The effect of alluvium on interpretation of geologic structure from gravity anomalies

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Outline

- Introduce a typical problem of deducing geologic structure from gravity anomaly curvature assuming homogeneously dense geologic units
- Briefly show that well data indicate density of alluvium is spatially correlated, and introduce a model of correlation
- Show the noise generated by the spatially correlated alluvial density interferes with the gravity anomaly curvature produced by the geologic structure
- Show how noise envelopes can help with understanding and visualization
- Conclusions

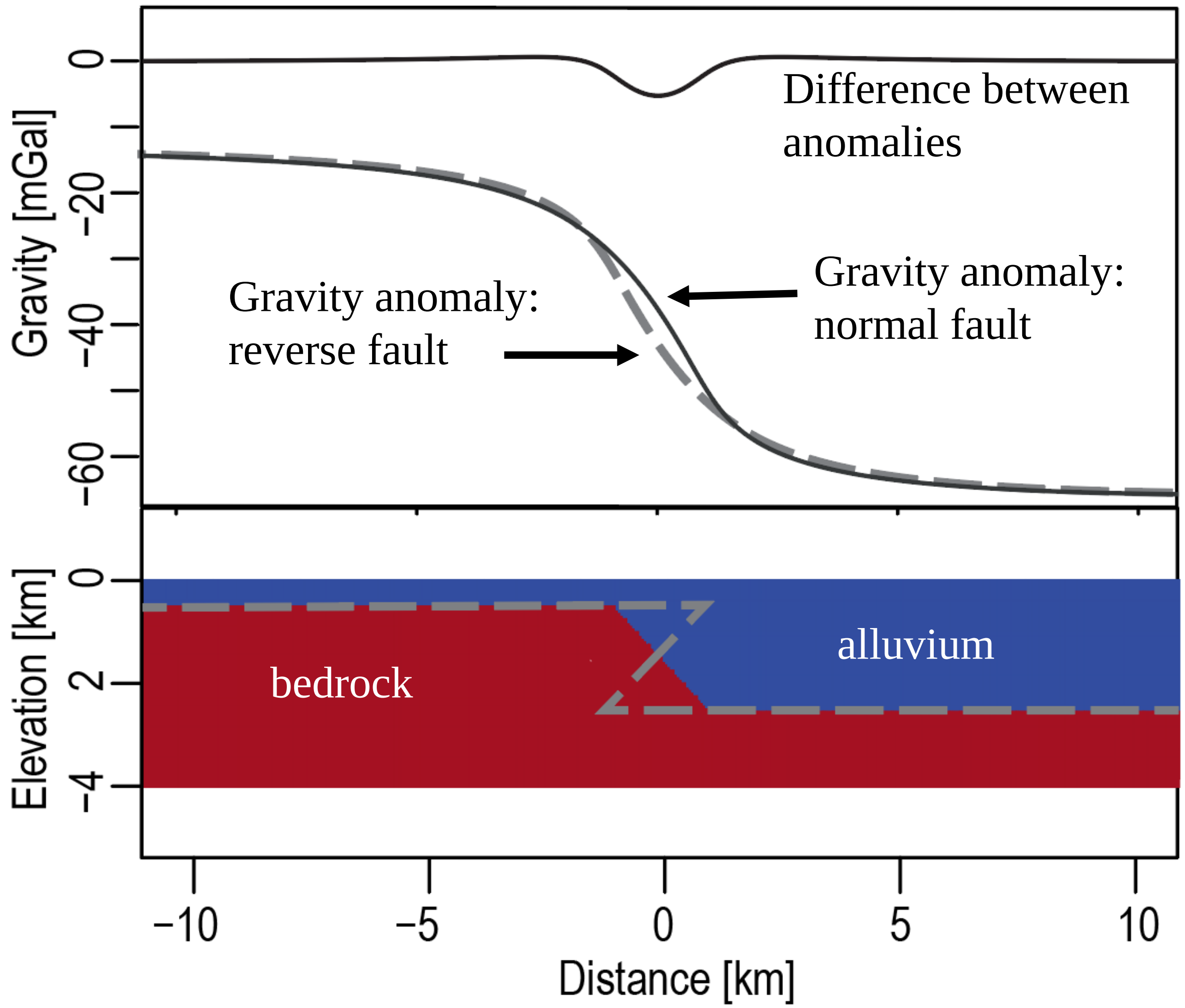
Typical geologic models and their gravity anomalies

