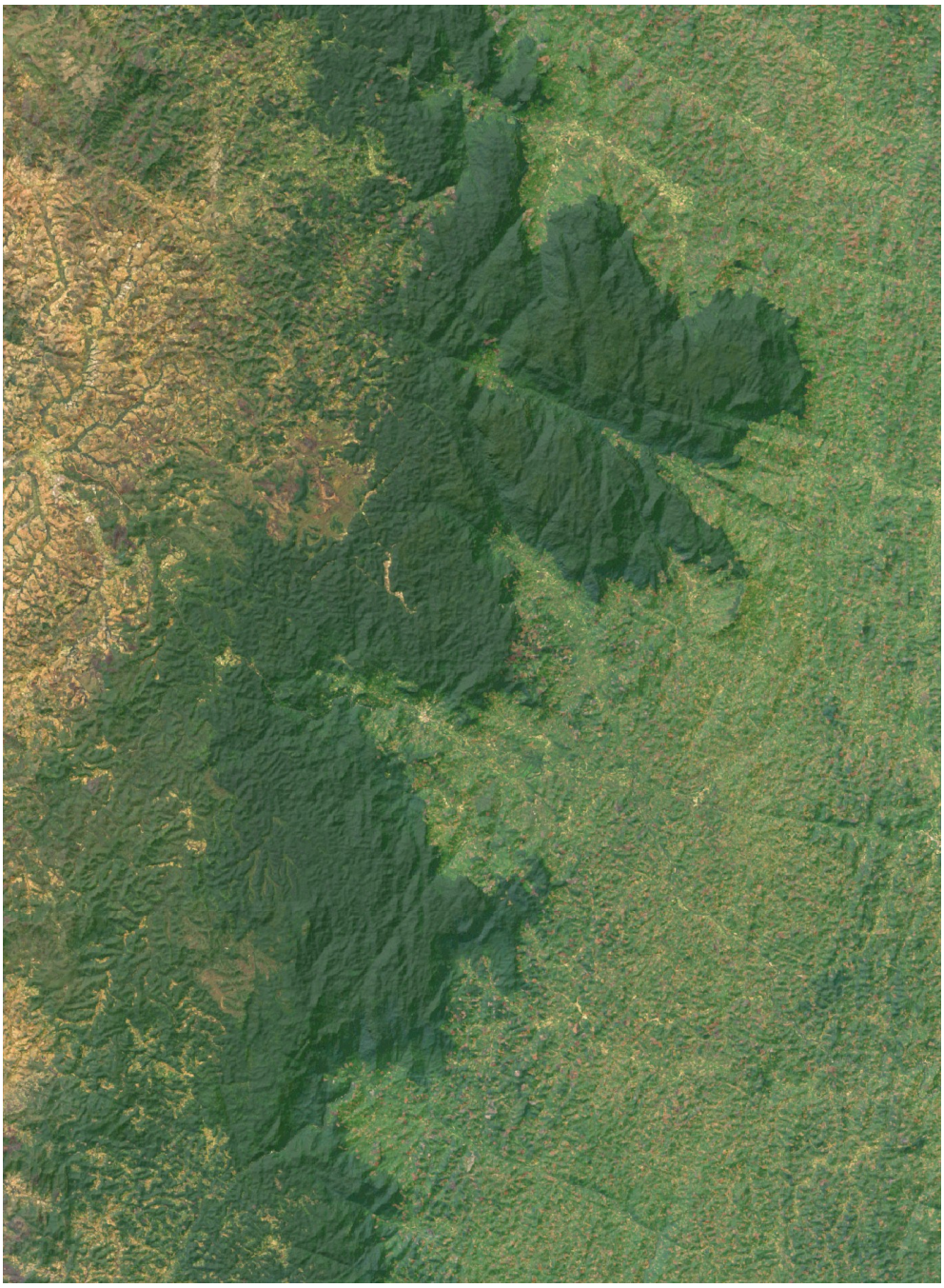


Region of Ranomafana National Park, south-eastern Madagascar

This tutorial describes a workflow I have recently settled on for making maps that I think may be useful for fellow GIS-users who are not GIS-professionals. As a bonus*, it uses only freely available data and software. Although I have over 10 years of on-and-off GIS experience, I'm by no means a professional-level user, and provide no guarantees that I'm not making any mistakes or sub-optimal decisions. I'd like to refine and update the 'protocol', and feedback is much appreciated.

