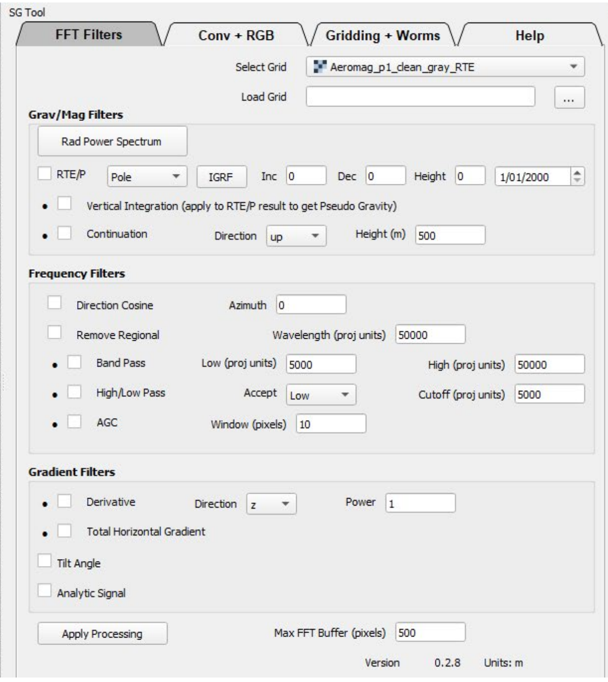
Structural Geophysics Tools v 0.2.8

Structural Geophysics Tools (*sgtools*) is a plugin to allow simple geophysical processing methods to be applied to data directly within QGIS. The primary motivation for developing the tool was to allow students to manipulate their datasets within the QGIS environment. It provides a subset of tools available in commercial or Open-Source packages in an Open Source environment without any need to install anything other than the plugin itself.



Contents

1. Load and Process Grid

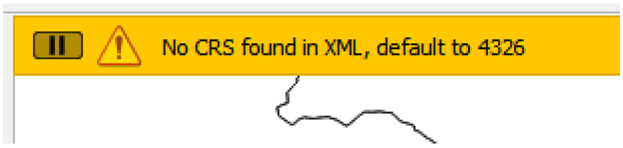
a) Load a raster image from file

- This tool can directly load TIF, ERS or GRD files, although you can use the standard QGIS Raster Grid import dilog to load many other formats that will be available for processing.

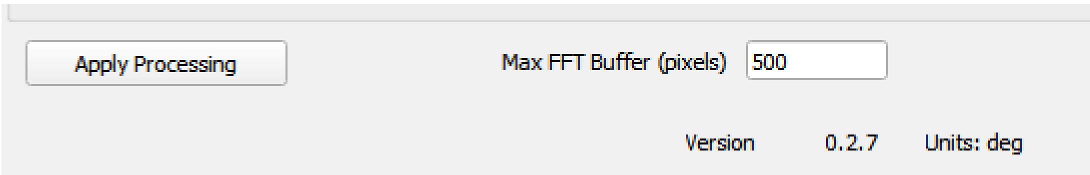
- If a GRD grid (Oasis Montaj) is selected, the plugin will attempt to load the CRS from the associated xml file, unfortunately (and by design) xml files come in a huge number of variations, and the *sgtools* code searches for an EPSG definition, and if it fails it defaults to EPSG:4236 (i.e. a degree-based projection).

- In any case the grid is saved as geotiff in the same directory as the original grid.

- The plugin flags if it can't find a valid CRS with a warning but you have to manually set the CRS in QGIS:



- The plugin also provides the units at the bottom right of the plugin for the currently selected layer:



b) Whatever layer is shown in the layer selector will be the one processed by whatever combination of filters are selected by check boxes.

- All processed files will be saved as geotiffs or ERS format files depending on the original format, will be saved in the same directory as the original file, and will have a suffix added describing the processing step.

- If a RTP or RTE calculation is performed, it is possible to define the magnetic field manually or the IGRF mag field parameters can be assigned based on the centroid of grid, plus date and survey height

- If a file exists on disk, it will be overwritten, although QGIS plugins don't always like saving to disks other than C: on Windows.

- Length units are defined by grid properties except for Up/Down Continuation (so Lat/Long wavelengths should be defined in degrees!)

c) If multiple processing steps are required, first apply one process, select the result and then apply subsequent steps.

2. Geophysical Filters

[_XXX] provides suffix added to original grid name, with _# indicating that the parameter controlling the filter is also added, e.g. _UC_500 indicates an upward continuation of 500m.

