Towards Ireland's First Marine Magnetometry Map

Frank Bastian, Mohit Tunwal, Aaron Lim

Department of Geography, University College Cork, Cork, Ireland

Motivation

Over the past 20 years, INFOMAR [1] and its predecessor INSS have undertaken a world-class and ambitious plan to map the entire Irish seabed. The 'Real Map of Ireland' is the most prolific output from these projects. It is an extensive IHO-standard bathymetric dataset that has underpinned Ireland's Marine Spatial Plan and supported cutting-edge research, as well as various economy-supporting industries. In addition, the INFOMAR project has acquired further datasets, such as sub-bottom profilers or magnetometry, whereas the magnetometry data set remained unprocessed. Here, we present an open-source GUI application that allows end users to process this INFOMAR magnetometry data set by aggregating and processing different surveys.

Total field magnetic anomalies

Following [2, 4], we denote $\bar{B}$ as the Earth's normal total magnetic field intensity vector, assumed to be uniform across the region and t represent the unit vector in the direction of $\bar{B}$. Additionally, we denote B as the total magnetic intensity vector, whose its magnitude B is measured by the magnetometer. The anomalous vector is $\bar{B} - B$ and the anomaly ΔB, is given as

$$\Delta B = (\bar{B} - B) \cdot t. \tag{1}$$

Following the standard assumption of $\Delta B \ll \bar{B}$, we approximate the **total field magnetic anomalies**:

$$\Delta B = |\bar{B}| - |B|. \tag{2}$$

User supporting features

- Preprocessing data, including outlier removal, smoothing and gridding of data
- Diurnal correction to meet industrial standards
- Automatic anomaly detection using edge detection (Sobel filter)
- Export of processed anomaly grids