**Disclaimer: mileage may vary depending on your operating system, experience with GIS and command-line software, state of caffienation, overall cartographic affinity, etc.*

Required Software
I'm using the following open-source software on Ubuntu Linux (14.04). Proprietary alternatives like ESRI ArcGIS and Adobe Photoshop can be used to replace QGIS and Gimp, respectively. It should also be possible to automate most, if not all of these steps in R using the raster package. These programs should all work on anything unix-like (including Mac). For Windows, QGIS and the "listgeo" utility should be available, but Gimp is not, and I'm not totally sure about geocp. Apologies to Windows-only users, but there are surely work-arounds.

1) QGIS – I'm using QGIS version 2.8. <http://www.qgis.org/en/site/> QGIS is a free, open-source graphical-user-interface (GUI) program for GIS that I have been using for a few years now. ArcGIS liscenses are not cheap; they seem to have a bit of a monopoly on (non-free) GIS GUI market. I've found QGIS to be a great, user-friendly alternative, and have been using it since 2013. It does everything I used to use ArcGIS to do, and more. I really recommend it! Also, QGIS does have much the same "feel" as ArcGIS, so ArcGIS users should feel at home pretty quickly.

2) GeoTiff Libs – I'm using the utilities "listgeo" and "geocp," both downloadable from https://trac.osgeo.org/geotiff/ . I use these utilities to extract and transfer projection metadata from the geo-referenced satellite images to the natural-color composite we'll make in Gimp.

3) Gimp – I'm using Gimp version 2.8. <https://www.gimp.org/downloads/> Gimp is a powerful open-source program for image modification. The learning curve can be pretty steep, but it should be able to replace proprietary software such as Photoshop and Illustrator for most purposes.

1) Obtain satellite imagery and digital elevation model (DEM) data

The USGS Earth Explorer is the tool that I use to download all the necessary data. It conglomerates data from a wide variety of sources and is easy to use. <http://earthexplorer.usgs.gov/>

Note that you'll need to create a username and password before downloading data.

First, add coordinates by clicking on the map to make a shape around the area you are interested in. Then you select the data sets you are interested in using the drop-down menu. They provide a nice tutorial for selecting data to download:
<https://lta.cr.usgs.gov/sites/default/files/SelectDatasetsfinal.pdf>

Aim to get the best-resolution data possible. To my knowledge, the best data for my region of interest are SRTM 1 Arc-Second Global (note: not actually available globally, yet!) for DEM data, and Landsat 8 data for satellite imagery. Sentinel-2 imagery has even better resolution, but I could not find cloudless images for my specific areas through the USGS website (though they might be available at the Sentinel website, <https://cophub.copernicus.eu/>). The best resolution will vary depending on your region, e.g., for small areas within the United States, you might be able to use aerial photos, and can skip step (2). ASTER is a good DEM alternative if SRTM 1 Arc-Second data has not been released yet for your region.

You'll also have to find a satellite image without cloud cover. Depending on where you're working, this could be non-trivial. If you can't find a suitable image, you may be able to work around this by making a composite of several images (but I haven't tried this yet). Use the preview images to check cloud cover (click on the thumbnail if it displays "Image not available"). Be sure to download the Geotiff and/or "Level 1" Files (the biggest file).

Note: depending on the size and location of your area, you may have to stitch together multiple

'tiles' of DEM or Landsat images. This is easy in QGIS or R, but I won't cover it in detail here. For QGIS, look at Raster->Miscellaneous->Merge. If you want to reduce the area, look at Raster->Extraction->Clipper. After merging satellite images, you can proceed to step 2.

2) Make an RGB or "natural color" image in Gimp using Landsat band images

If you downloaded Landsat 8 data, the directory you downloaded should have a number of files with "B1," "B2," etc. at the end of the filename. These "band" files correspond to different wavelength intervals of light. By combining different band images, you can create a variety of "natural" or false-color images. Each satellite may have different wavelengths corresponding to each band number, so be sure to look these up if not using Landsat 8.

