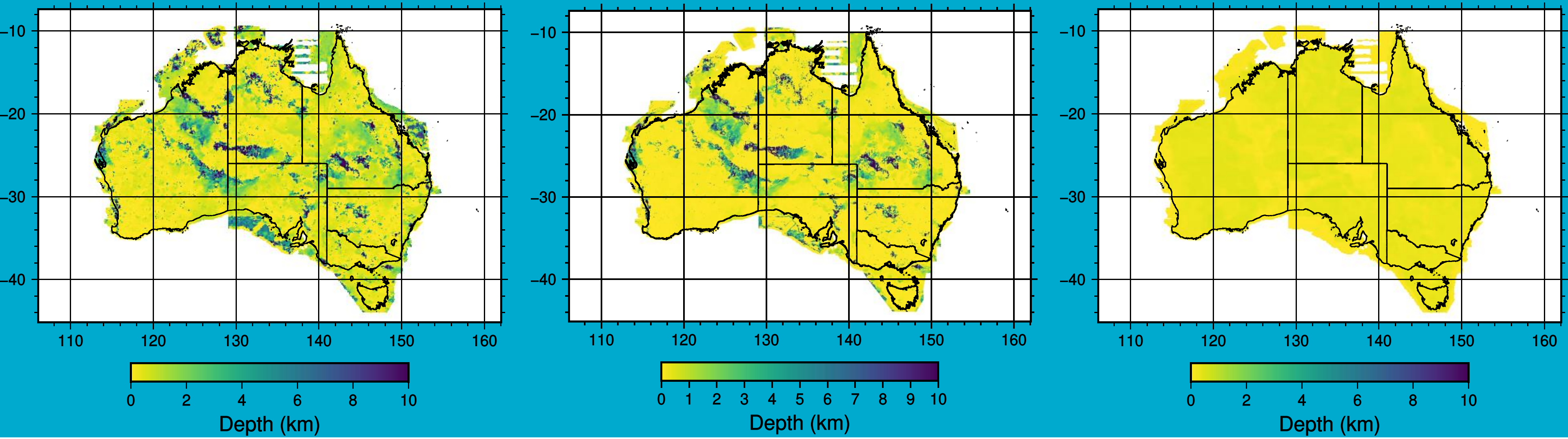

Selecting Optimal Frequency Range for Estimating Depth to Magnetic Sources

These slides have added text to cover the spoken portion of the presentation

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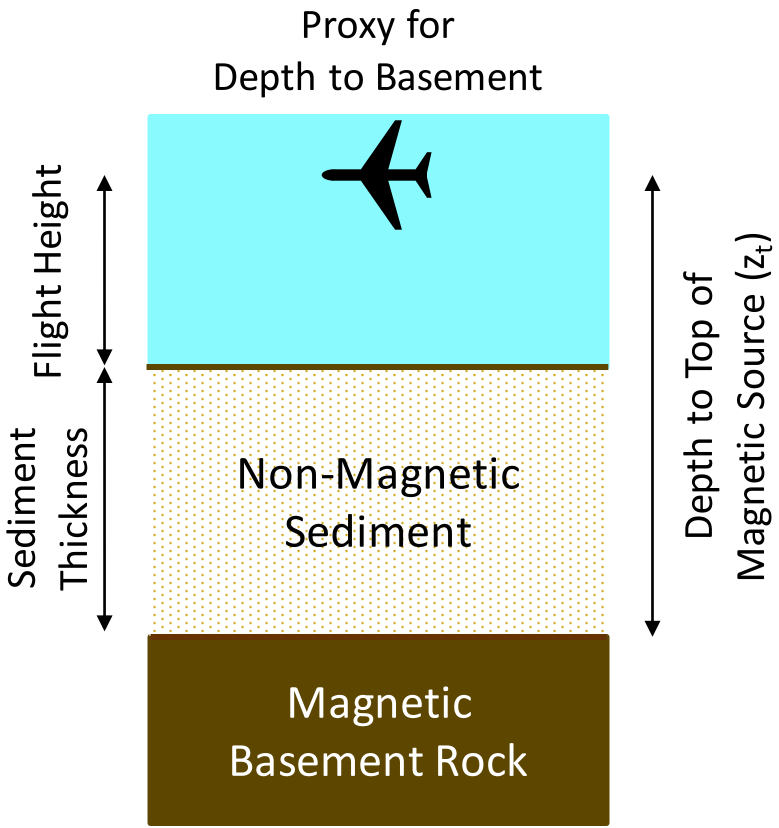
Australia's National Science Agency

CSIRO

Motivation

- Large quantities of aeromagnetic data are available, we want to analyse this data to create estimates of depth to basement, z_t
- We use spectral analysis because it is fast, but there are search parameters whose optimal values need to be determined
- We want an automated method for deciding these parameters, in particular the frequency range used and the window size
  - These parameters are often chosen survey wide, we want to determine locally-optimal values for these parameters

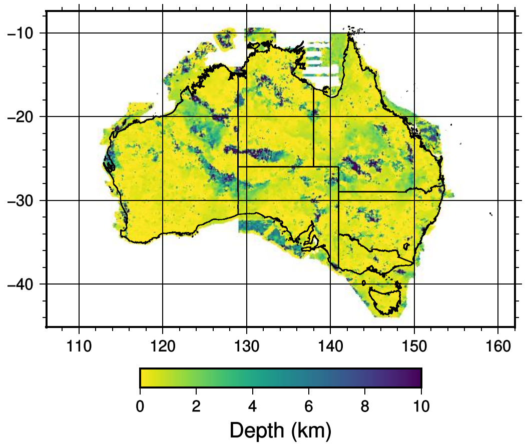


Outline

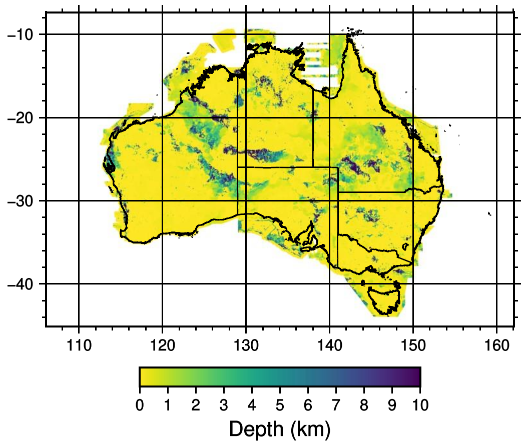
1. Introduction
   a) Motivation
   b) Outline
   c) Frequency Range Example
   d) Physical Model
2. Spectral Analysis Workflow
3. Frequency Range
   a) Frequency Range Example
   b) Choosing the Optimal Frequency Range
4. Demonstration on Australia
5. Window Size
6. Conclusion

Magnetic Depths Using Different Frequency Ranges

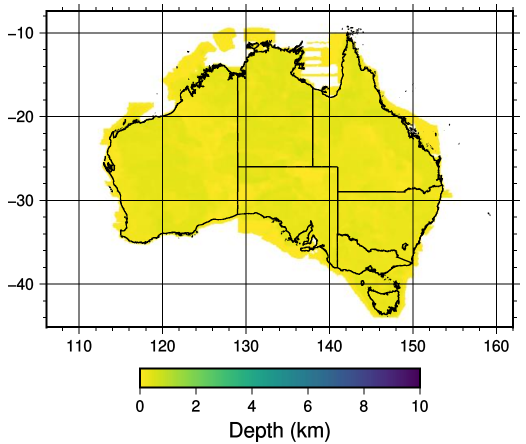
Up to 5 radians/km
Results are close,
but not robust