Graphical user interface

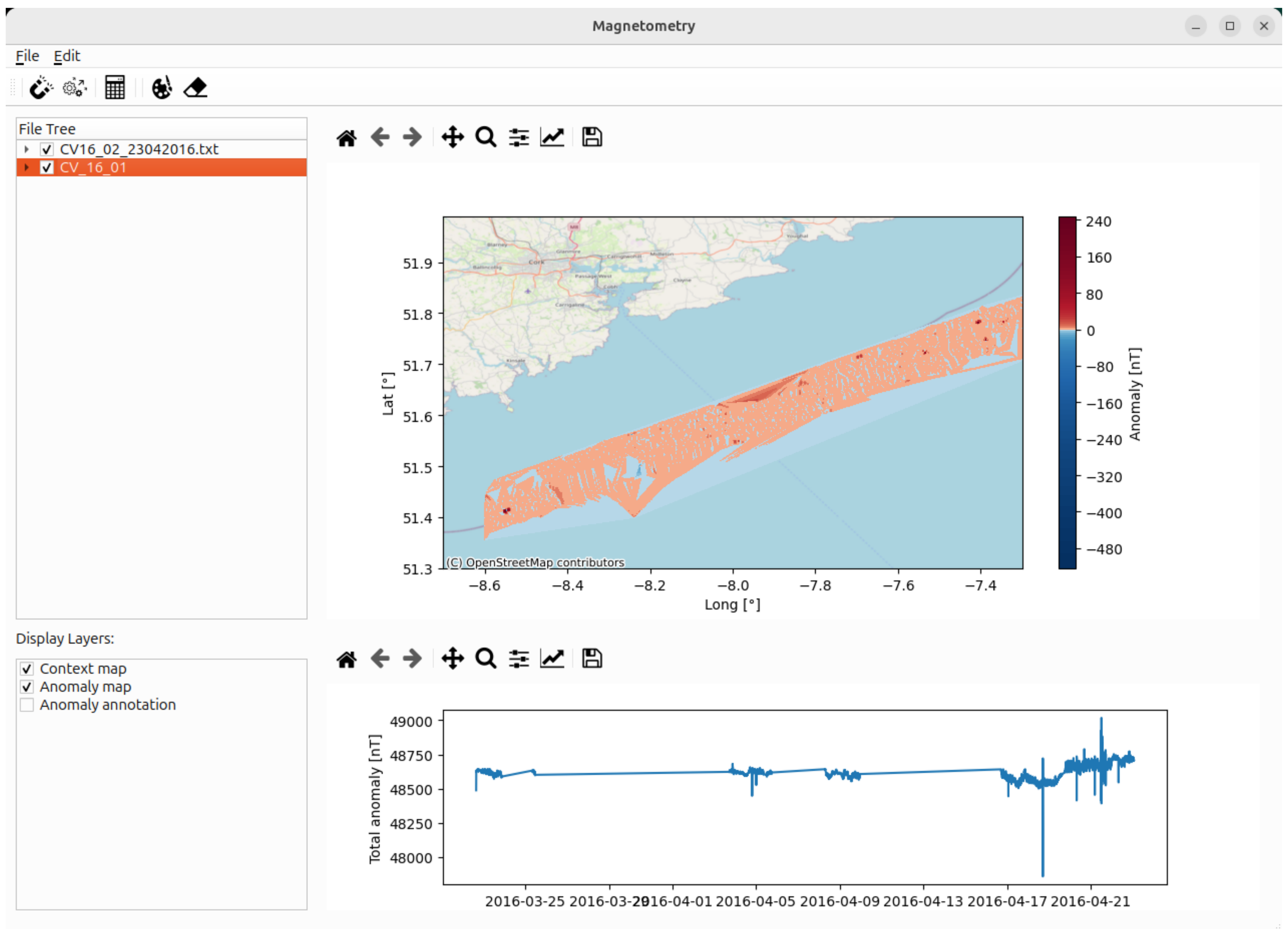

Figure 1. The Ui of the software consists of four major panels. The two left panels allow the user to dynamically select survey and visual layers, whereas the right panels depict the magnetic anomalies' time and spatial representation. The here used dataset is obtained by InfoMar [1] through the surveys CV 16_01 and CV 16_02, corresponding to areas in the Celtic Sea south of Cork.

