- Declination Error at Depth: A Comparison Study of Gyro vs. MWD Surveys
- Chad Hanak

# Speaker Information



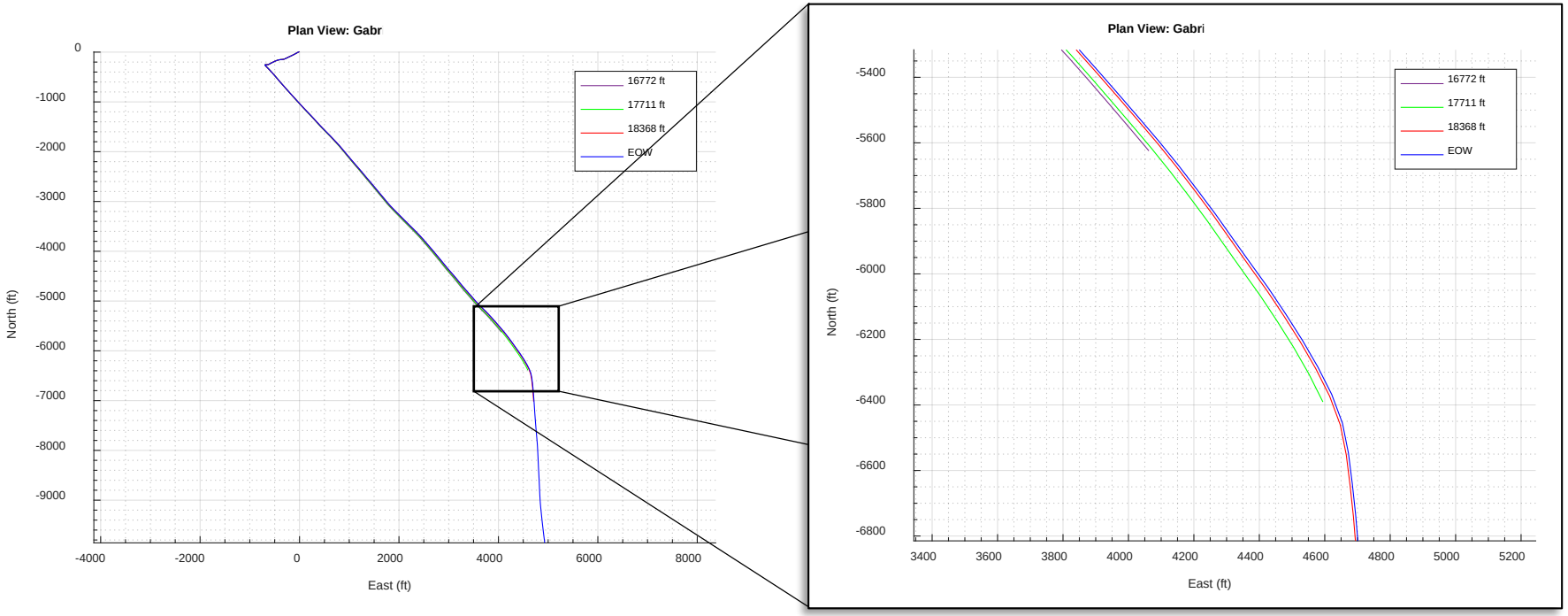
- Chad Hanak
- President
- September 27, 2018
- Superior QC