Optimal Range



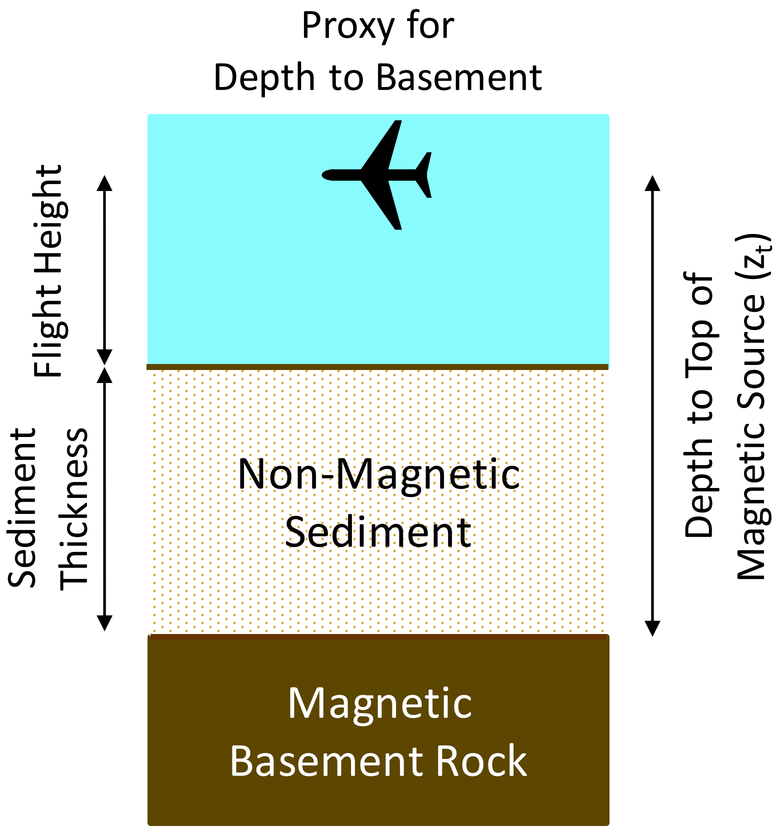
Up to 20 radians/km
Using more data,
but fitting to noise



Using the Magnetic Anomaly Map of Australia, 6th Edition,
by Geoscience Australia

Model

- We assume that the basement is a horizontal surface of randomly-magnetised material
  - The magnetisation of the basement rock is assumed to be fractally distributed, rather than uniform
- The basement is covered by some amount of non-magnetic sediment
- We are interested in the distance between the surface and the top of the magnetic layer, z_t
- The data is collected by a plane flying at a constant height above the ground
- The magnetic data is converted into a magnetic anomaly map
  - That is, it includes only the contribution from magnetic sources below the surface but not the Earth's or the Sun's magnetic fields



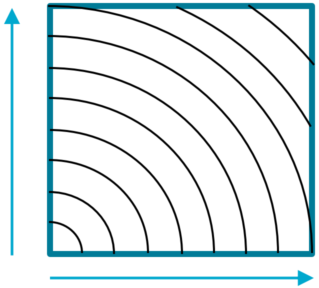
Spectral Analysis Workflow

Magnetic Anomaly Map $\xrightarrow{\text{Extract Window}}$ Window of Interest $\xrightarrow{\text{Multiply by Taper Function}}$ Tapered Window of Interest

$\xrightarrow{\text{2D Fast Fourier Transform}}$ Frequency-Domain Data

Frequency-Domain Data $\xrightarrow{PS[k_x, k_y] = |F[k_x,k_y]|^2}$ 2D Power Spectrum $\xrightarrow{\text{Take Logarithm}}$ Log of 2D Power Spectrum

$\xrightarrow{\text{Average with Radial Binning}}$ 1D Averaged Log of Power Spectrum $\Phi_{B,1d}[k_H]$ $\xrightarrow{\text{Fit Parameters}}$ Source Parameters C, z_t, β



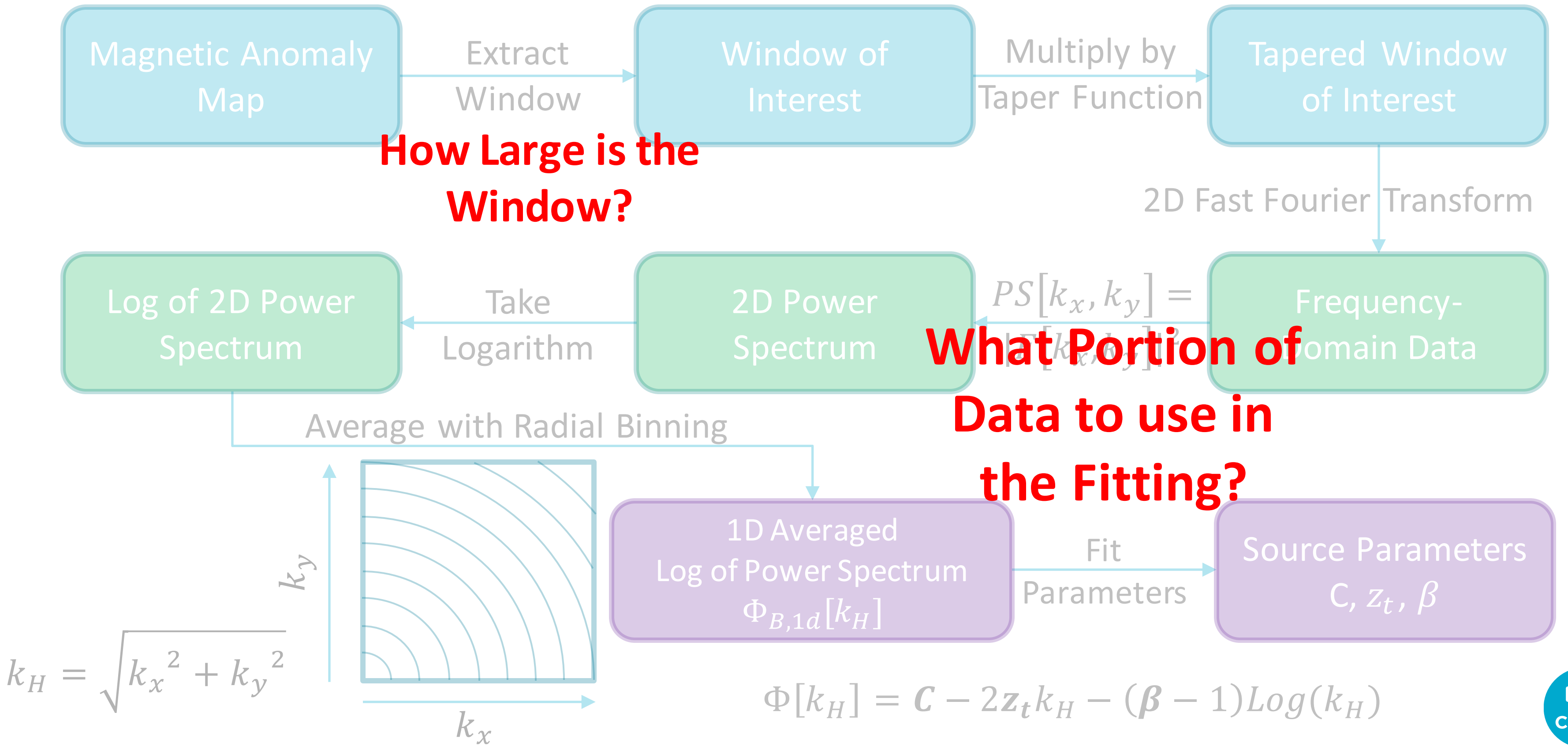
k_y

k_x

$$k_H = \sqrt{{k_x}^2 + {k_y}^2}$$

$$\Phi[k_H] = \boldsymbol{C} - 2\boldsymbol{z_t}k_H - (\boldsymbol{\beta} - 1)Log(k_H)$$

