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Virtual Conference

Wellbore Positioning Technical Section

The Industry Steering Committee on
Wellbore Survey Accuracy (ISCWSA)

Three Considerations in Building an Accurate Crustal Magnetic Field Model

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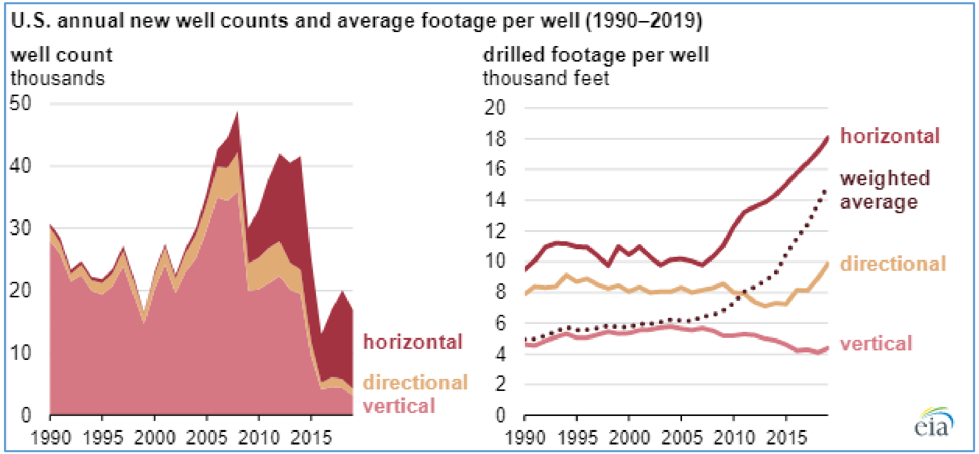
Xcalibur Multiphysics

Longer and Closer Horizontal Wells Require More Accurate Positioning

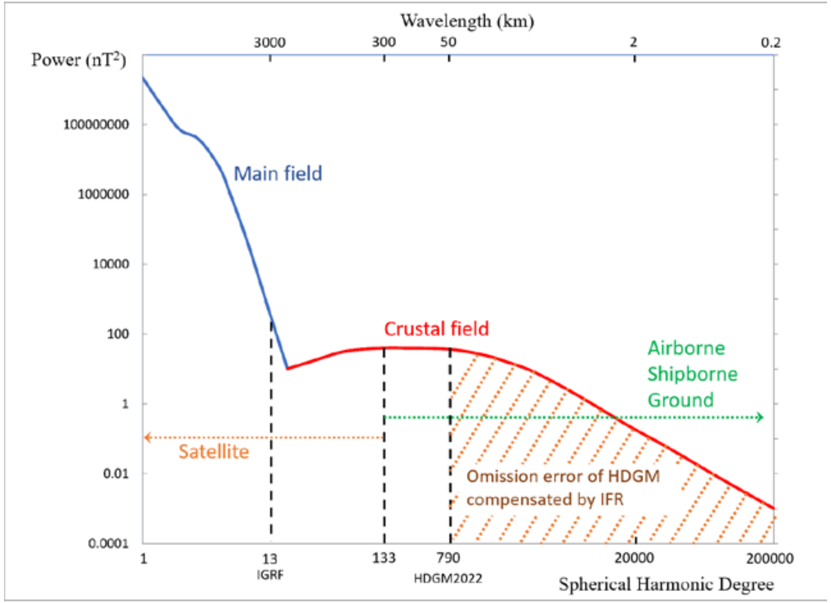
"By drastically increasing the horizontal length of wells, producers have increased production despite using fewer rigs and drilling fewer wells."



http://www.eia.gov/todayinenergy/detail.cfm?id=44236

- Wells are drilled not only longer but also closer.
- Reducing the positional uncertainty becomes more important when a geological target gets smaller, a wellbore is longer, and multiple wells are spaced closer.
- The IFR technique that uses local magnetic data increases wellbore positioning accuracy.

Geomagnetic Reference Field Model and IFR

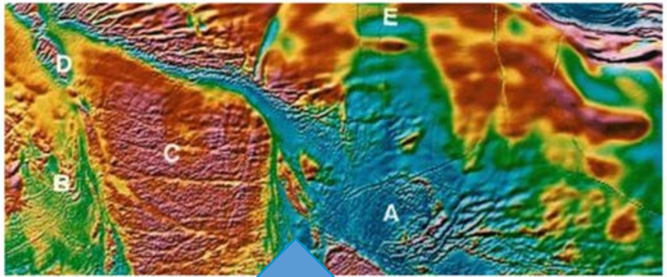


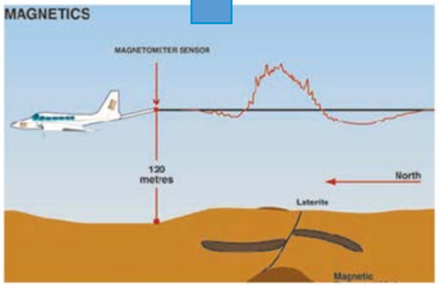
Full wavelength (km) = 111 * 360 / SHD

- SHDs 16 and above are of the crustal magnetic field. SHD 133 is the resolution of satellite magnetic data. Shorter-wavelength information is determined by local airborne, ground, and shipborne magnetic surveys.
- Global geomagnetic reference field models contain very long wavelengths of the crustal field. IFR is designed to reduce the omission error on top of these global models.
- The local magnetic data grid must have a dimension of at least twice the spatial resolution of the reference field model.