Geologic models derived from gravity are often simplified, and units are assumed to be homogeneously dense.

- **Normal fault** model: 2 km offset ("red" = bedrock, "blue" = alluvium)
- **Reverse fault** model: 2 km offset (bedrock below dashed grey line, alluvium above)
- Bedrock density 2.67 g/cc
- Alluvial density 2.0 g/cc

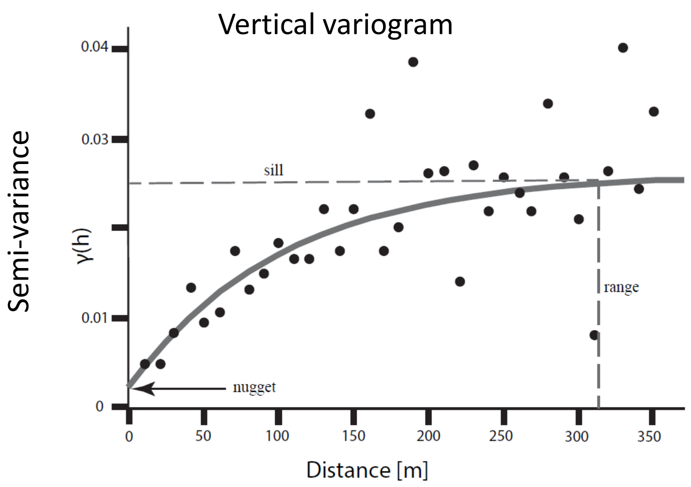
Signal at top is the difference between both anomalies, the signal one needs to detect in order to to distinguish one model from the other