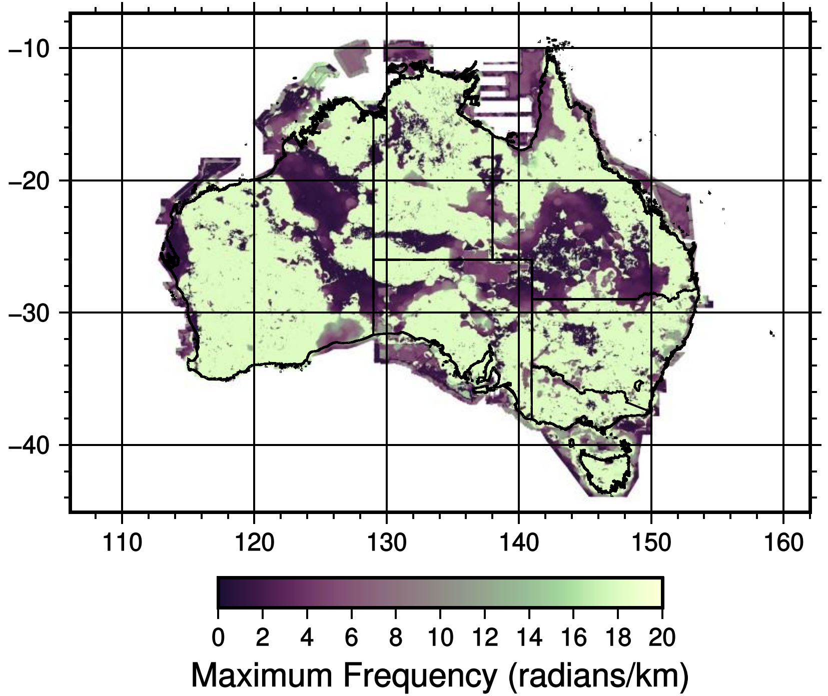
Spectral Analysis Workflow



Frequency Range

- The parameters are determined by fitting the model to the log of the magnetic power spectrum
- The signal we are looking for is stronger at lower frequencies, and weaker at higher frequencies
- Therefore the data is dominated by the signal at lower frequencies, but it becomes dominated by noise at higher frequencies
  - Here "noise" includes noise from data collection, imperfections in data processing, and sidelobes from the Fourier transform

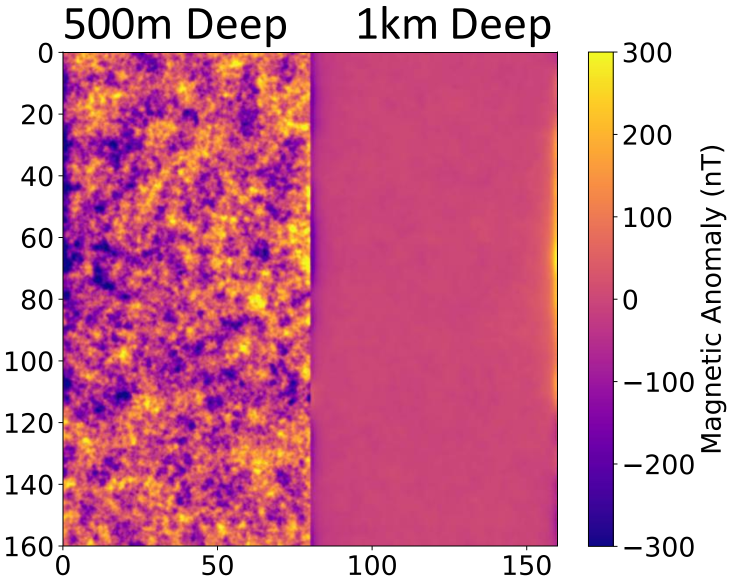
Optimal Maximum Frequency Across Australia



Frequency Range Examples

- Frequency range selection is a trade-off
- Using too little of the frequency range produces an unreliable fit
- Using too much fits to noise
- The crossover point varies between windows
- We fix the minimum frequency to that which corresponds to the un-tapered portion of the window

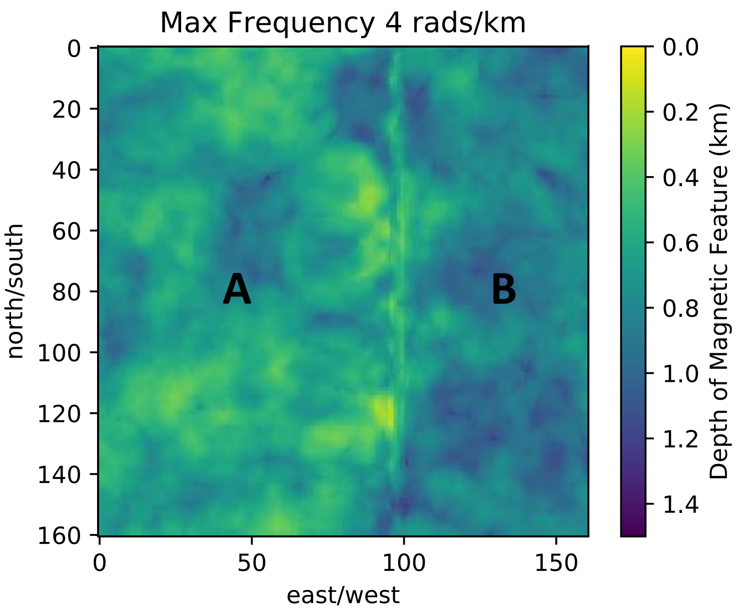
Example Magnetic Field with Two Basement Depths