To make a natural color image from Landsat 8 data, you want bands 4(red) 3(green) and 2(blue). You can also explore options for making various false-color images, or alternative "natural-looking" options, by combining different band sets. Google is your friend, but here's a starting point: <https://blogs.esri.com/esri/arcgis/2013/07/24/band-combinations-for-landsat-8/>

To combine the bands, I use Gimp, with quick instructions below. It's also possible in Photoshop, see this piece by Robert Simmon: <http://earthobservatory.nasa.gov/blogs/elegantfigures/2013/10/22/how-to-make-a-true-color-landsat-8-image/>. This is a must-read either way, as it explains adjustment to the histogram using curves, and helped me to learn the whole process.

Open the three bands files in Gimp. Then select the *Color->Compose* tool to combine the bands into a single image. Check that the band numbers are assigned to the correct color. The resulting image may seem very dark. You'll need to adjust the colors manually using white balance, brightness, contrast, and "curve" adjustment the color histogram.

The first thing I've been doing is *Color->Auto->White Balance*. This has been getting me most of the way there to a natural looking image, but it's just a quick and easy suggestion. You can correct the white balance using a 'reference' white point of the image, explained in the Photoshop tutorial linked above.

After this, I use *Color->Curves*. Once you get used to adjusting curves, they are a very powerful, easy way to adjust image color and contrast. The Photoshop-based tutorial gives a great explanation of how to adjust curves, which I won't attempt to replicate here. There's no one right way to do this, though, and I consider this step far from optimized. Explore different options in the *Color* drop down menu.

When you're happy with how the image looks, export the file as an uncompressed .tif file.

3) Apply the projection metadata of a band file to the new composite image using Libgeotiff utilities:

Now you have a natural-looking satellite image, but the projection (coordinate reference) isn't retained by Gimp, and the file will be useless for GIS until you provide one.

The utility "listgeo" will output projection metadata from any projected .tiff(=.tif) image. Send the output of listgeo from any one of your original band files to a text file. The "geotifcp" utility will transfer metadata from the text file to your unprojected .tif image.

listgeo documentation:

<http://web.archive.org/web/20160817035938/http://www.remotesensing.org/geotiff/listgeo.html>

geocp documentation:
<http://web.archive.org/web/20160817035546/http://www.remotesensing.org/geotiff/geotifcp.html>

4) Import your data and create a hillshade using QGIS:

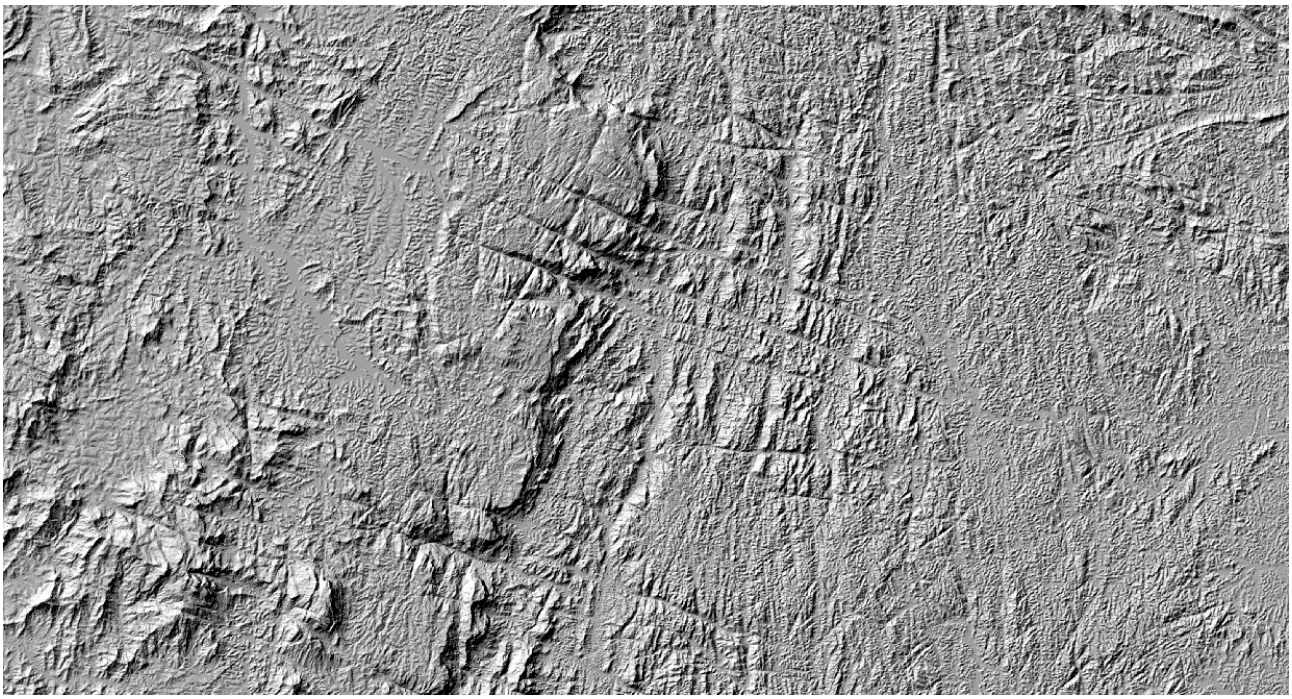
QGIS makes it very easy to import layers. You can actually just drag-and-drop them to the layers toolbox on the left-hand side, or use the drop-down menu, e.g., for your DEM and landsat layers, *Layer->Add Layer->Add Raster Layer*. Import your projected landsat image and the digital elevation data.