ASSUME ALLUVIAL DENSITY IS NOT SPATIALLY CORRELATED

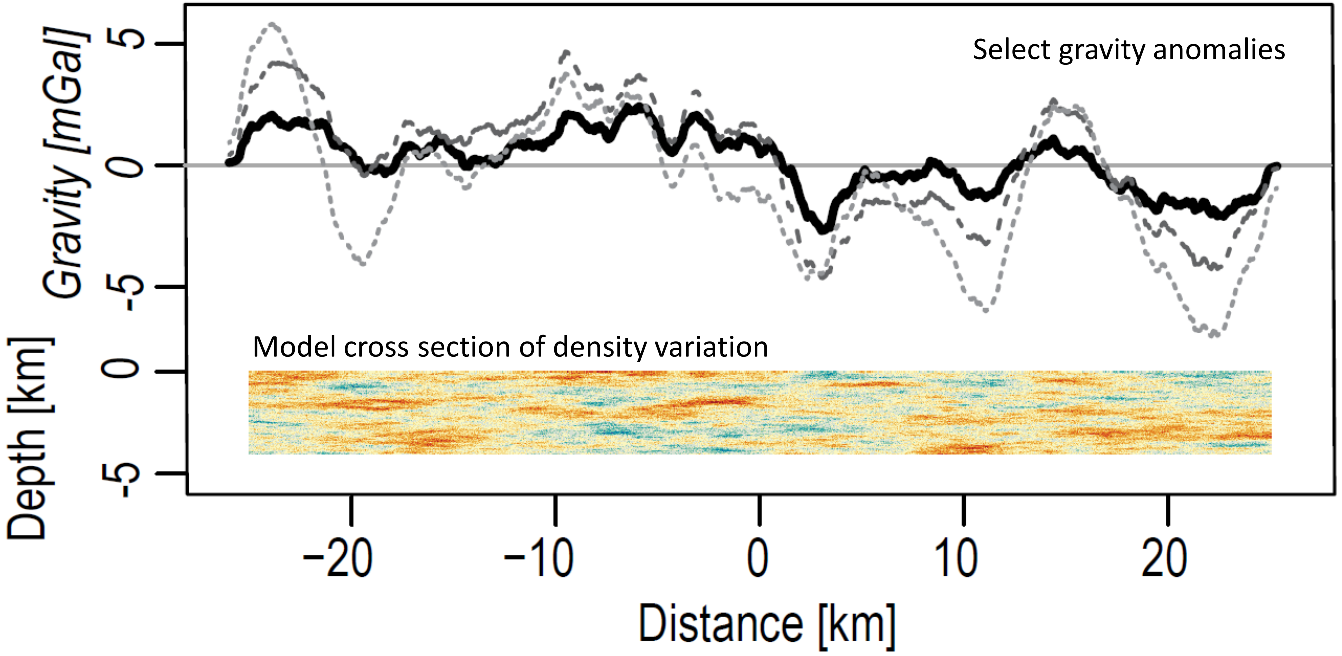


Alluvial density is spatially correlated; what does it look like?

- Model alluvial density as a Gaussian random field (image, lower right)
- Vertical variogram based on borehole gravity data from 18 drill holes in Yucca Flat and vicinity, Nevada (figure, right)
- Insufficient data for characterizing the horizontal variogram, but
    - Horizontal correlation length likely >> vertical (geologic principles)
    - Density likely correlated with mapped geology
- Correlation length vertical: ~300 m
- Correlation length horizontal: ~3 km
- Warm colors, above mean
- cool colors, below mean
- Standard deviation 0.15 g/cc