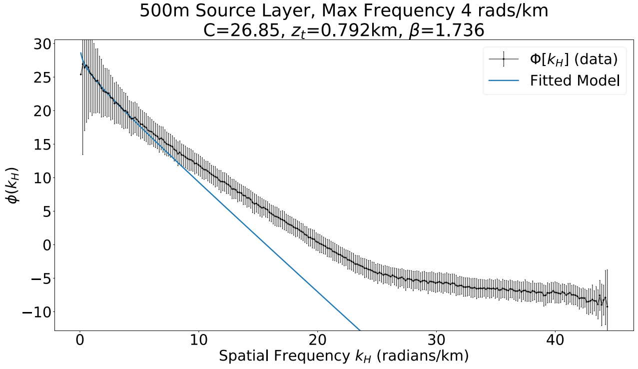
Frequency Range is Too Small

Synthetic Example

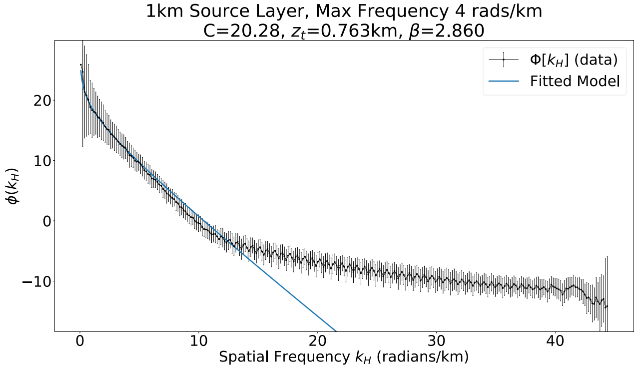
Layers at 500m and 1km Depth



A



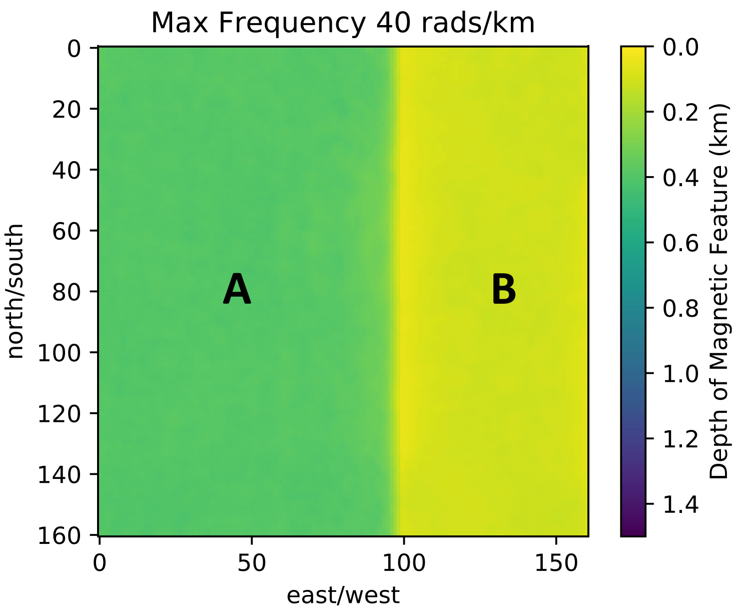
B



The layers are off-centre here because the shallower source is more prominent when both are present in the same window

Frequency Range is Too Large

Synthetic Example
Layers at 500m and 1km Depth



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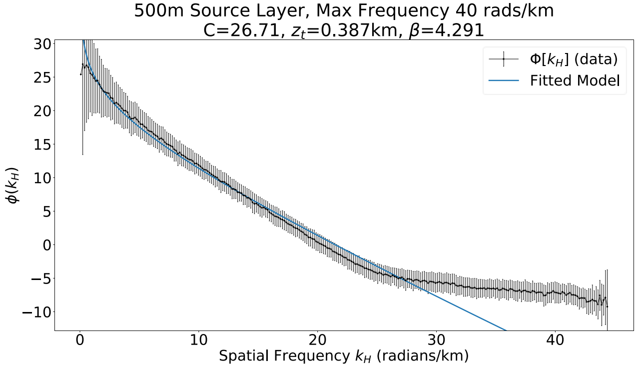

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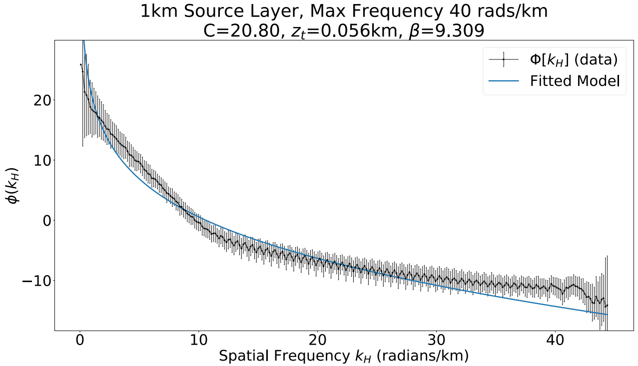
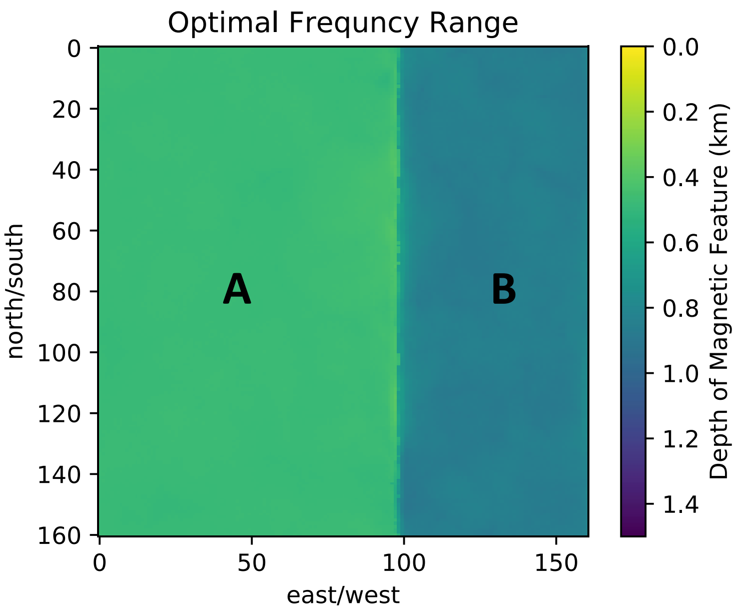


Optimal Frequency Range

Synthetic Example
Layers at 500m and 1km Depth



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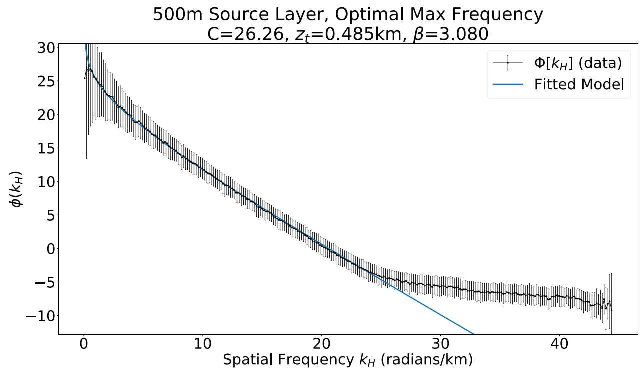