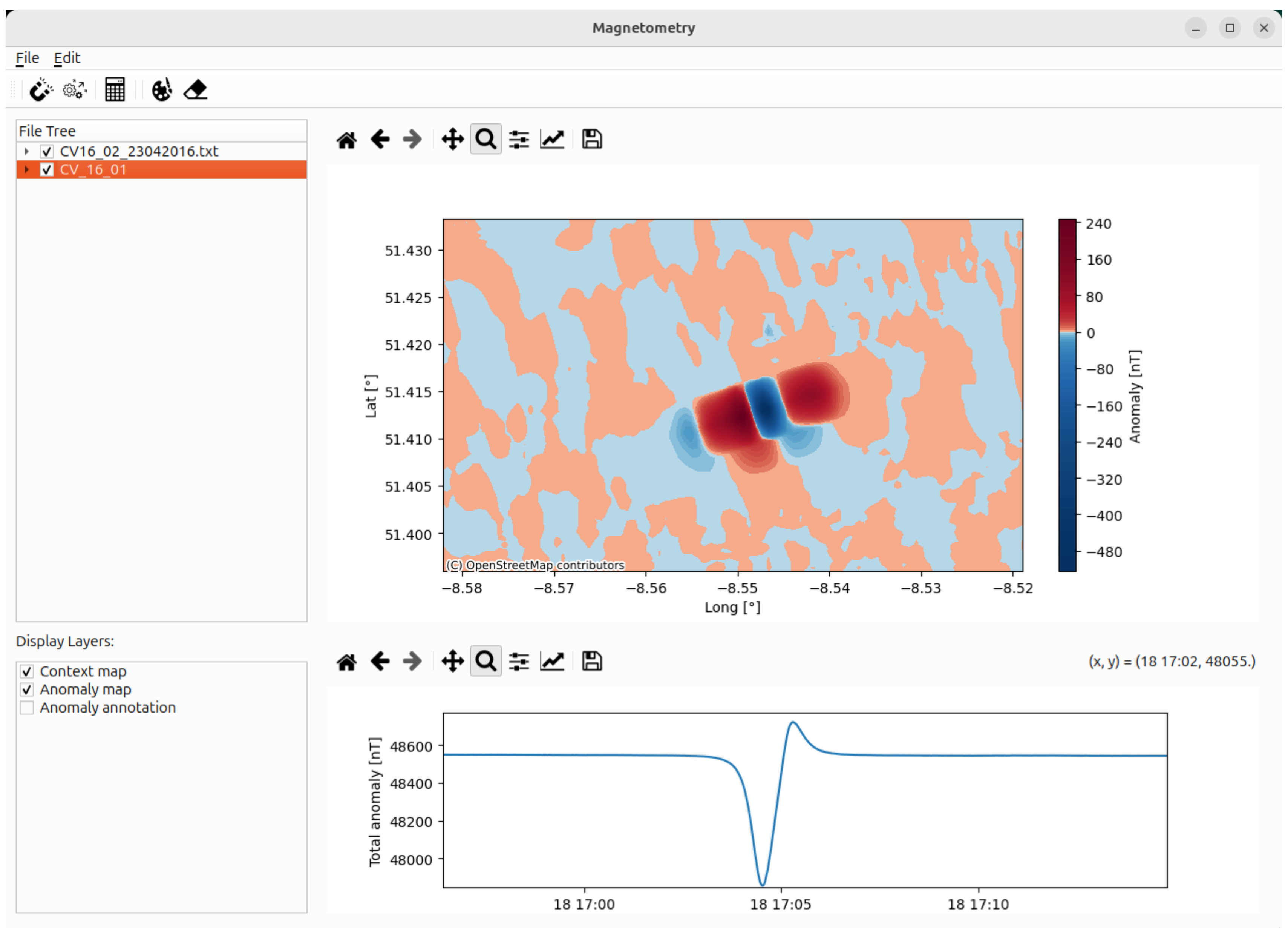

Figure 2. The UI allows the user to interact with both representations through the well-established plotting library matplotlib. As an example, a zoom-in to the anomaly of the RMS Lusitania is presented.

Downward continuation of total field magnetic anomalies

From Green's third identity, one can derive the *upward-continuation integral* [2, 4]:

$$\Delta B(x, y, z_0 - \Delta z) = \frac{\Delta z}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{\Delta B(x', y', z_0)}{[(x - x')^2 + (y - y')^2 + \Delta z^2]^{3/2}} \, dx' dy'. \tag{3}$$

We note that Eq. (3) a two-dimensional convolution,

$$\Delta B(x, y, z_0 - \Delta z) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \Delta B(x', y', z_0) \psi_u(x - x', y - y', \Delta z) \, dx' dy', \tag{4}$$

where

$$\psi_u(x, y, \Delta z) = \frac{\Delta z}{2\pi} \frac{1}{(x^2 + y^2 + \Delta z^2)^{3/2}}. \tag{5}$$

We seek to apply the Fourier-convolution theorem and denote the Fourier transform of the surface anomaly $\Delta B(x, y, z_0)$ as:

$$\mathcal{F}[\Delta B](u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \Delta B(x, y, z_0) e^{-i(ux + vy)} \, dx dy.$$

Therefore, we can rewrite Eq. (4) in Fourier space as

$$\mathcal{F}[\Delta B_u] = \mathcal{F}[\Delta B] \mathcal{F}[\psi_u], \tag{6}$$

and $\mathcal{F}[\Delta B_u]$ denoting the Fourier transform of the upward-continued field and $\mathcal{F}[\psi_u]$ the Fourier transform of Eq. (5) given by

$$\mathcal{F}[\psi_u] = e^{-\Delta z \sqrt{u^2 + v^2}}. \tag{7}$$

To obtain the transformed anomaly grid, we need to inverse transform $\mathcal{F}[\Delta B_u]$. Note that $\Delta z > 0$ denotes an uplifting and a smoothing of the data. However, we are interested in $\Delta z < 0$, i.e. downlifting, which corresponds to an exponential amplification of high frequencies. This renders this operation numerically very unstable.

Tikhonov regularisation

Next, we follow [5] who proposed a Tikhonov regularisation for Eq.(7)

$$\mathcal{F}[\tilde{\psi}_u] = \frac{1}{1 + \lambda(u^2 + v^2) e^{-\Delta z \sqrt{u^2 + v^2}}} e^{-\Delta z \sqrt{u^2 + v^2}}, \tag{8}$$

with regularisation parameter λ.