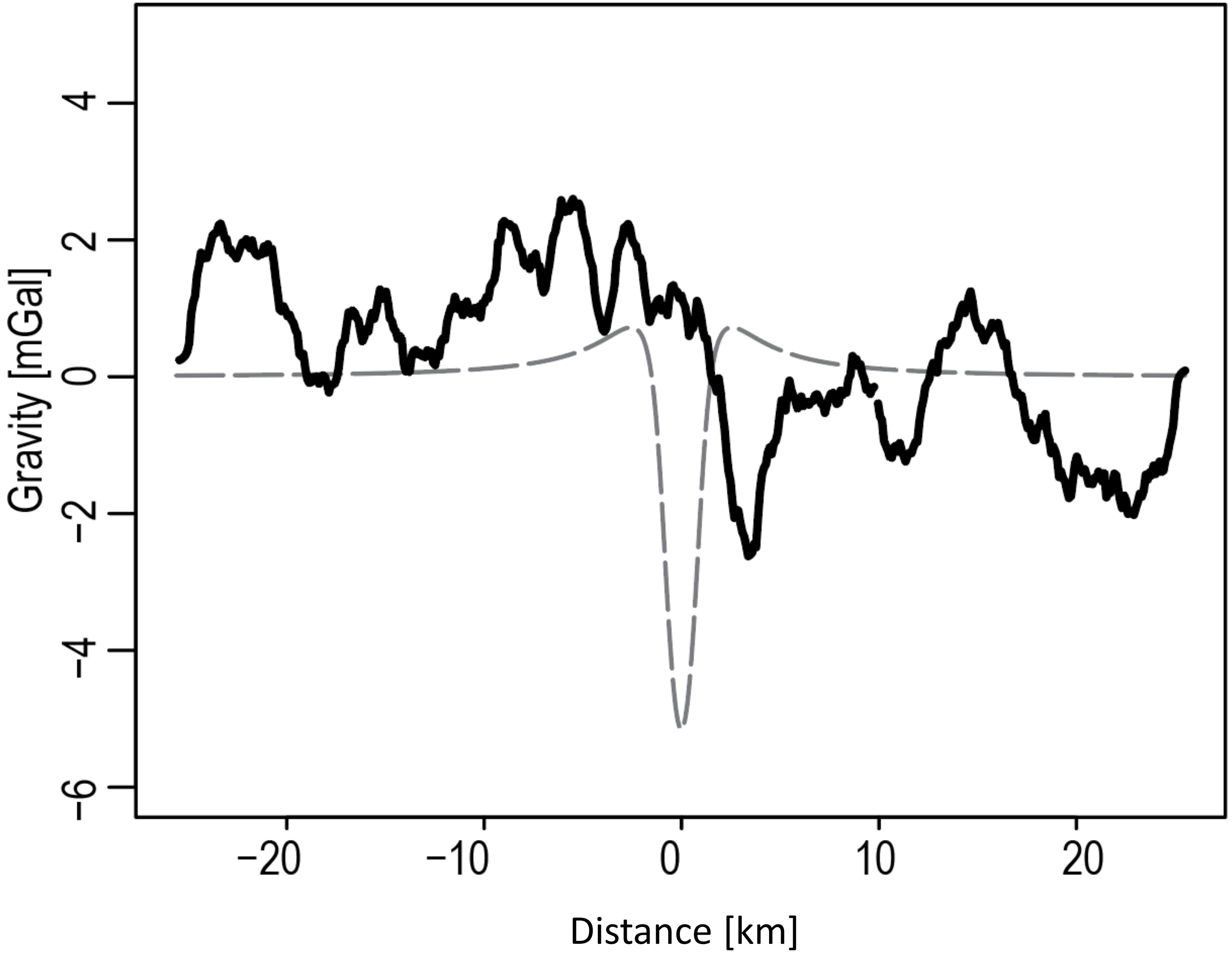


Model entire cross-section volume for better understanding. Calculate the gravity anomaly caused by ONLY upper 200 (solid black), 500 (long-dash grey), and 1000 m (short-dash grey).



Noise from 200 m of alluvium compared with the signal

- Noise from one realization of 200 m of alluvium (black)
  - Noise amplitude: ~5 mGal
- Signal (from slide 1), the difference between the normal and reverse fault models (dashed grey)
  - Signal amplitude: ~6 mGal
- Noise amplitude from 200 m of alluvium is large compared to the signal needed to detect the difference between the two fault models