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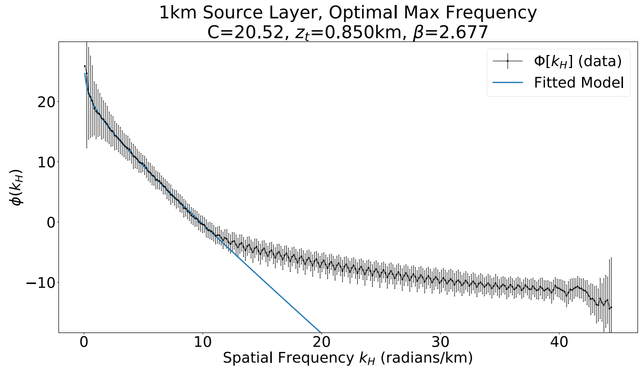
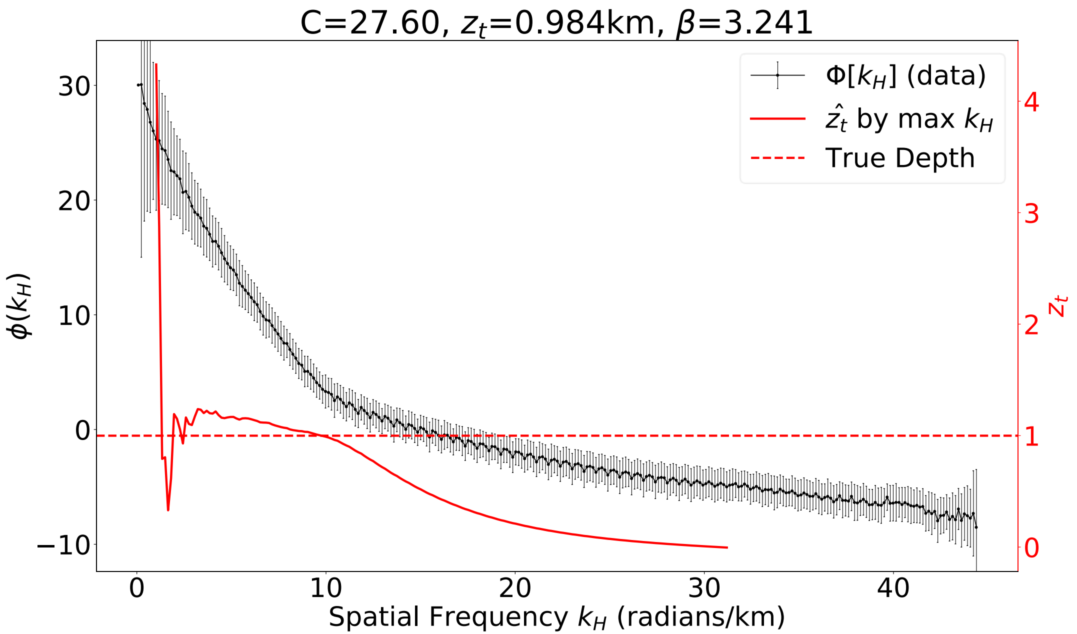


Choosing the Optimal Frequency Range

- We can see that the optimal frequency range changes in different windows from the same dataset
- We have devised an automated method for choosing the optimal frequency range, based on identifying the linear potion of the spectrum

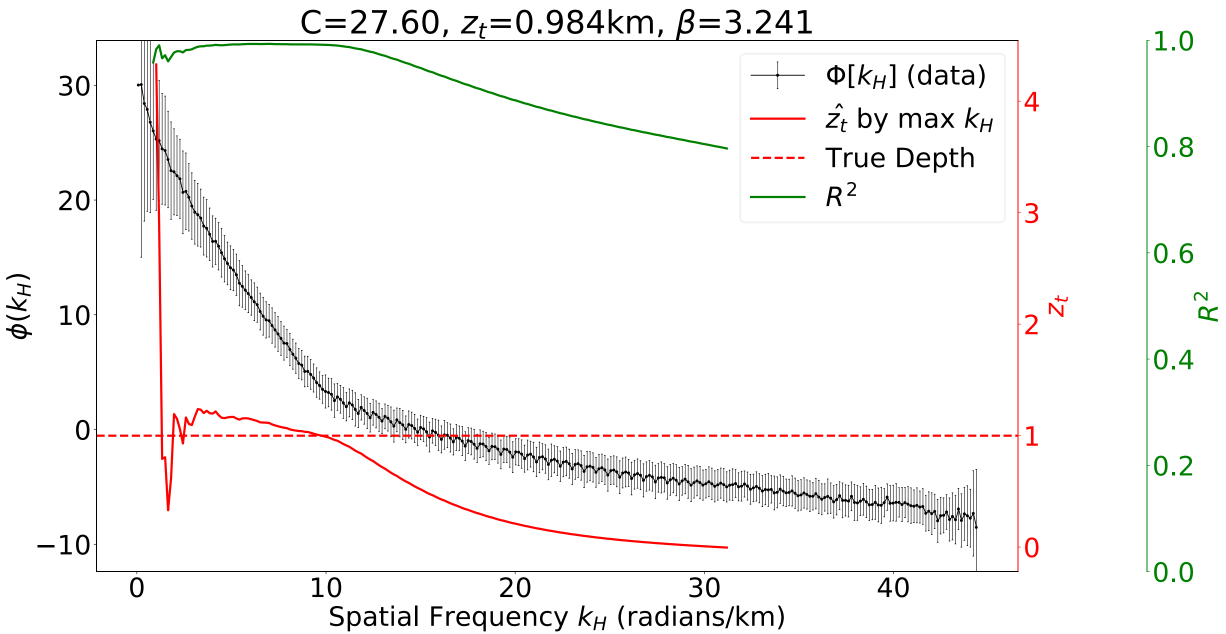
Choosing the Optimal Frequency Range



The red line shows the recovered depth z_t as a function of the upper limit of the frequency range for fitting

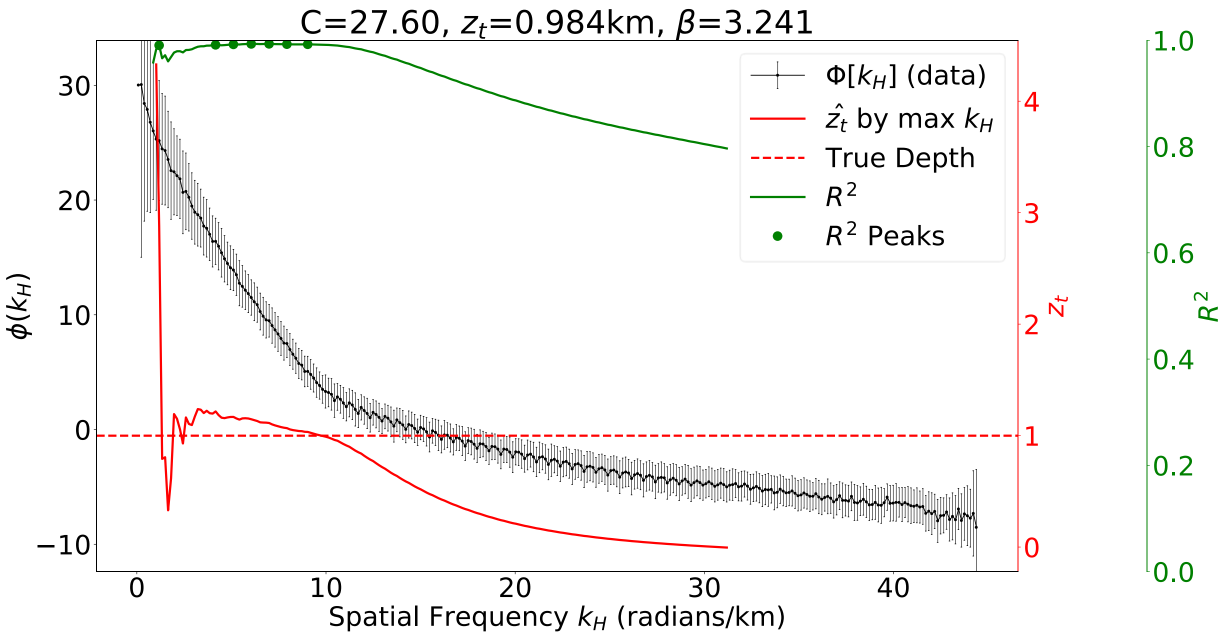
The dashed red line is the true depth for this example