Derivation and Use of an IFR Model

Scalar crustal TMI anomaly on surface

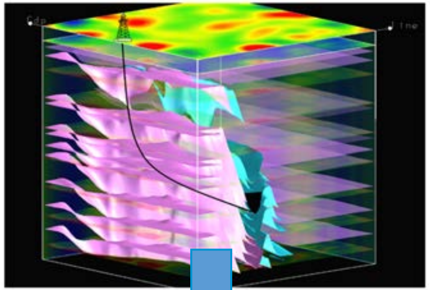




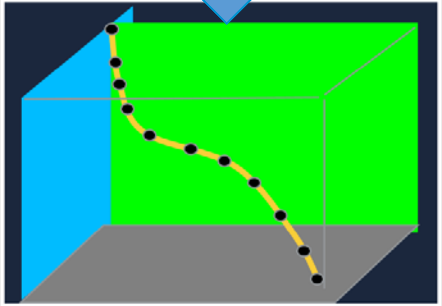
Downward Continuation

Scalar to Vector Conversion

Vector magnetic field at depths



3D interpolation



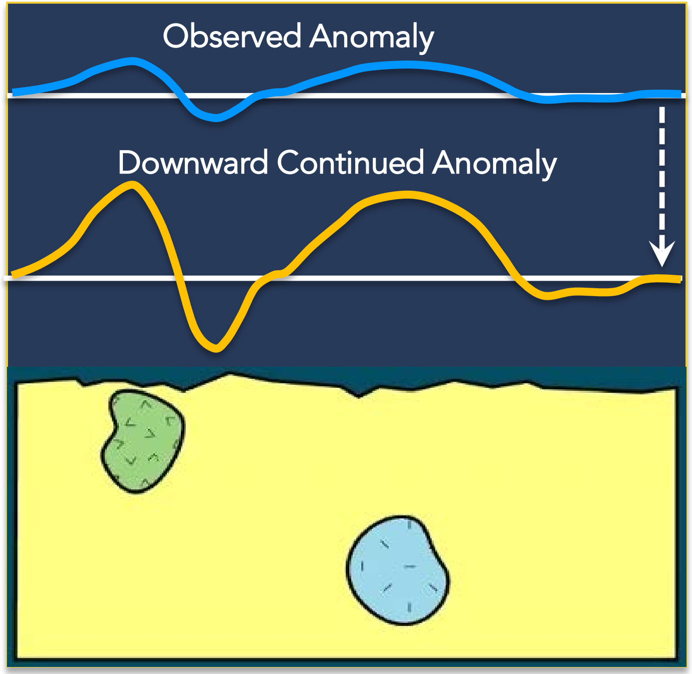
OWSG Error Model Global Values (1-sigma)

	MWD	MWD + IFR1
Declination (º)	0.36	0.15
BH-Dependent Declination (º x nT)	5000	1500
Magnetic Dip (º)	0.2	0.1
Total Magnetic Field (nT)	130	50

Three Considerations

- Geological constraint in downward continuation
- Variable declinations and variable inclinations (dips) in conversion
- High-resolution aeromagnetic data

Downward Continuation



- The magnetic field decays with the cubic of the distance.
- The magnetic field gets stronger when we drill deeper or closer to crustal magnetic sources (e.g., geological basement).

$$|B| \sim r^{-3}$$

Downward Continuation by the Fourier Transform Method

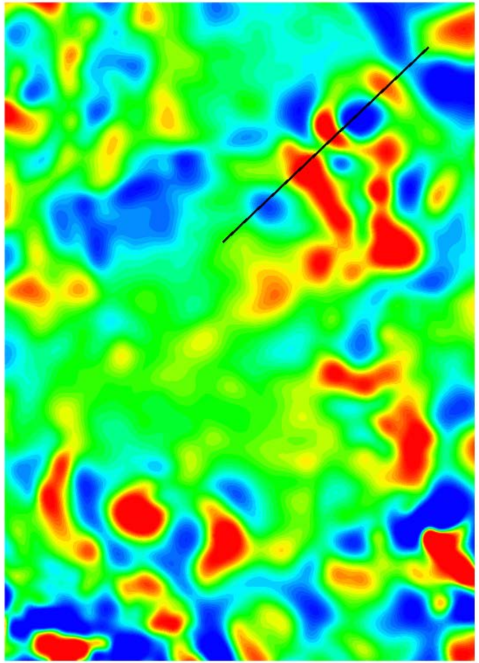
$$F(T_{down}) = exp(kz)F(T_{obs})$$

- *k* is the wavenumber (frequency) and *z* is the continuation distance
- Downward continuation is unstable and amplifies shorter-wavelengths and noise extremely
- Different tricks can be used to stabilize the continuation
    - A low-pass filter before or after the continuation
    - Application of damping to the operator

$$F(T_{down}) = \frac{exp(-kz)}{exp(-2kz) + \alpha k^n} F(T_{obs})$$

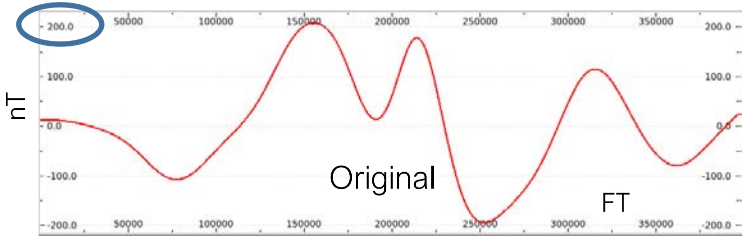
- Different continuation distances require different cutoffs of a filter or different damping values
    - Parameter choice is arbitrary and has no geophysical or geological meaning
    - Such a modification means changes to the observed magnetic data