Now we'll make a hillshade layer from the DEM data. The hillshade comprises the "shaded relief" portion of the map, it gives a "3D" impression and generally speaking, makes the map look good! More specifically, it's a digital model of how the topography would look for given position of sun (adjusted using the altitude and azimuth parameters).

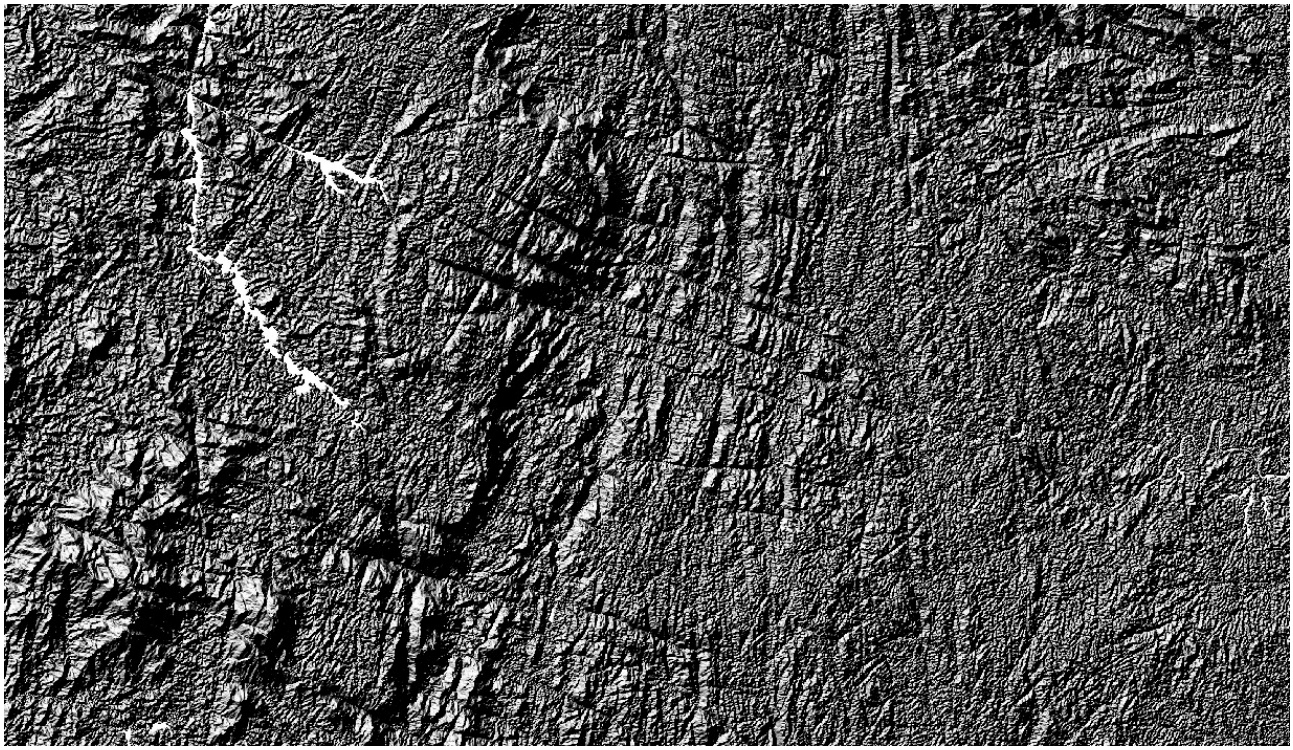
To make a hillshade, from the dropdown menu select *Raster -> Analysis -> DEM (Terrain models)*.