For Fourier Domain Filtering the maximum buffer can be defined, smaller buffers reduce calculation time at the expense of stronger edge effects so start with a smaller buffer to see if you can live with the edge effects before increasing it as needed. The max buffer is internally limited by the size of the grid.

Reduction to the Pole [_RTP]

Centres anomalies over causative body use for magnetic latitude > +/- 20 degrees, usually viewed in pseudo colour to highlight absolute value changes. Good place to start

$$H_{RTP}(k_x, k_y) = \frac{k\cos I\cos D + ik_y\cos I\sin D + k_x\sin I}{k}$$

Converts magnetic data measured at any inclination and declination to what it would be if measured at the magnetic pole. Where

- k_x and k_y : The wavenumber components in the x and y directions.
- k = The total wavenumber magnitude = sqrt{k_x^2 + k_y^2}
- I : Magnetic inclination (in radians).
- D : Magnetic declination (in radians).
- i : Imaginary unit.

Reduction to the Equator [_RTE]

Centres anomalies over causative body use for magnetic latitude < +/- 20 degrees, usually viewed in pseudo colour to highlight absolute value changes. Good place to start

$$H_{RTE}(k_x, k_y) = \frac{k\cos I\cos D + ik_y\cos I\sin D + k_x\sin I}{k\cos I\cos D - ik_y\cos I\sin D + k_x\sin I}$$

Converts magnetic data measured at any inclination and declination to what it would be if measured at the magnetic equator. Where

- k_x and k_y : The wavenumber (1/wavelength) components in the x and y directions.
- k = The total wavenumber magnitude = sqrt{k_x^2 + k_y^2}
- I : Magnetic inclination (in radians).
- D : Magnetic declination (in radians).
- i : Imaginary unit.

Continuation [[_UC_# or _DC_#]

UC enhances larger structures and features in area. DC (but never below land surface) enhances near surface signal. Also needed for stitching surveys at different heights.

$$H(k) = e^{-kh}$$

Where
h > 0 for upward continuation.
h < 0 for downward continuation.

Vertical Integration [_VI]

Highlights larger structures and features, such as terrane boundaries and intrusions; good when joining two surveys with very different line spacing. When combined with RTP or RTE of Mag data produces so-called Pseudo Gravity images. Loses high frequency information.

$$H(k_x, k_y) = \frac{1}{k}$$

When applied to an RTE or RTP image provides the so called Pseudogravity result
Where
k = sqrt{k_x^2 + k_y^2} .

3. Frequency Filters

High pass Fourier Domain filters have a tendency to create a ringing effect in grids, especially near the edges of the grid, this can be suppressed by using a Low pass filter with a cutoff 4 times the cell size.

Band Pass [_BP_#_#]

Restricts wavelengths to be within a given range. There is a partial relationship between frequency and depth of source (high frequency signals are near surface, low frequency signals can be low gradient variations near the surface or can be deep). People use this to do "depth slicing" of different layers but as frequency-depth is only a partial correlation (and potential field data is in any case inherently ambiguous) it is only a guide to depths.

$$e^{-(k - k_c)^2 \,/\, (2\sigma^2)} - e^{-(k + k_c)^2 \,/\, (2\sigma^2)}$$

The band-pass filter retains frequencies within a specified range, suppressing both low and high frequencies outside this range. Where
k_c : The central frequency of the band. sigma : The width of the frequency band.

Directional Cosine Filter [_DirC]

Suppresses linear features in a given direction, very useful for reducing line noise in airborne data. Should be applied prior to any other filtering if line noise is an issue.

$$H(k_x, k_y) = \left|\cos(\theta - \theta_c)\right|^p$$

The Directional Cosine Filter suppresses frequency components along a specific direction.
$H(k_x, k_y)$: Filter response as a function of wavenumber components k_x and k_y.
theta = \arctan\left(\frac{k_y}{k_x}\right) : Angle of the frequency component.
theta_c : Center direction (in radians), representing the direction to emphasize.
p : Degree of the cosine function. Higher (p) sharpens the directional emphasis.

High Pass [_HP_#]

Restricts wavelengths to be below a given value. Useful for highlighting shallower features.

$$H(k) = 1 - e^{-k^2 / (2k_c^2)}$$

The high-pass filter removes low-frequency components (long wavelengths) while retaining high-frequency components (short wavelengths). Where
k_c : The cutoff frequency where the filter begins attenuating lower frequencies.