Examination of Downward Continuation

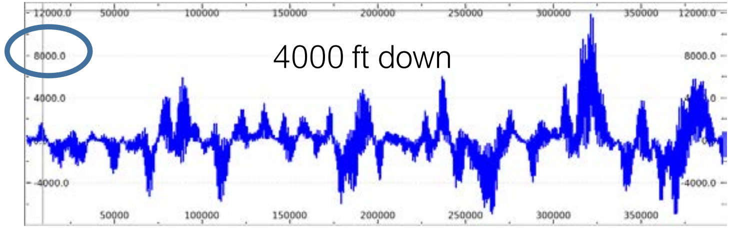


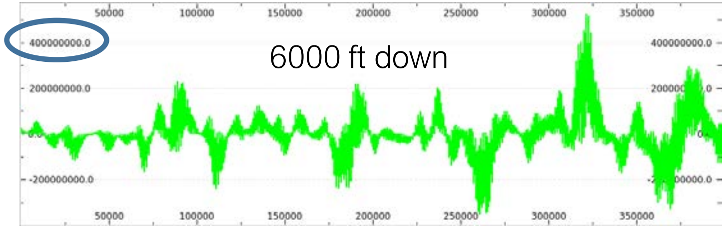
- This magnetic anomaly grid will be downward continued 4000 ft and 6000 ft, respectively.
- We check the continuation results along the profile.

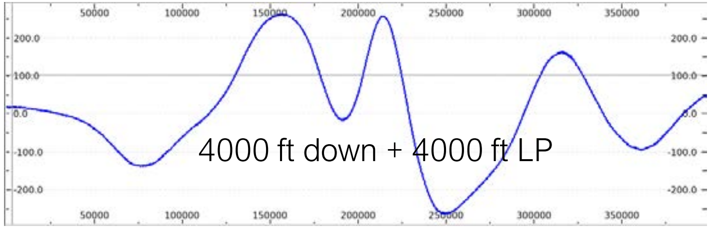
Downward Continuation by the Fourier Method

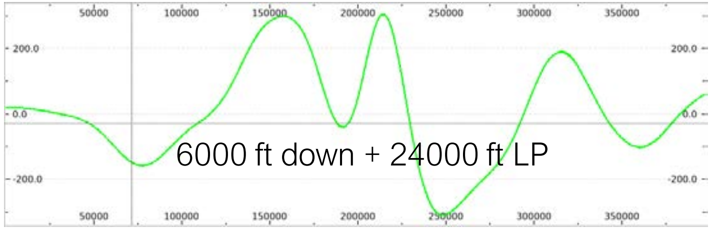


Different continuation distances require different cutoffs for a low-pass filter or different values for a damping factor.