# Speaker Bio

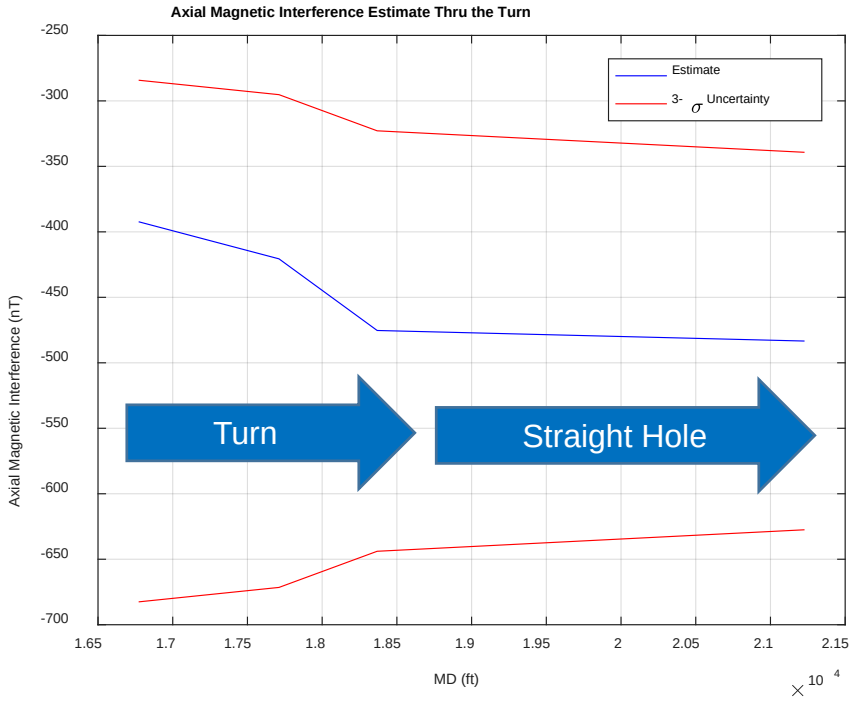

- President of Superior QC
  - A Patterson-UTI Company
  - Survey FDIR
- Past Experience:
  - NASA
  - Baker Hughes
- University of Texas
  - Ph.D. in Aerospace Engineering
  - Specialized in Guidance, Navigation, and Control
- Based in Houston
- Expertise
  - Wellbore navigation (survey correction)
  - Automation
  - Machine Learning

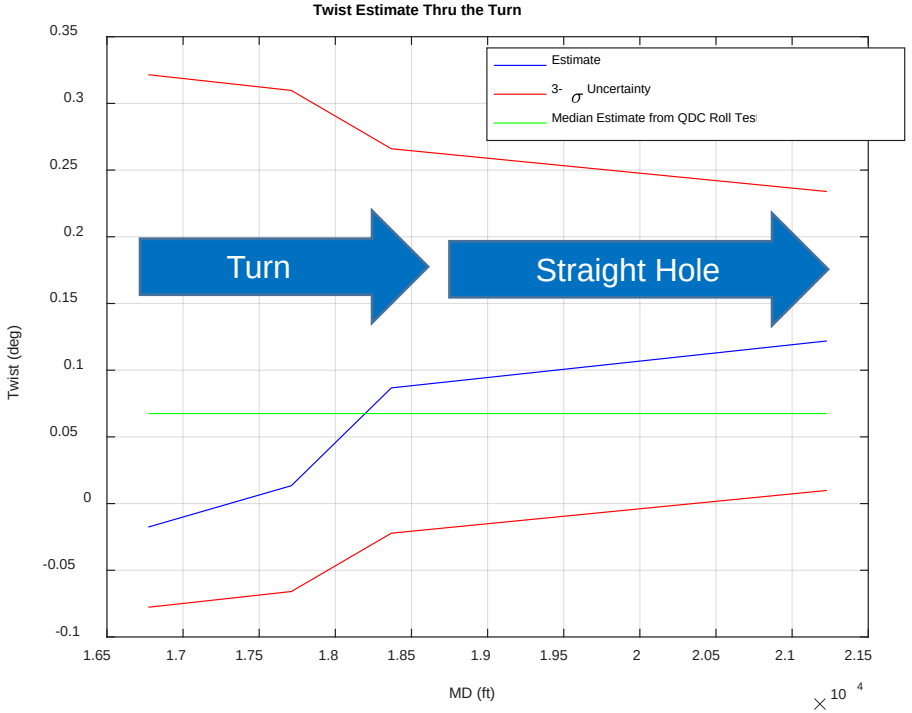
# Why Are You Re-correcting Surveys!?