Low Pass [_LP_#]

Restricts wavelengths to be above a given value. Useful for highlighting ?deeper? features..

$$H(k) = e^{-k^2 / (2k_c^2)}$$

The low-pass filter suppresses high-frequency components (short wavelengths) while preserving low-frequency components (long wavelengths). Where: k_c : The cutoff frequency where the filter begins attenuating higher frequencies.

Remove Regional [_RR_#]

Subtracts low pass filtered data from original to highlight shorter wavelength features.

$$H(k) = e^{-k^2 / (2k_c^2)}$$

The low-pass filter suppresses high-frequency components (short wavelengths) while preserving low-frequency components (long wavelengths). Where
k_c : The cutoff frequency where the filter begins attenuating higher frequencies.

Automatic Gain Control [_AGC]

Further highlights near-surface geology and high frequency features in magnetically 'quiet' areas of geology, usually viewed in grayscale. Often makes high frequency mag areas hard to interpret. Other uses include when there are either highly magnetic rocks such as BIF in an area of lower magnetic susceptibility, such as. Another case where AGC was useful was for ultramafic rocks in a greenstone belt with thick sedimentary rock packages to better discern contacts in the mafic-ultramafic sequence.

$$AGC(x, y) = \frac{f(x, y)}{\mathrm{RMS}(f(x, y), w)}$$

Where

RMS(f, w) is the root mean square of the data over a window w.

Radially averaged power spectrum

$$P(k) = \frac{1}{N_k} \sum_{(k_x, k_y) \in k} |\, \mathrm{FFT}(f)|^2$$

Where

P(k) is the radially averaged power spectrum, and N_k is the number of samples in the radial bin.

4. Gradient Filters

Derivative [_d#]

Calculates spatial gradient (or derivative) of field in x, y or z direction to 1 or more orders. Vertical derivative in z direction highlights near-surface geology and high frequency features, and images are usually viewed in grayscale. The vertical gradient of field, is derived from the two horizontal gradients, based on the knowledge that grav/mag fields are Greens Functions. Vertical derivative images show low-high-low triple anomaly for narrow linear magnetic features.

di

$$\frac{\partial f}{\partial u} = \frac{\partial f}{\partial x}\cos\theta + \frac{\partial f}{\partial y}\sin\theta$$

Where

theta is the angle defining the direction of the derivative (x,y or z).

Total Horizontal Gradient [_THG]

Calculates maximum spatial gradient of the field in x and y directions, and highlights contacts and is often used to better locate very deep boundaries, such as MT and seismic tomography.

$$THG(x,y) = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

Analytic Signal [_AS]

Reflects total amount of ~~magnetic~~ magnetic or density material beneath surface. Tends to 'over-join' features so not great on its own for understanding structures, but good for lithostratigraphic analysis.

$$A(x,y) = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2}$$

Computes the total amplitude of the gradients, independent of field inclination or declination. Useful for locating edges of potential field sources (e.g. faults or contacts).

Tilt Angle [_TDR]

Highlights near-surface geology and high-frequency features (i.e. is not applicable to use for long wavelength components); usually viewed in grayscale. Tends to 'over-join' features so not always great on its own for understanding structural relationships.

$$T = \tan^{-1}\left(\frac{\frac{\partial f}{\partial z}}{\sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}}\right)$$

Enhances the contrast of geological features by highlighting gradients relative to the vertical component. Where
df/dz : Vertical derivative of the field. df/dx , df/dy : Horizontal derivatives of the field.

5. Convolution Filters

Mean Applies a mean filter using a kernel of size n x n . **[_Mn]**

Smooths data

Median
Applies a median filter using a kernel of size n x n . **[_Md]**

Removes high frequency noise from data.