Choosing the Optimal Frequency Range



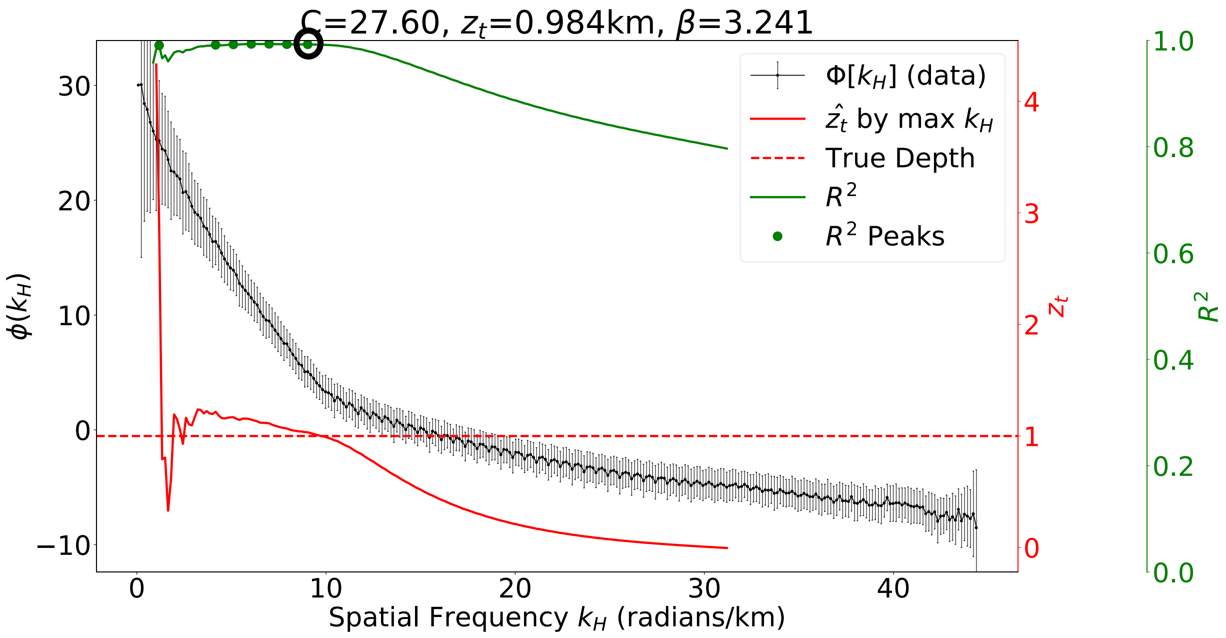
1. For each selection of data points, calculate the linear regression its R^2 value

Choosing the Optimal Frequency Range



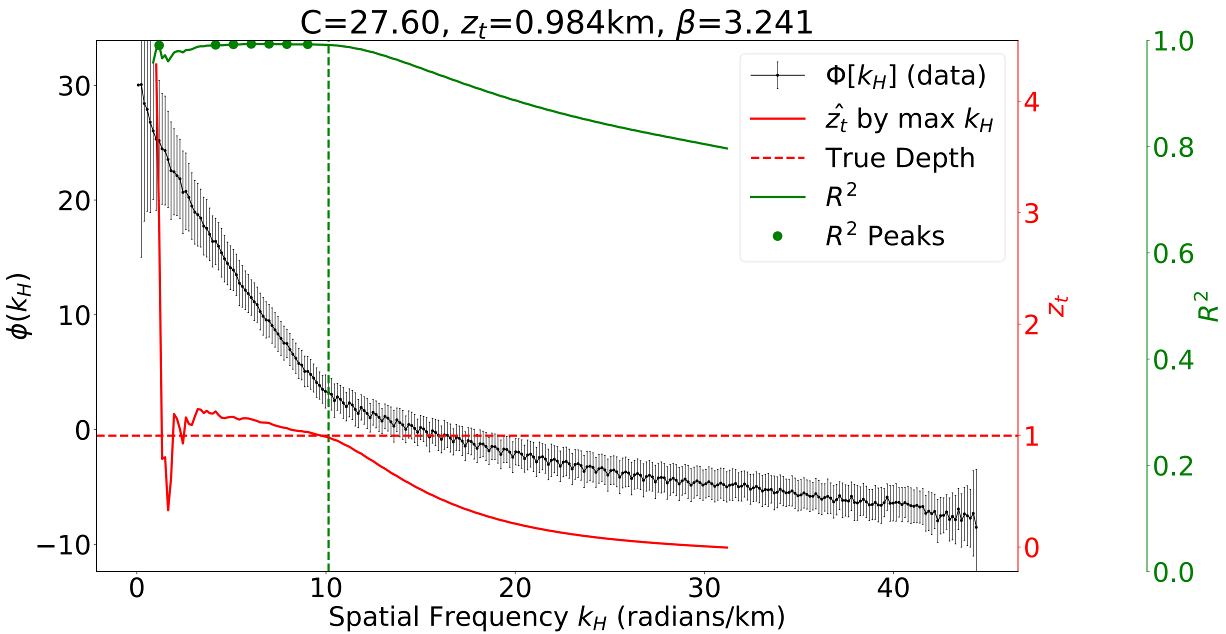
1. Calculate Linear Regression -> R^2 values
2. Identify peaks in R^2 values

Choosing the Optimal Frequency Range



1. Calculate Linear Regression -> R^2 values
2. Identify peaks in R^2 values
3. Choose max-frequency peak

Choosing the Optimal Frequency Range



1. Calculate Linear Regression -> R^2 values
2. Identify peaks in R^2 values
3. Choose max-frequency peak
4. Move to the edge of the plateau

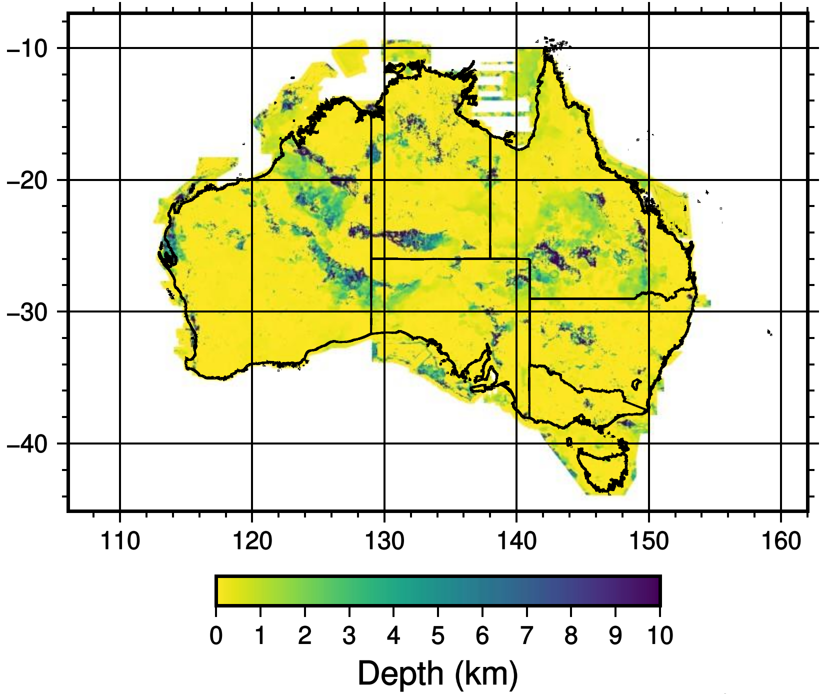
Move right until the R^2 is less than 0.999 the value of the chosen peak