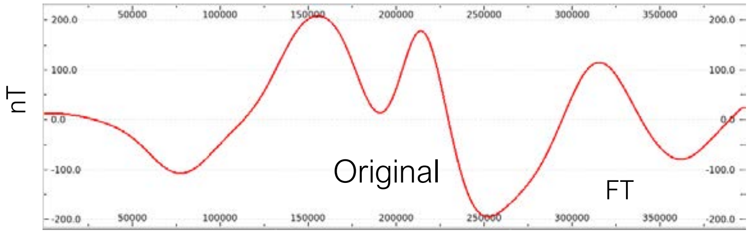




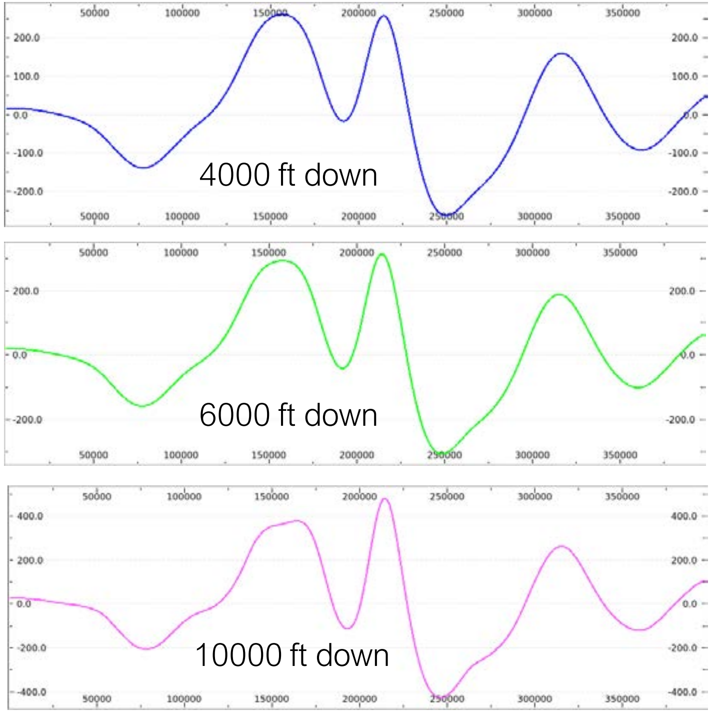




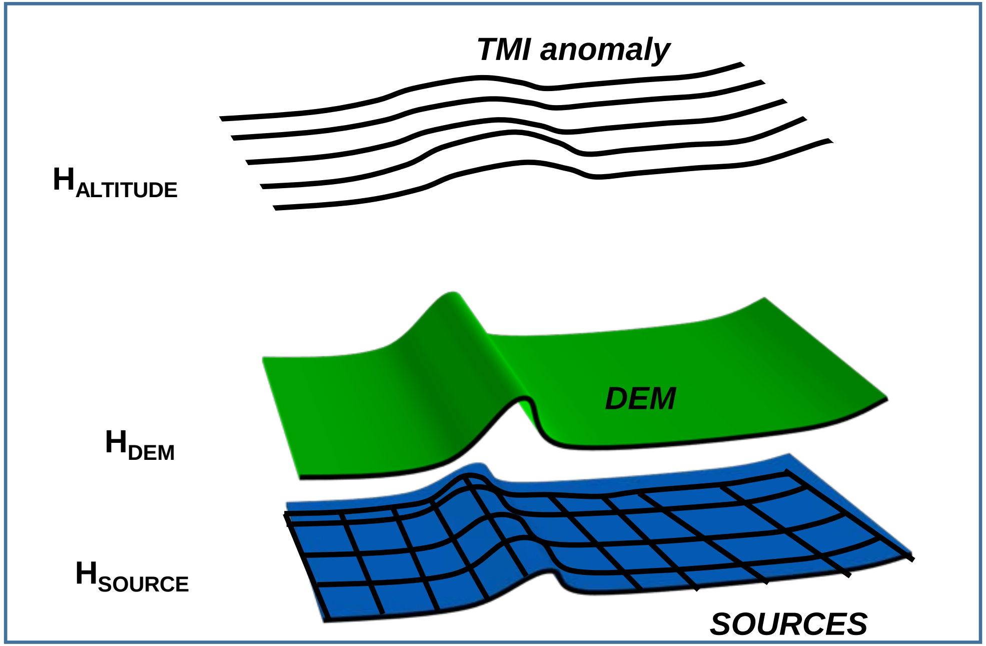
Downward Continuation by the Equivalent Source Method



- Results at all continuation depths are produced by the same equivalent sources placed at 14000 ft below the observation surface.
- These results are stable and make geological sense.

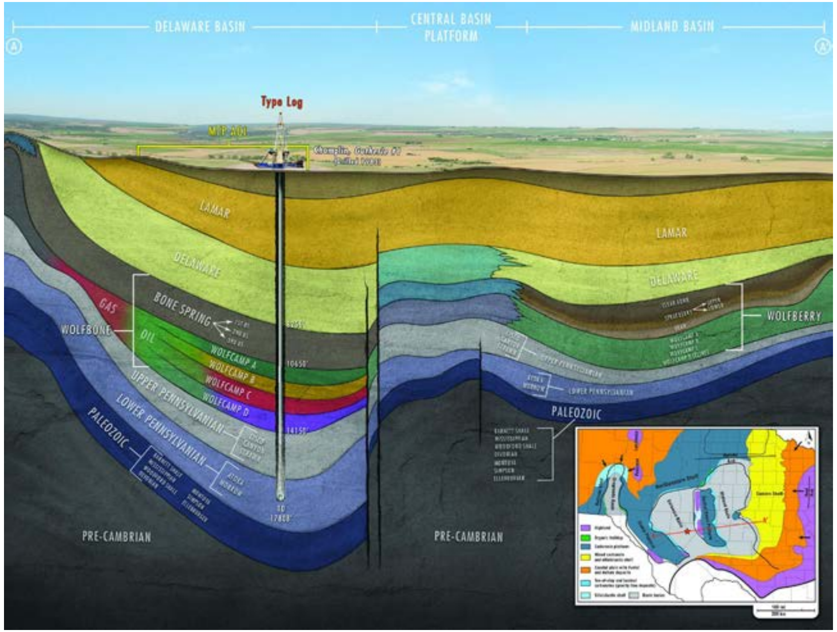


Downward Continuation by the Equivalent Source Method



- Observed anomalies can be interpreted by fictitious (equivalent) sources because geophysical inversion is non-unique.
- The equivalent source technique works for an undulating observation surface and is stable.

Sediments over Basement: The Permian Basin



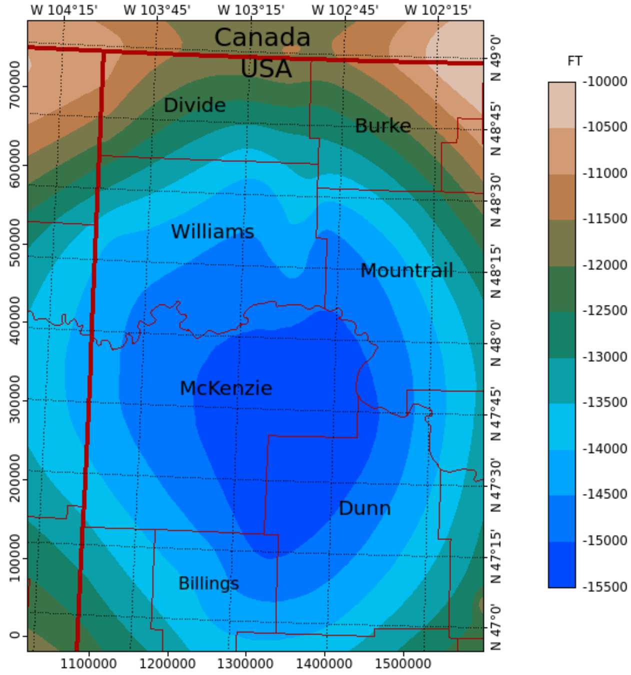
https://wiki.seg.org/wiki/Permian_basin#/media/File:Tarka-Permian-Xsection.jpg