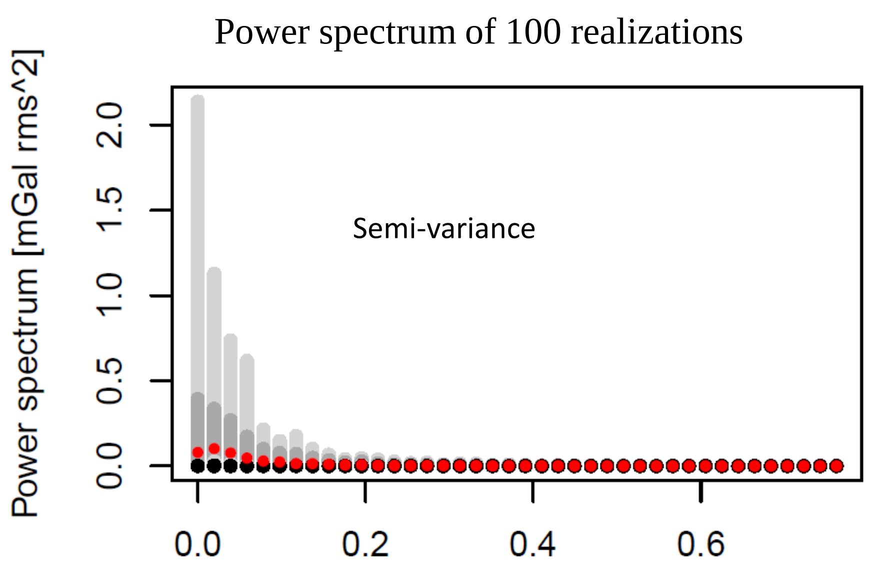


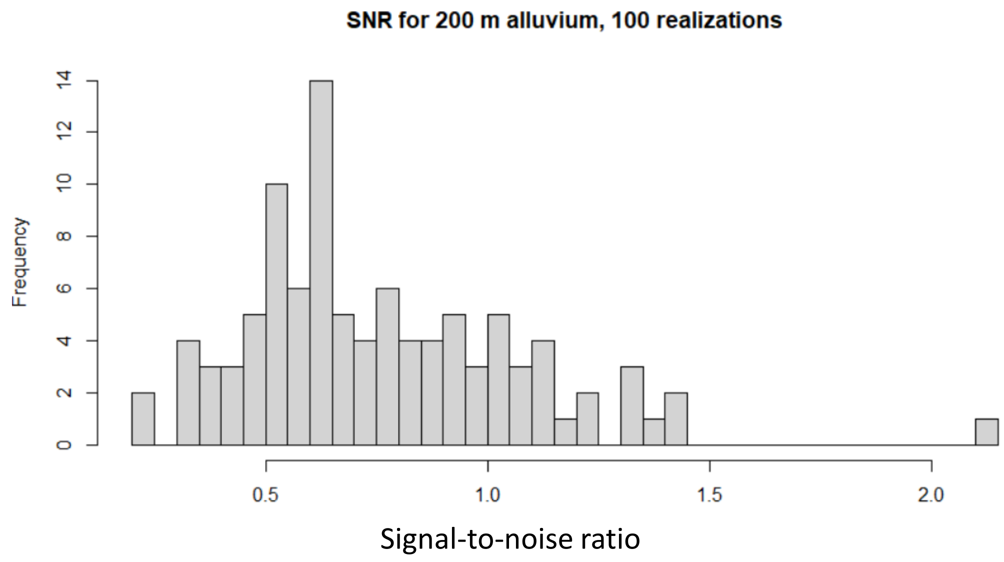
Are longer wavelengths caused by deeper sources?

Not always

- Given 100 realizations of alluvial density:
- Power spectrum of 100 realizations of noise from 200 m of alluvium, showing the distribution d100 (light grey), d90 (dark grey), d50 (red), d0 (black)
    - Power is concentrated in the lower frequencies
    - Peak frequency distributed across the lower four frequencies
- SNR mostly below 1, best-case ~2.2
- Even with ***perfect sampling***, 200 m of alluvium will contaminate the signal