Magnetic Depths of Australia

- We now demonstrate out method using data from Australia
- The dataset used is the Magnetic Anomaly Map of Australia, 6th Edition, produced by Geoscience Australia
- This data has been collected from 836 grids, compiled into a single map
  - The data has been normalized to a flight height of 300 metres, which has been subtracted from the recovered depth values to produce a sediment thickness map
- Our depths are compared against the OzSEEBASE v2 Sediment Thickness map
- The combines magnetic, gravity, seismic, borehole, and outcrop data in the places where they are available

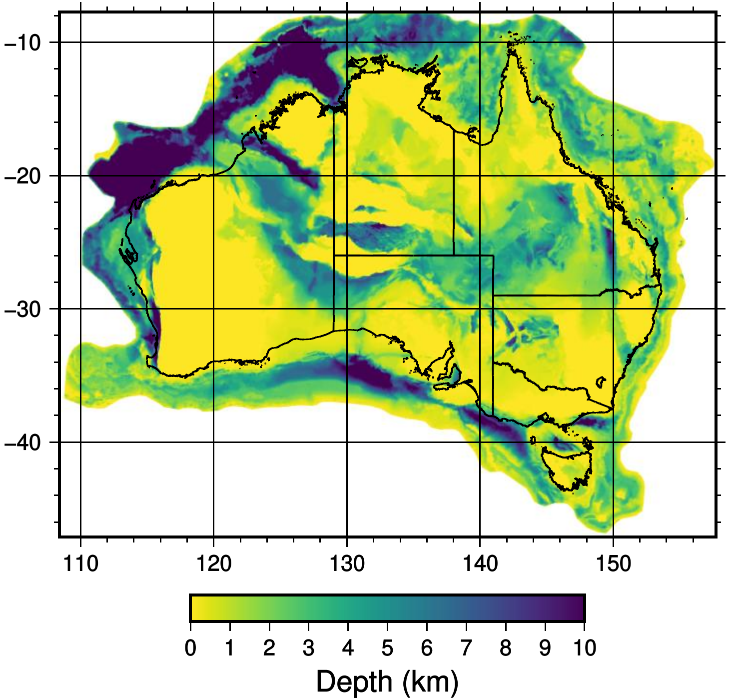
Magnetic Depths of Australia

Our Results



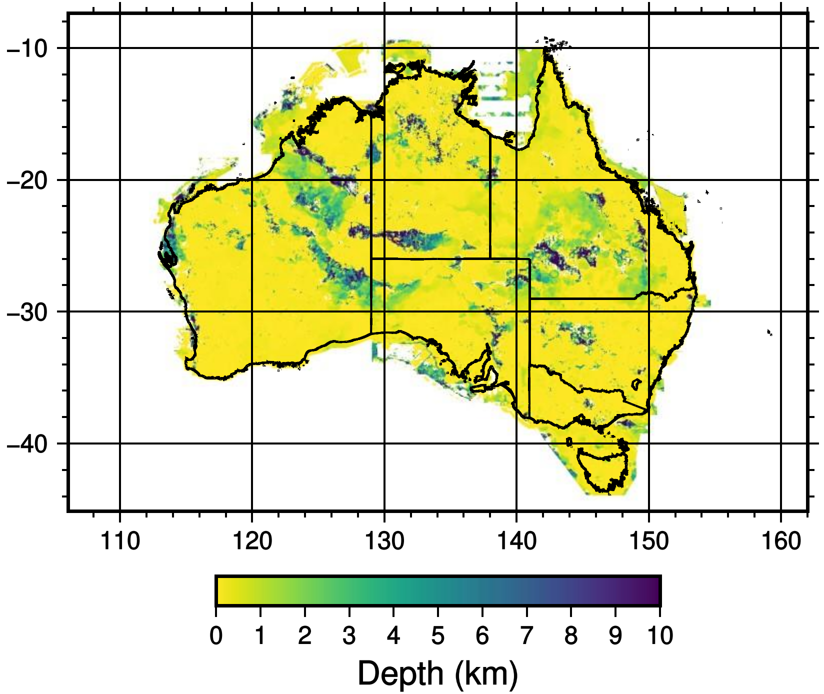
Using the Magnetic Anomaly Map of Australia, 6th Edition, by Geoscience Australia