Select your DEM as the input file, and choose a filename and location for your output. Check that *hillshade* is selected for *Mode*. Also make sure the *Load into canvas when finished* box at the bottom is checked to make things easier.

In order to get a good-looking hillshade, it's critical that your z-factor ("vertical exaggeration") and scale (ratio of vertical to horizontal units) are set correctly. In more recent versions of QGIS, you'll need to change the scale, and can leave the z-factor untouched. Typically, your DEM data will be in meters, and your map projection in lat/long degrees. Under these conditions, set the scale to **111120**, and leave the z-factor unchanged. You can try experimenting with different z-factors, azimuths, and altitudes for slightly different aesthetic outputs. If it worked correctly, you should get a hillshade that looks something like this poor resolution facsimile:



Your z-factor and/or scale are likely set incorrectly if your image looks more like this (which kinda hurts to look at):



5) Adjust transparency and other layer properties to combine the data in QGIS:

The order of layers (top-to-bottom) in the layers toolbox determines their priority for visualization. You can click and drag to adjust the order. If you have two layers that are entirely opaque (default), you'll only see the top-most layer. You can uncheck a layer to ignore it (e.g., for the DEM, after you've made a hillshade).

To combine the layers, I adjust transparency. I find this to be a straightforward/intuitive way, but there are others (see last paragraph of this section). To adjust a layer's transparency, right-click it, select *Properties*, and then click the *Transparency* tab, and use the slider.

You can choose to either 1) make the landsat image slightly transparent (say, 20%), and place it over a totally opaque hillshade or 2) make the hillshade mostly transparent (say, 80%) and place it over a totally opaque landsat image. In my experience, these both look about the same. Experiment with different transparencies and orders to get your desired result.

You can also visualize the raw DEM together with the hillshade and satellite imagery. I've found that this can serve to "exaggerate" high-elevation areas in the satellite image using the DEM, but this is certainly optional and 100% aesthetically driven. The problem with combining the raw DEM and landsat imagery is that the color from the satellite image will always interfere with the DEM color, making it impossible to have an accurate legend.

However, if you want a shaded-relief map that is precisely informative about elevation, you can (and should) combine just the DEM and hillshade! You could of course produce both types of maps, if precise information about land-cover and elevation are both important to you.

To change the visualization of the DEM (default is greyscale), right click it on the layers menu and select *Properties*. From here, select the *Style* tab. For *Render type*, select *Singleband pseudocolor.* You can either use a predefined color ramp, or make your own. *Classify* is useful to produce a starting point. You can also choose to have the colors interpolated (*Color Interpolation -> Linear)* or to have discrete boundaries (*Color Interpolation -> Discrete*). The *Style* tab also allows you to combine layers without adjusting transparency through the use of the *Blending mode* option. I don't have much experience using this method, but if you're interested in this, you can try *Multiply* as a starting point.

6) Add point coordinates, shapefiles, etc:

At this point, you're ready to add other data to your map. This could be point data, shapefiles for park boundaries, etc. QGIS makes this easy. To the left of the *Layers* toolbox, there are a set of buttons for importing various types of data. Importation should be fairly intuitive. It's also fairly easy to draw your own polygon shapefiles in QGIS, but I won't cover that here.

7) Export the map using the print composer:

To export from QGIS, select *Project->New Print Composer* from the drop-down menu after zooming in to your area of interest in the main window.

The composer will be blank. To see your map, select the *Add New Map* button on the left-hand side (blank sheet with a green plus sign). Click and drag a box, and you'll see that your map will appear, with the zoom approximately the same as your main QGIS window.

From here, you can add a scale bar, text, north arrow, legend, etc., using the buttons on the left, and adjust the appearence of these using the *Item properties* tab on the bottom-right.

When you're happy with your print composer, you can export it as a high-quality image (e.g., PNG) or vector-format (PDF) using the buttons on the top row or the drop-down menu.

8) Add finishing details and final color adjustment in Gimp

At this point, I add any final details or adjustments (e.g., text labels, cropping, etc.) with Gimp or Adobe Illustrator. This is also a final chance to tweak colors without having to repeat all of the QGIS steps. There you have it!