Noise from alluvium may be confused with signal from deeper sources



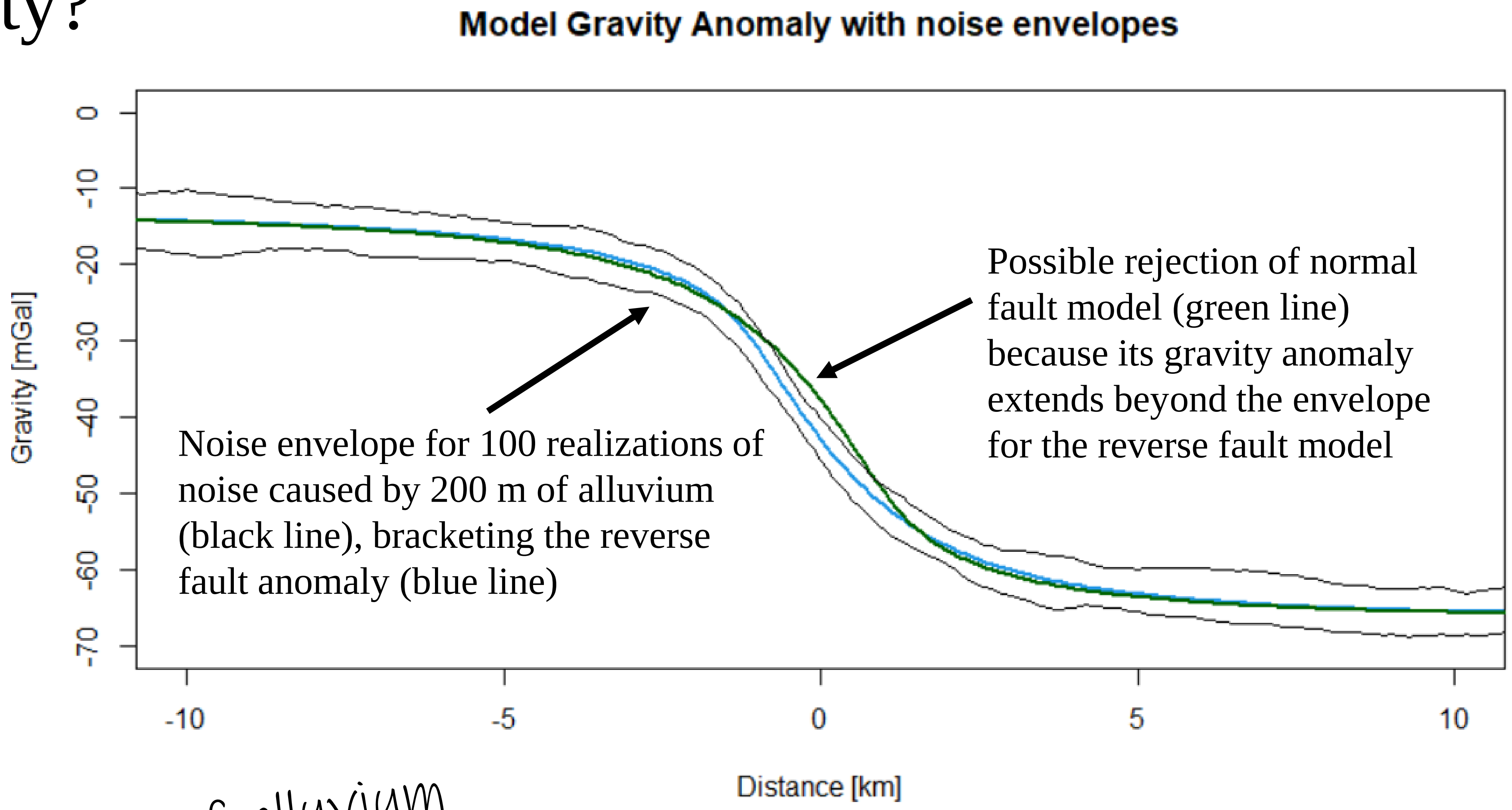


How to manage the uncertainty?

If the alluvium can be modeled as previously shown, then envelopes can be defined around a given model by calculating the anomaly for a set of noise realizations and demarcating the envelope they generate around the fault model.