In a sedimentary basin

Sediments contain no significant magnetization

Basement has significant magnetization variations and produces dominant crustal magnetic anomalies

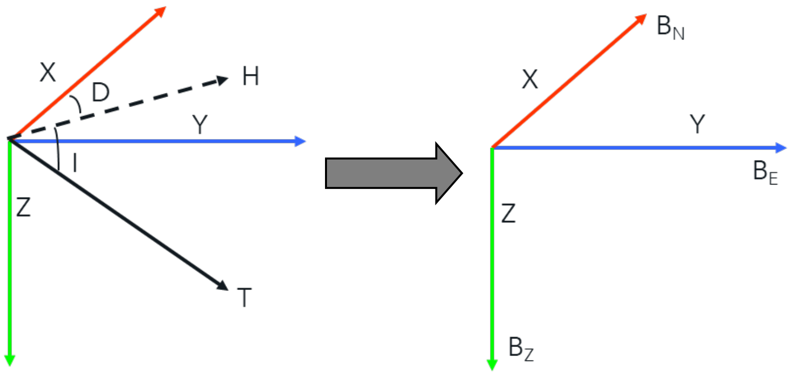
Basement Depths in the Bakken



Equivalent sources can be placed on the top of the basement of the Williston Basin – A geological constraint

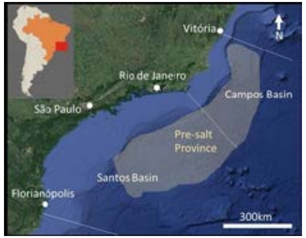
- Depths are subsea in feet
- The coordinate system is NAD83 / North Dakota North (US ft)

Scalar (T) to Vector (B_E, B_N, B_Z) Conversion

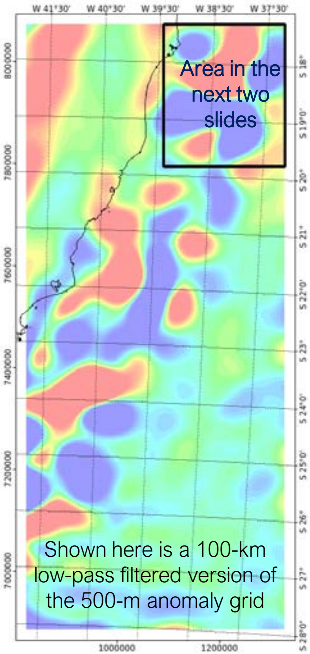


- The scalar TMI (total magnetic intensity) anomaly (T) is in the direction (inclination I and declination D) of the local geomagnetic field.
- The direction of the geomagnetic field varies from point to point (exactly speaking).
- This conversion is done for a surface, not a profile not a point.
- Routine algorithms for this conversion use a constant declination and a constant inclination.
- When the data area is large, variable declinations and variable inclinations need to be considered.