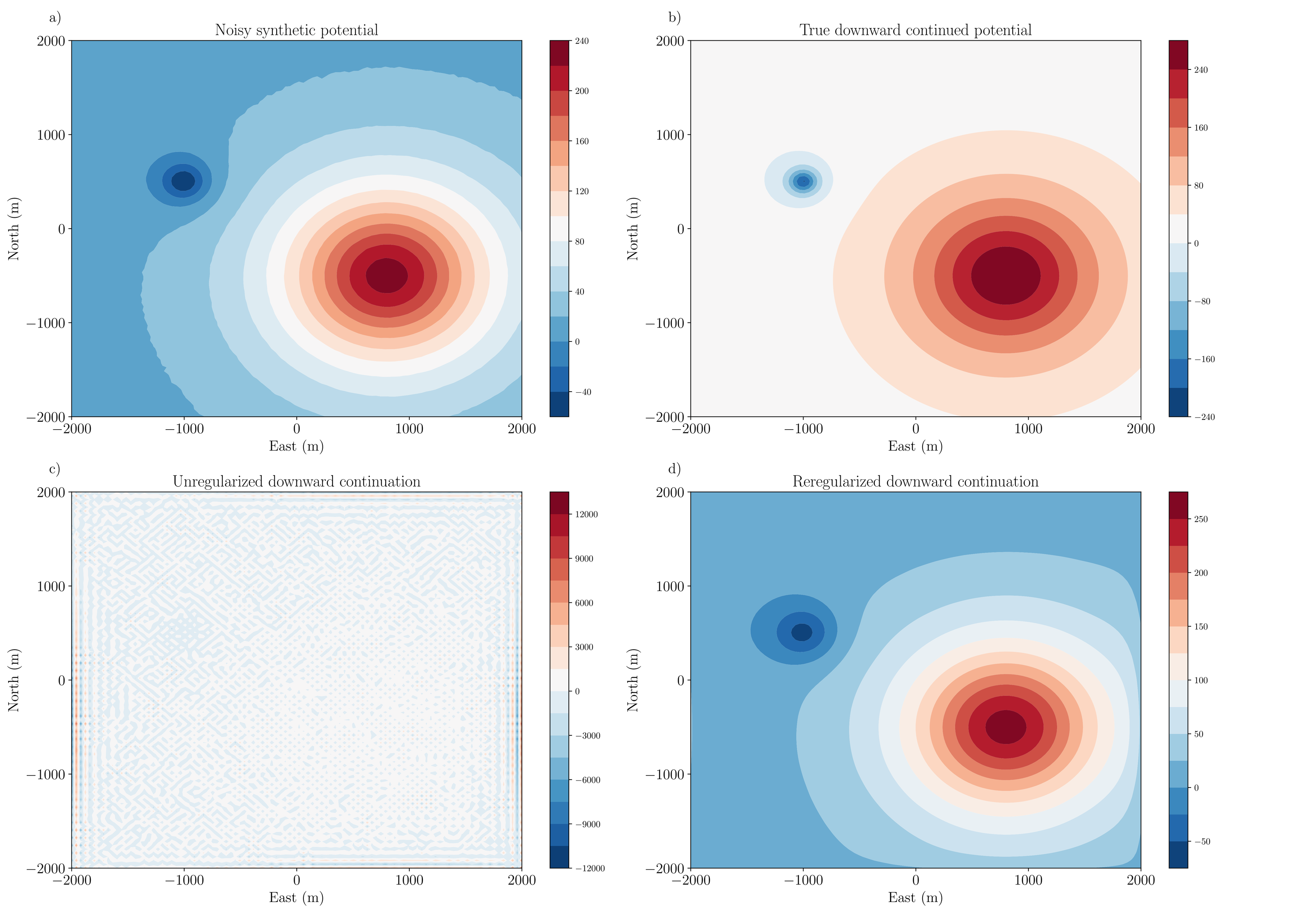

Figure 3. We adopt the upward continuation example of a gravity potential done by [3] to the downward direction. a) depicts a white noise perturbed signal corresponding to an assumed measured signal. b) depicts the analytically downward continued unperturbed potential of a). c) depicts the reconstructed potential using the default downlift operator Eq. (7). d) depicts the reconstructed potential using the regularized operator given Eq. (8). The hyperparameter $\lambda = 8000$ was obtained by minimizing the L1-norm of the reconstructed image.

Outlook

- QGIS Plugin
- Further stabilizing the downward continuation
  - Hyperparameter tuning for InfoMar data and non-even surfaces (seabed)
  - Further improvement of regularization techniques
- Classification of anomalies

Acknowledgements

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References

[1] Infomar 2007. infomar - a successor to the irish national seabed survey. proposal & strategy. https://www.infomar.ie/.

[2] Richard J Blakely. *Potential theory in gravity and magnetic applications*. Cambridge university press, 1996.

[3] Nelson Ribeiro Filho. https://github.com/nelsondelimar/master.

[4] Roland G Henderson. On the validity of the use of the upward continuation integral for total magnetic intensity data. *Geophysics*, 35(5):916–919, 1970.

[5] Pašteka R., Karcol R., Kušnirák D., and Mojzeš A. Regcont: A matlab based program for stable downward continuation of geophysical potential fields using tikhonov regularization. *Computers & Geosciences*, 49:278–289, 2012.