Gaussian
Applies a Gaussian filter with a specified standard deviation. **[_Gs]**

Smooths data

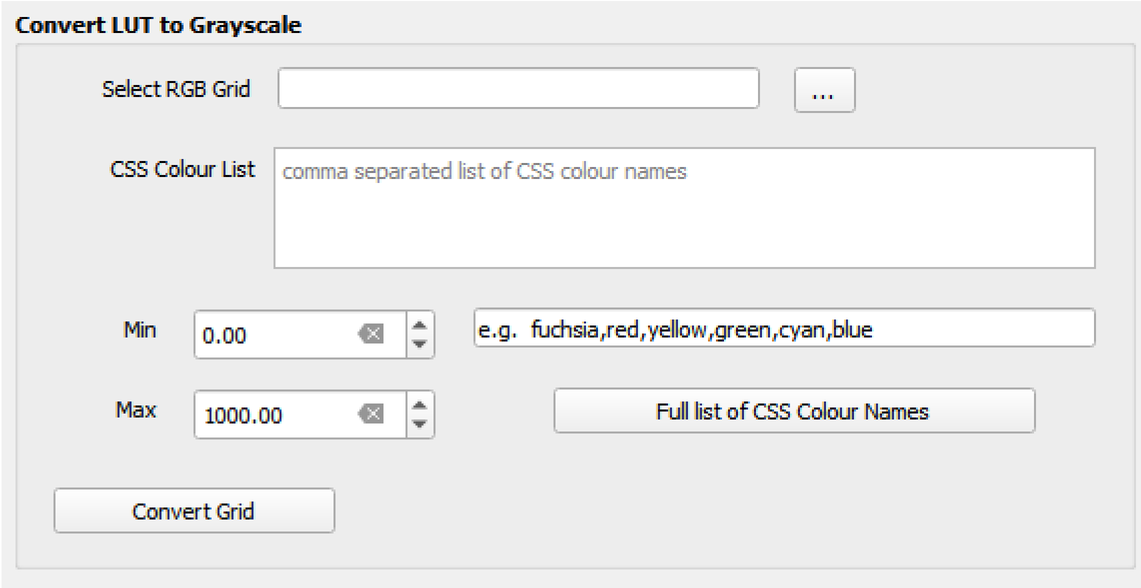
Directional
Apply directional filter (NE, N, NW, W, SW, S, SE, E) **[_Dr]**

Highlights specific orientations in data.

Sun Shading
Computes relief shading for a digital elevation model (DEM) or other 2D grids. Azimuth provides the direction of the “sun” and zenith its angle from horizontal. **[_Sh]**

A form of directional high pass filtering which accentuates high frequency information, but offsets the peaks of anomalies, so use with caution. Sometimes a zenith of 90 causes problems, so it is limited internally to 88 degrees.

6. RGB Importer



This tool takes a 3-band RGB image of some data and attempts to convert it to a monotonically increasing 1-band grid. The user provides the sequence of colours seen in the look up table using colour names from the CSS colour list as provided by matplotlib.

a) The **min max** values define the range of the data (if known)

b) The new grid (originalfilename_gray.tif) is saved in the same directory as the original grid

c) Assumes a linear look up table display (e.g. not histogram equalised, quantised…)

d) Best <u>without</u> shading applied to image, but not awful if it has been used

e) Reasonably close colour choice required.

f) Rename existing grey scale extract so you can try different colour lists, as you can’t overwrite current layer

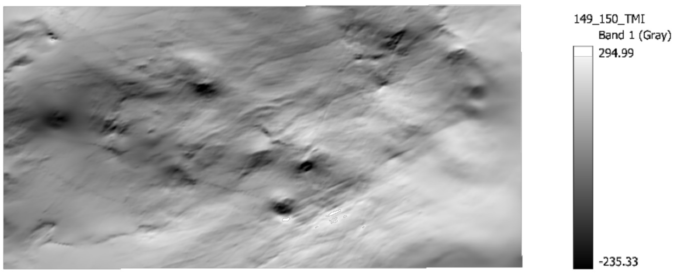
g) Could be modified to accept full csv LUT definition for more geeky users?

h) Resulting image usually needs a Gaussian filter to be applied first if high pass filters are to be used

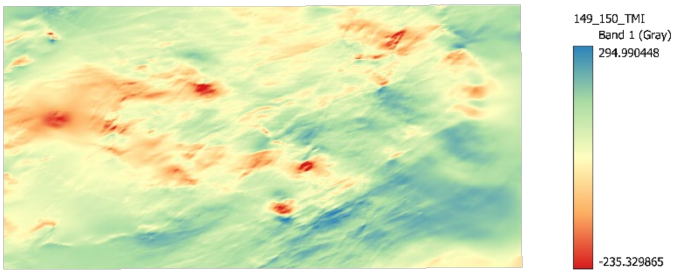
CSS Colour Names https://matplotlib.org/stable/gallery/color/named_colors.html#css-colors