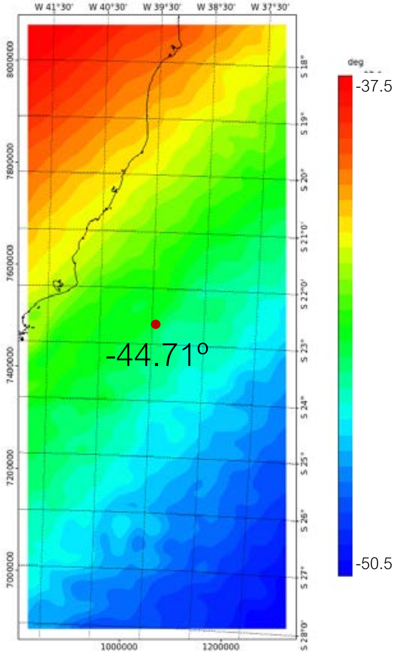
Campos Basin: At 5000 m below MSL



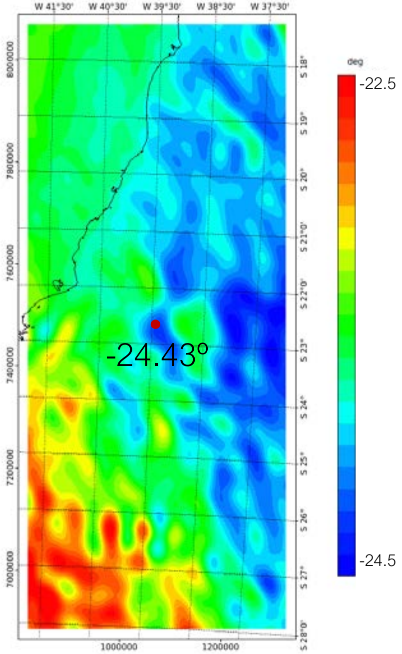
TMI anomaly



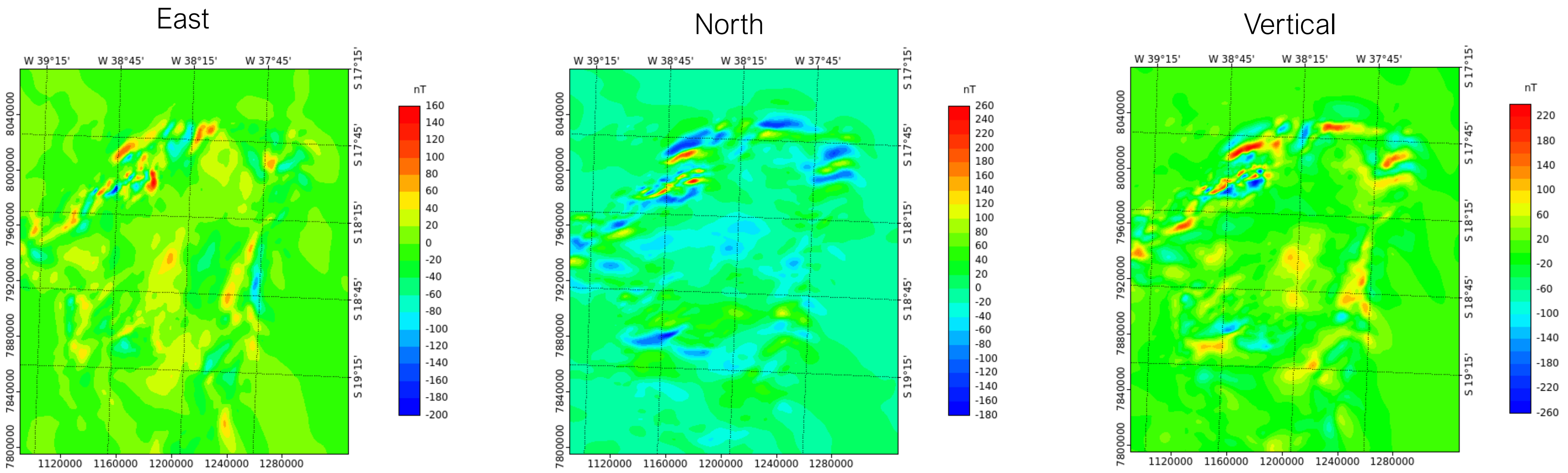
HDGM Inc



HDGM Dec

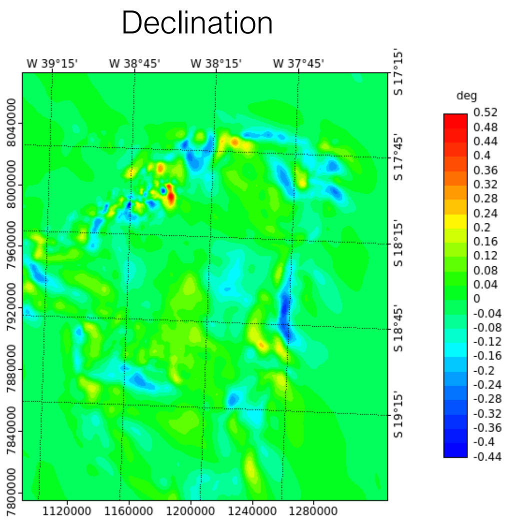


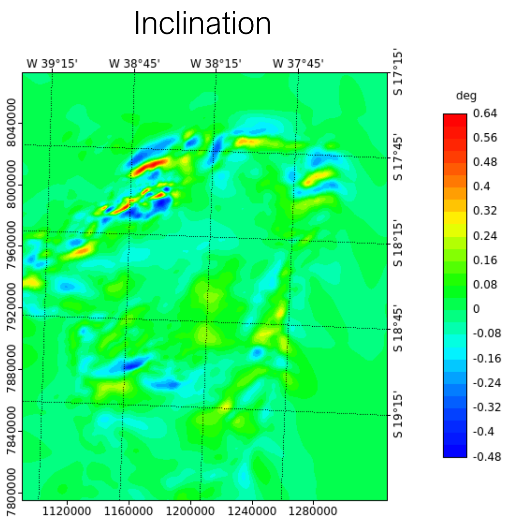
East, North and Vertical Component Differences: At 5000 m below MSL



The images show the east, north and vertical component differences resulting from two conversions: (i) using a constant inclination and a constant declination and (ii) using variable inclinations and variable declinations.

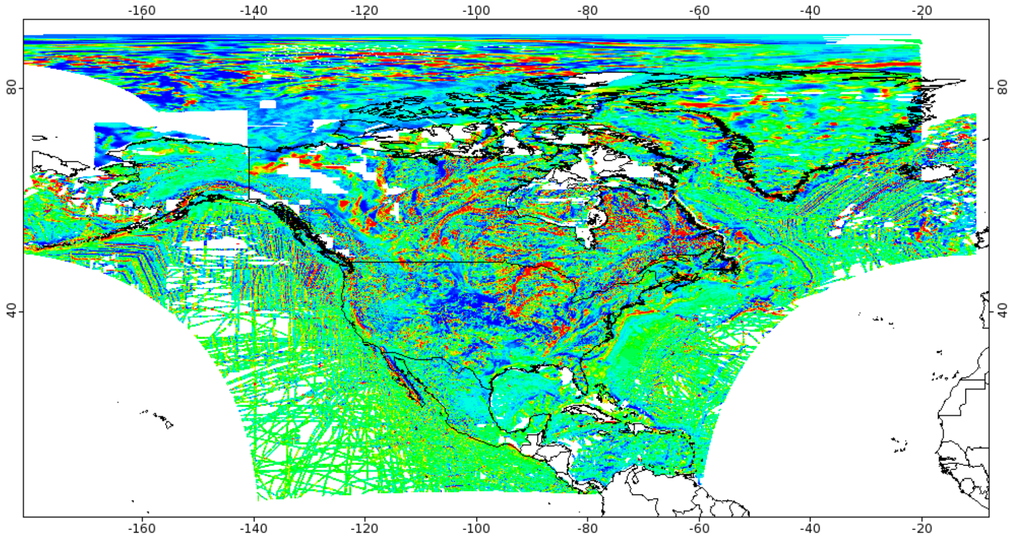
Declination and Inclination Differences: At 5000 m below MSL





The images show the declination and inclination differences resulting from two conversions: (i) using a constant inclination and a constant declination and (ii) using variable inclinations and variable declinations.