This may help to reject some models

Add noise envelopes to the model

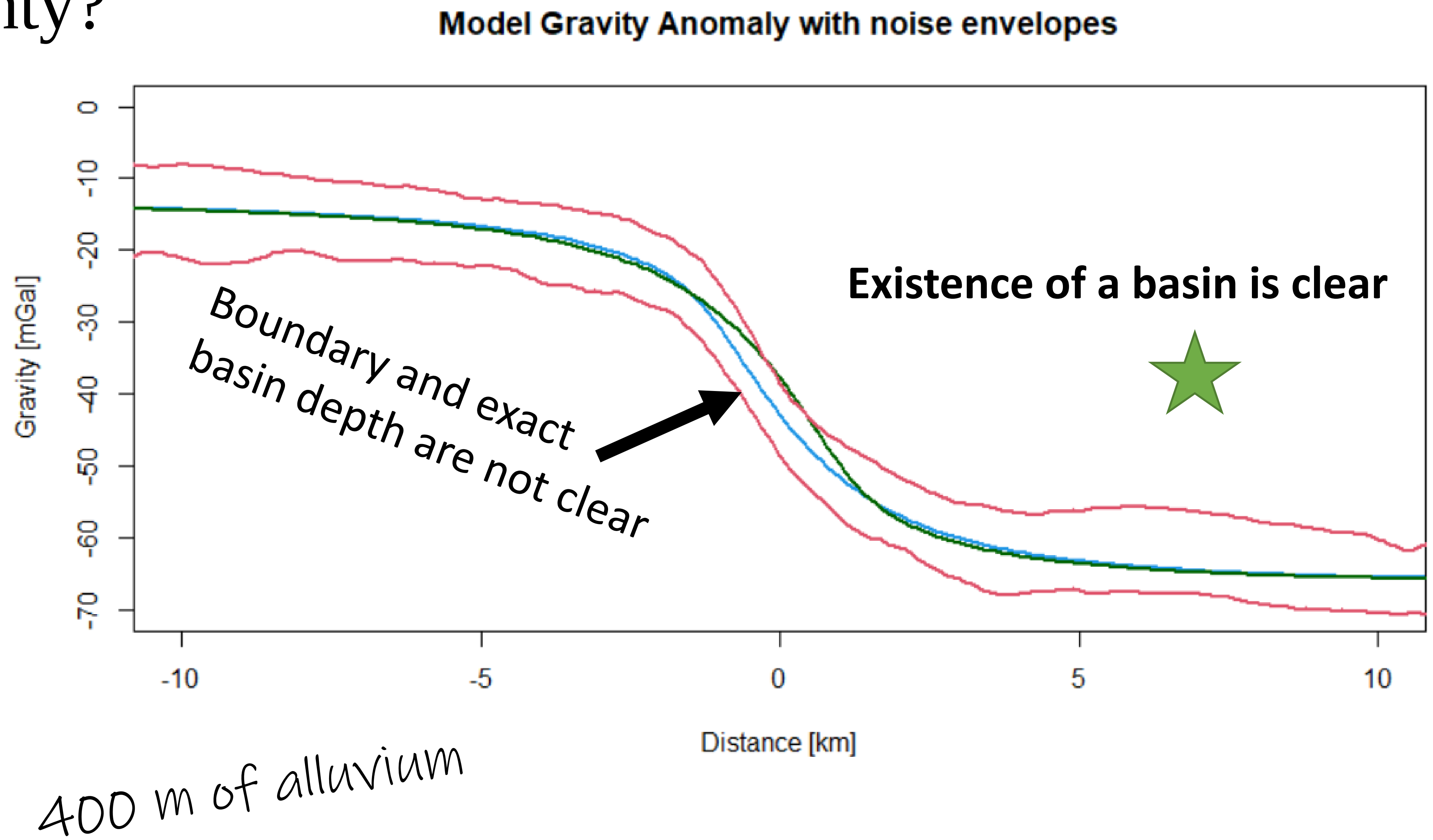


200 m of alluvium

How to manage the uncertainty?

The noise may be too large to distinguish the desired signal. This knowledge helps avoid model overfitting. With 400 m of alluvium adding noise to the signal, the boundaries of the basin (e.g. normal/reverse fault model) are uncertain, but the general shape of the basin is clear despite uncertainty at edges and depth.

Understand the limitations



Conclusions and Questions

- Density of alluvium (and rock) is **spatially correlated**, not independent
- Correlated density variations **add low-frequency noise** to the gravity signal
- Alluvium adds enough noise to obscure the shape of moderately deep (> 500m) source boundaries
- Uncertainty envelopes can help with understanding the set of permissible geologic models

Does seismic velocity exhibit similar noise properties?

What would be the effect on process models, e.g. ground motion?

Can test this using existing velocity data and a similar strategy