Example usage

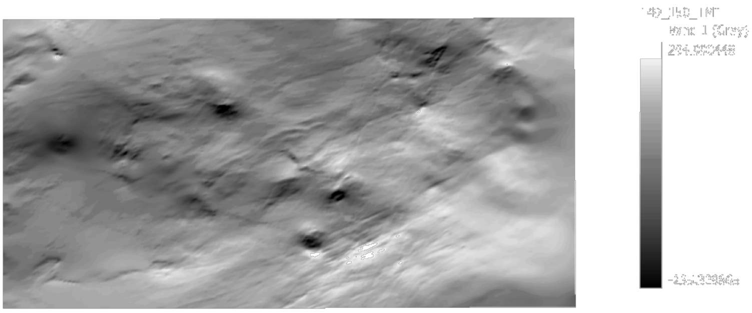
The original greyscale representation of a 1-band TMI grid (image approximately 110 km across) :



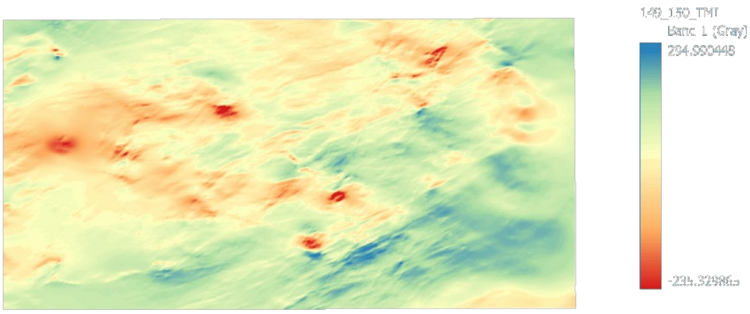
The colour representation of a 1-band TMI grid (QGIS Spectral LUT). <u>This image is saved out as a 3-band RGB representation</u>:



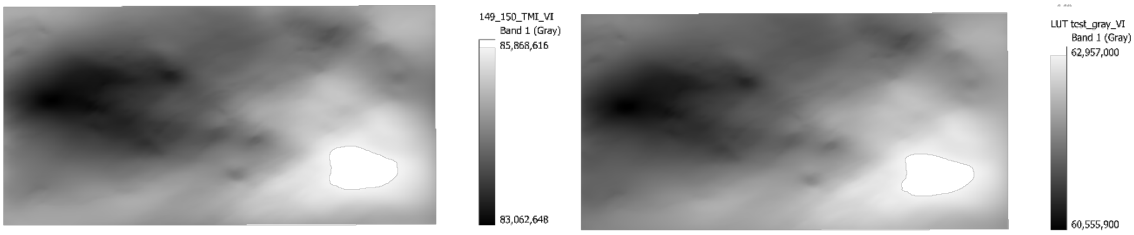
The greyscale representation extracted from the 3-band RGB using the colour LUT sequence [teal, lemonchiffon, red] :



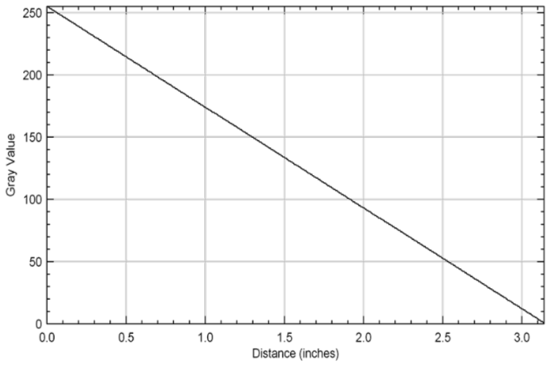
The colour representation of a the extracted TMI grid (QGIS Spectral LUT).



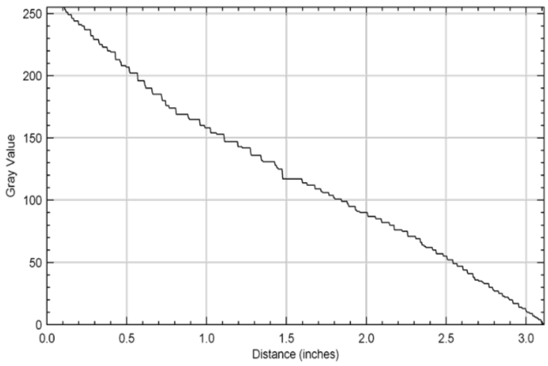
Comparison between Vertical Integration of original data (left) and extracted data (right)



LUT from Original



LUT extracted from RGB



Comparison between original data LUT and data LUT extracted from RGB image

7. Import point or line data

This tool allows you to import a csv file (which of course you can do anyway in QGIS) or an XYZ format file (an ascii format that divides data up by flight line numbers). Optionally include tie lines for the latter option.