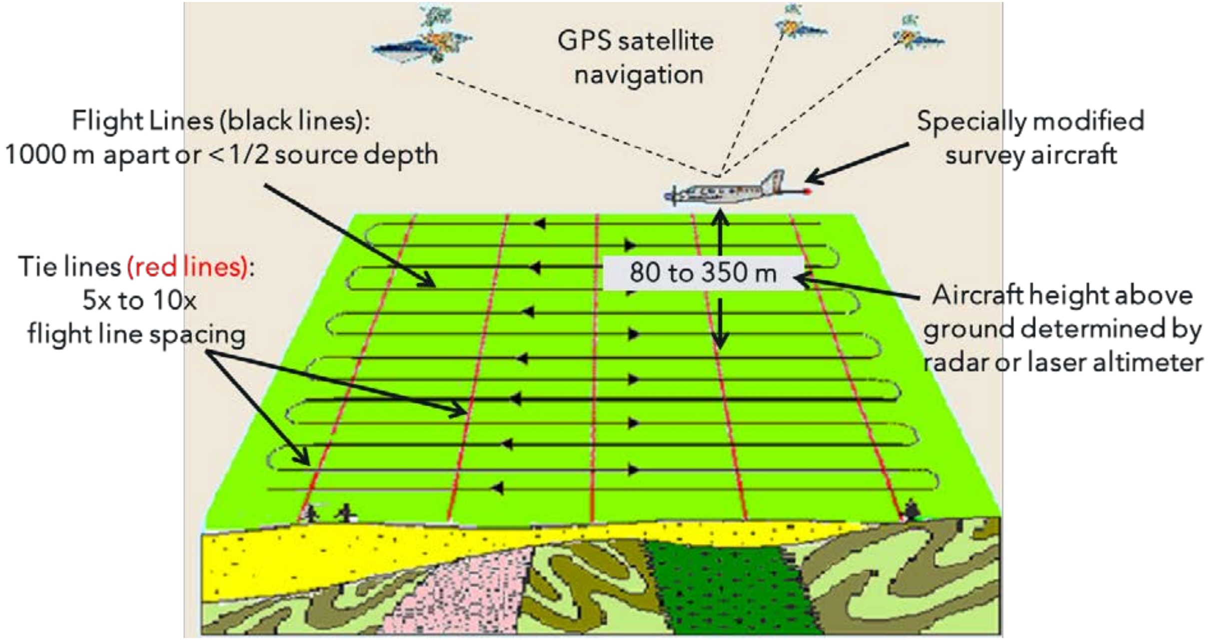
The 1-km NAmag



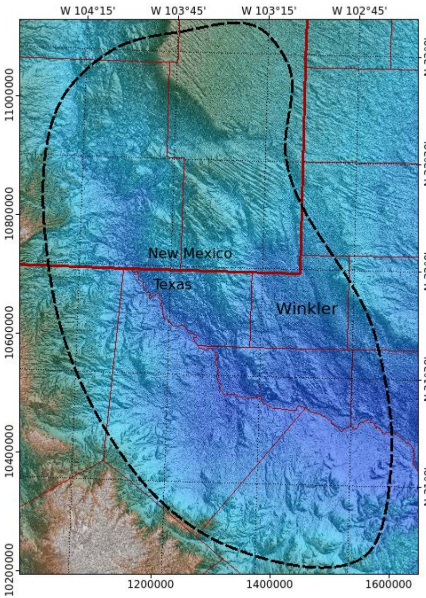
https://mrdata.usgs.gov/magnetic/

- The 1-km NAmag (North American magnetic anomaly grid) was released in 2005.
- Canada, the US, and Mexico compiled their country-wide magnetic anomaly grids first, and then merged.
- USmag and NAmag are the same within the USA.
- The grid spacing is 1 km but the actual spatial resolution varies and depends on individual surveys.

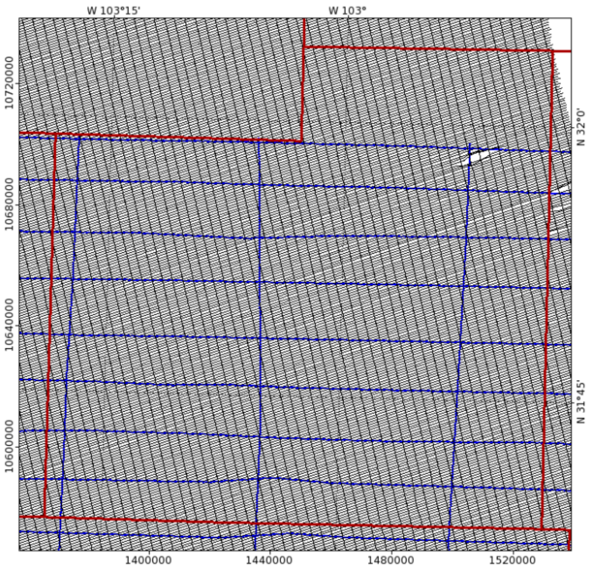
High-Resolution AeroMagnetic (HRAM) Survey