OZ SEEBASE v2 Sediment Thickness

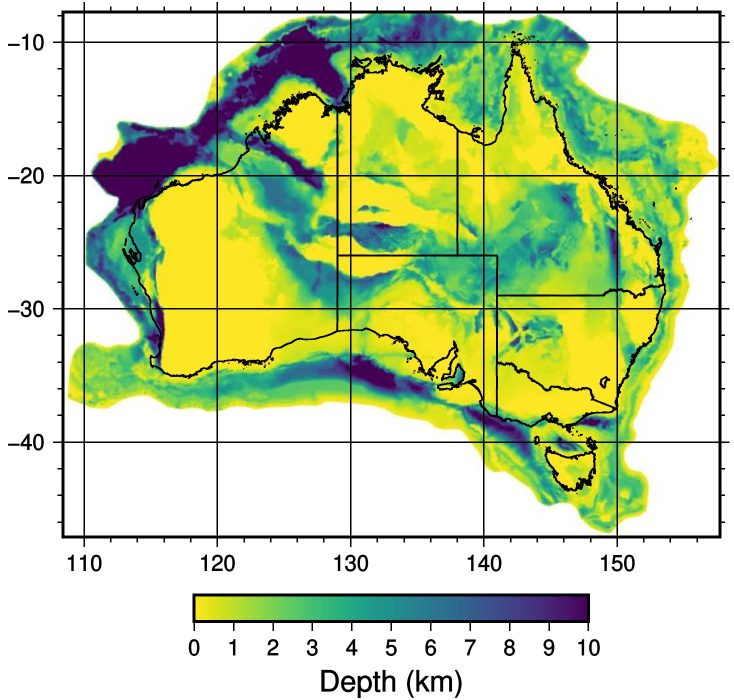


Magnetic Depths of Australia

Our results, Cleaned



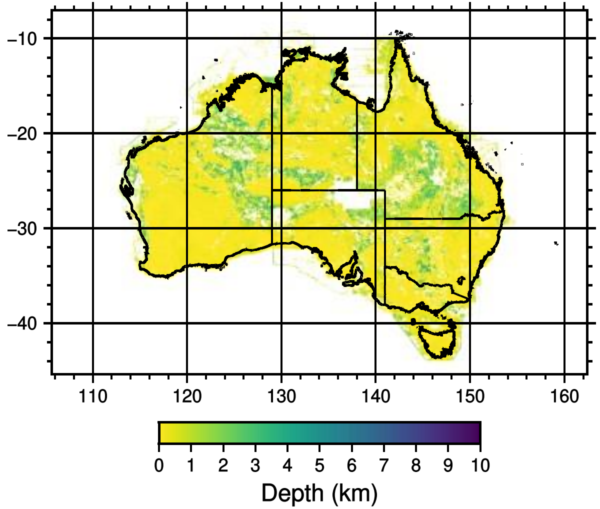
OZ SEEBASE v2 Sediment Thickness



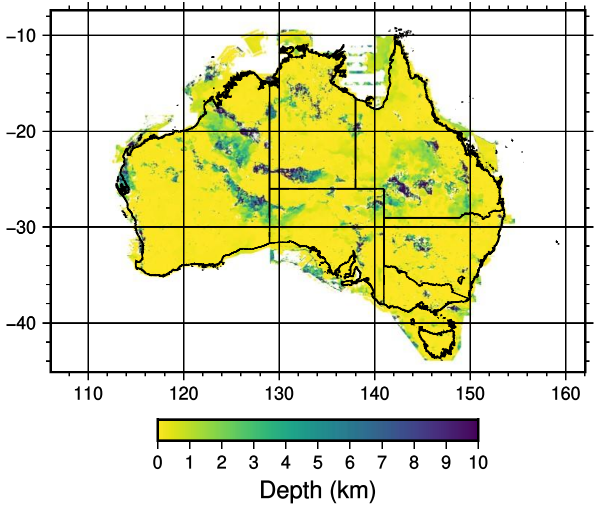
Remove depths that appear above observation height – these values are incorrect

But What About the Window Size?

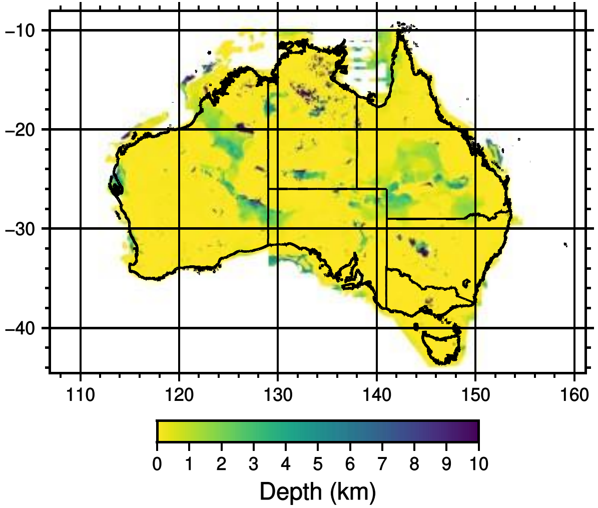
10km Window



40km Window
(Shown Previously)



100km Window



Window Size

- Window size is also a trade-off
- Larger windows include more data, which helps to average out randomness of the sources, and noise
  - This is especially important for deeper sources, which are visible in a smaller portion of the power spectrum
- But larger windows include data from new locations
- Larger windows might include signal from multiple sources, and the strongest source will dominate the data
- Therefore smaller windows improve locality

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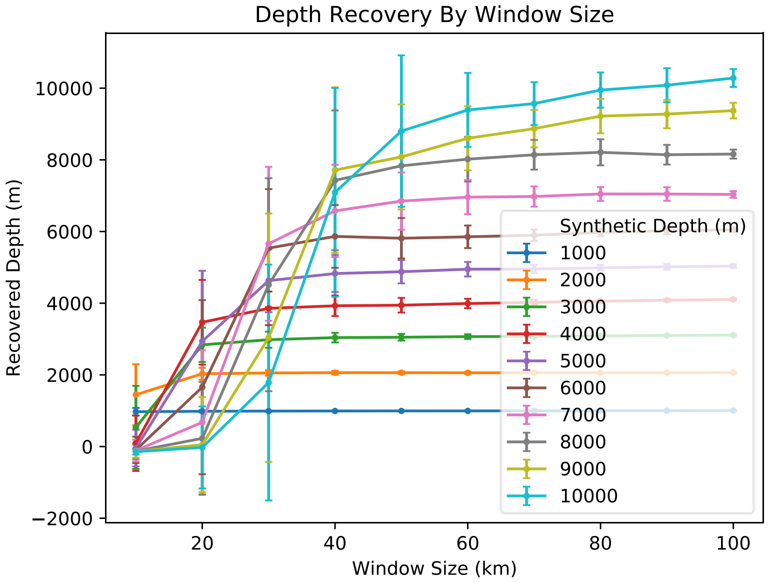
Window Size

- We want to use the smallest window size that still accurately recovers the depth
- We are still developing a method to do this robustly
- Using iteratively larger windows can be inconsistent, as changes in depth can be due to either improving the depth recovery or due to observing a new source on the edge of the window

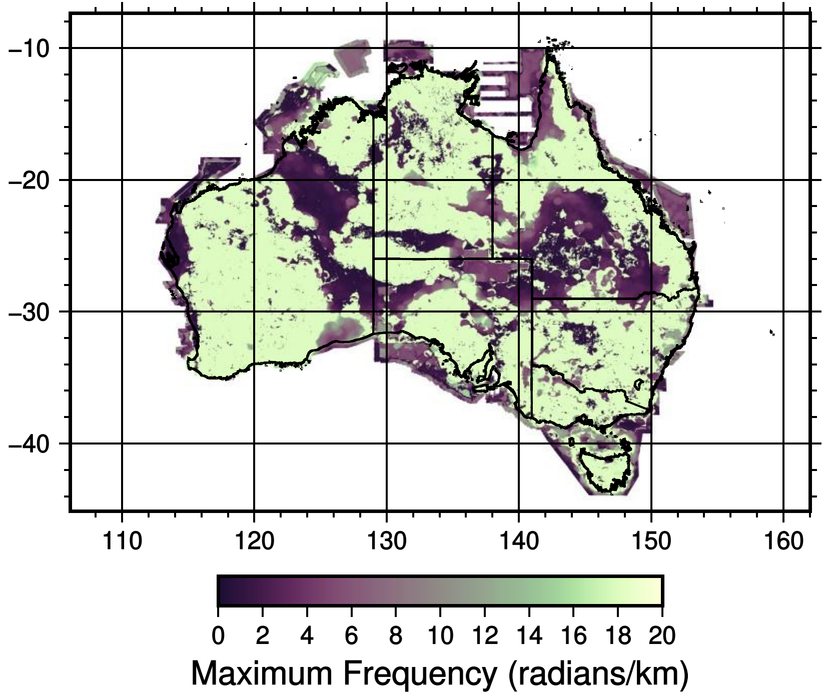
We can calculate the recovered depth as a function of window size and true depth, for synthetic data with a single layer



Conclusion

- Locally-optimal frequency range improves recovery of depth to basement
- Further improvement is possible by optimising the window size
- This technique is useful for automated, near-real time analysis of large data volume aeromagnetic surveys

Maximum Frequency Used
In Parameter Fitting (40km Window)



Thank You

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