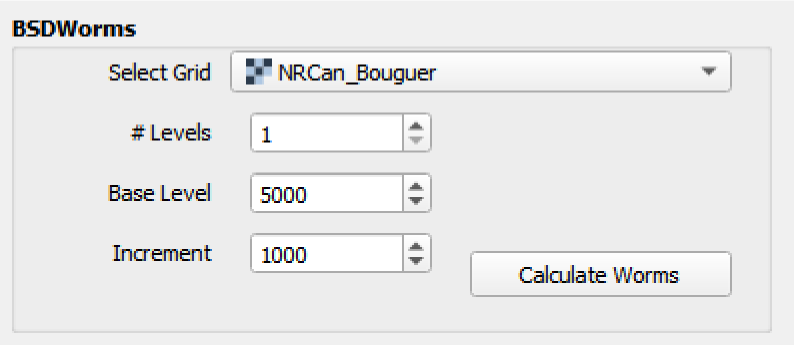
8. Gridding

This tool gets you started with gridding point data by allowing you to select an already-loaded point file and field to be gridded and to see the consequence of a given cell size in terms of number of rows and columns. Full dialog for each interpolation method allows other parameters to be set.

9. Threshold to NaN

This tool allows you to define NaN (aka NULL aka None) values based on a thresholding approach which is useful when an imported grid has a margin that should not be used in calculations. You can define an upper value beyond which all pixels are set to NaN, a lower value beyond which all pixels are set to NaN, or an upper and lower bound between which values are set to NaN.

10. BSDWorms



This tool uses Frank Horowitz's bsdwormer tool (https://bitbucket.org/fghorow/bsdwormer/) to build wavelet transform "worms" for metre-based grids. "Worms" are calculated by upward continuing the data to different heights (levels), and calculating the peaks in the data at each level using wavelet transforms of the horizontal gradient of the data.

For more information see:

Hornby, P., Boschetti, F., Horowitz, F.G., 1999. Analysis of potential field data in the wavelet domain. Geophys. J. Int. 137, 175–196.

Holden, D., Archibald, N., Boschetti, F., Jessell, M.W., 2000. Inferring geological structures using wavelet-based multiscale edge analysis and forward models. Explor. Geophys. 31, 617–621.

a) The grids must be of gravity or RTE/RTP + Vertical Integration grids of magnetic data

b) This will not work for degree-based projections

c) **# Levels** are the number of levels of worms to calculate

d) **Base Level** is the upward continuation height above 0 to calculate the first worm level by (often the 0 level is very noisy so best ignored, and is in any case recast as 0.01 to avoid problems)

e) Increment provides the spacing in metres the data is upward continued between levels

f) Worms are saved out in the same directory as the original grid as a single csv file (originalfilename_worms.csv) that can be loaded into QGIS or a 3D renderer such as Mira Geoscience's Geoscience Analyst

g) A padded version of the grid is also saved out and this can be removed after the worms are calculated but is provided for debugging purposes.

11. Code development

This code is developed using QGIS 3.34.1 but has been tested on versions back to 3.24.0. It appears to fail to install on significantly older versions (3.4.0).

- Calculations ChatGPT and Mark Jessell

- Plugin construction—Mark Jessell using QGIS Plugin Builder Plugin, https://g-sherman.github.io/Qgis-Plugin-Builder/

- IGRF calculation—pyIGRF https://github.com/ciaranbe/pyIGRF

- GRD Loader & Radially averaged power spectrum Fatiando a Terra crew (https://www.fatiando.org/) and & Mark Jessell

- Example geophysics data in image above courtesy of Mauritania Government, https://anarpam.mr/en/ Second Projet de Renforcement Institutionnel du Secteur Minier de la République Islamique de Mauritanie (PRISM-II) Phase V, Open-File Report 2013-1280, Prepared in cooperation with the Ministry of Petroleum, Energy, and Mines of the Islamic Republic of Mauritania, Edited by: Cliff D. Taylor, https://doi.org/10.3133/ofr20131280

- Worming of grids uses Frank Horowitz's bsdwormer https://bitbucket.org/fghorow/bsdwormer/

- Thanks to Lyal Harris for extensive beta testing!