The Delaware Basin and Winkler County of Texas



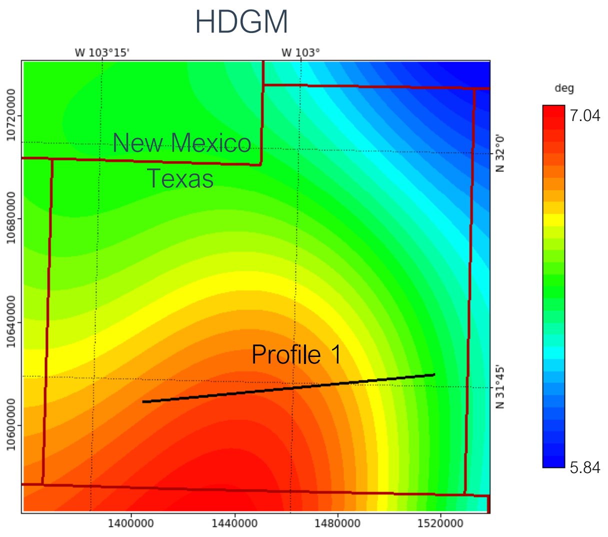
The dashed closure is the drilling area, and the image shows SRTM elevation.

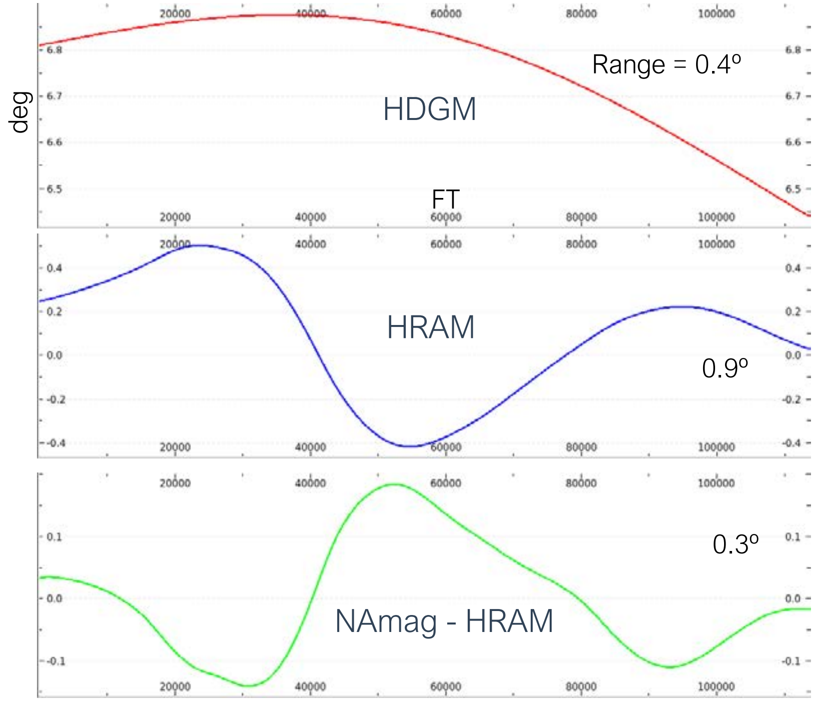


NAD83 / Texas Central (US ft)

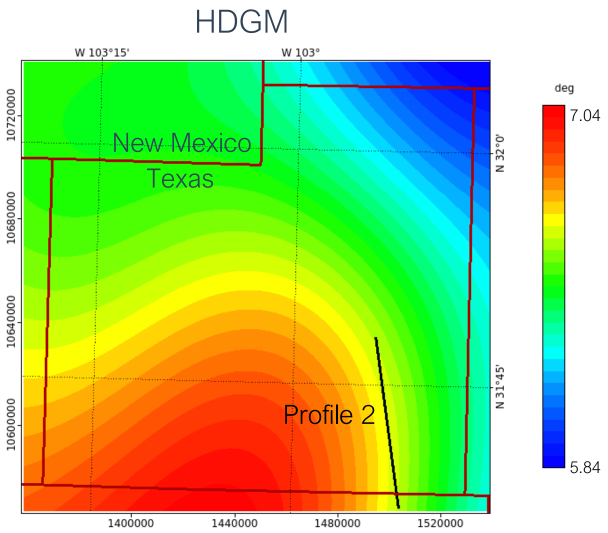
- The public-domain aeromagnetic survey used a flight line spacing of 3 miles (blue lines) while a high-resolution aeromagnetic survey had a line spacing of 250 m (black lines).
- To build an IFR model, we have used 1000-m not 250-m lines.

HDGM and Crustal Declinations at 8000 ft below MSL: Profile 1





HDGM and Crustal Declinations at 8000 ft below MSL: Profile 2



Conclusions

All three are important when building an accurate IFR model

I. A stable downward continuation using geological constraint (basement depths) by a technique such as the equivalent sources.

II. A conversion from the scalar TMI anomaly into the vector magnetic field considering variable declinations and variable inclinations.

III. High-resolution magnetic data.

Thank you

Questions (bets@xcaliburmp.com)