# 35° Turn in Lateral Results in Back Corrections

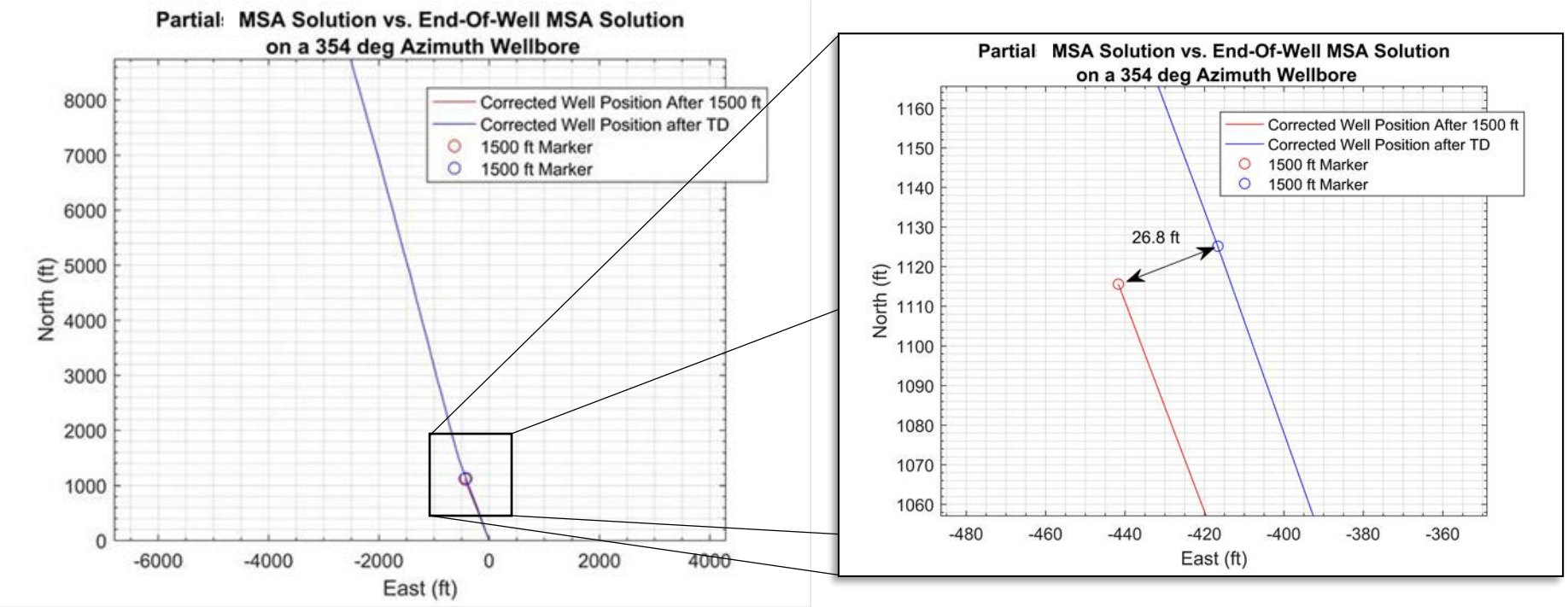


# AMI & Twist Estimates Gain Observability in Turn



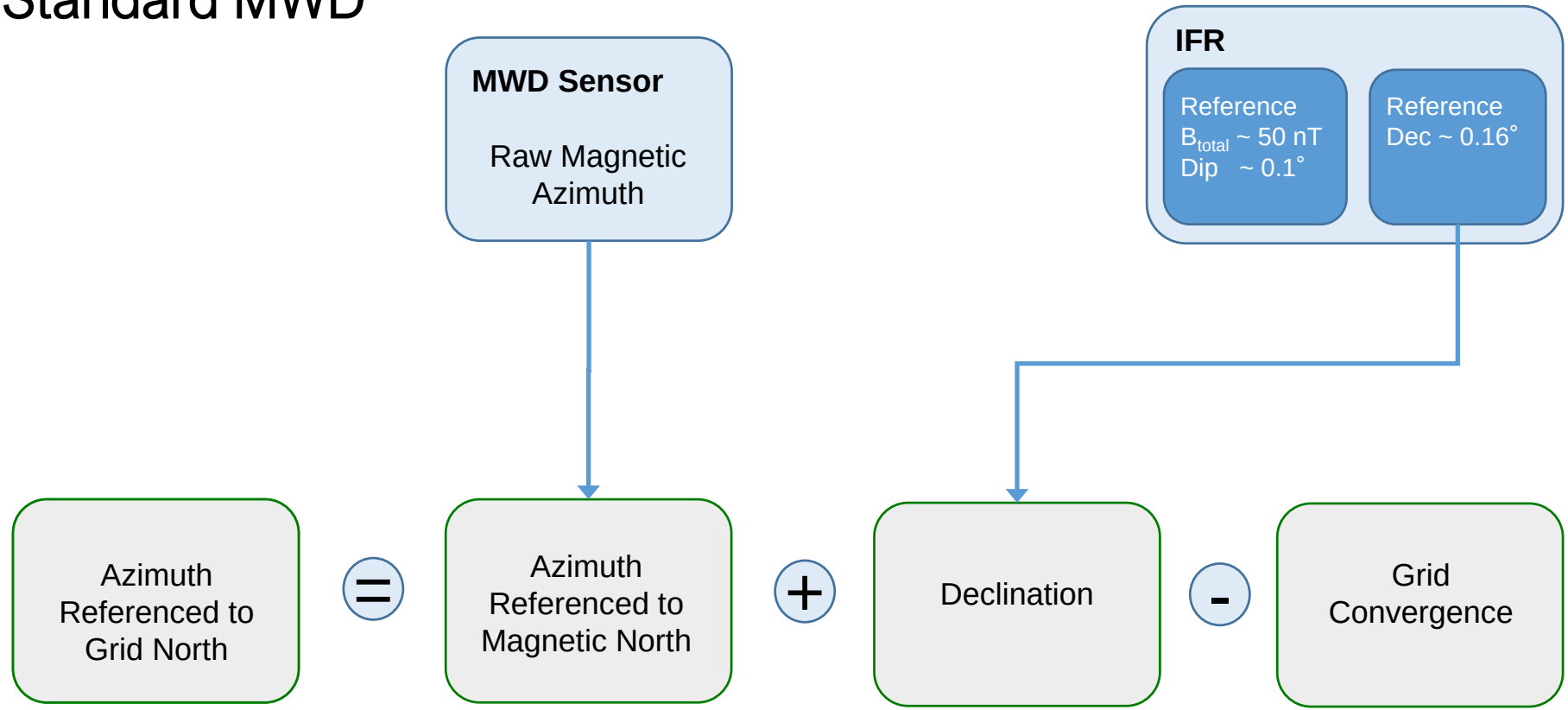
# A 5° Lateral Turn Example Using Multi-Station Analysis (MSA)



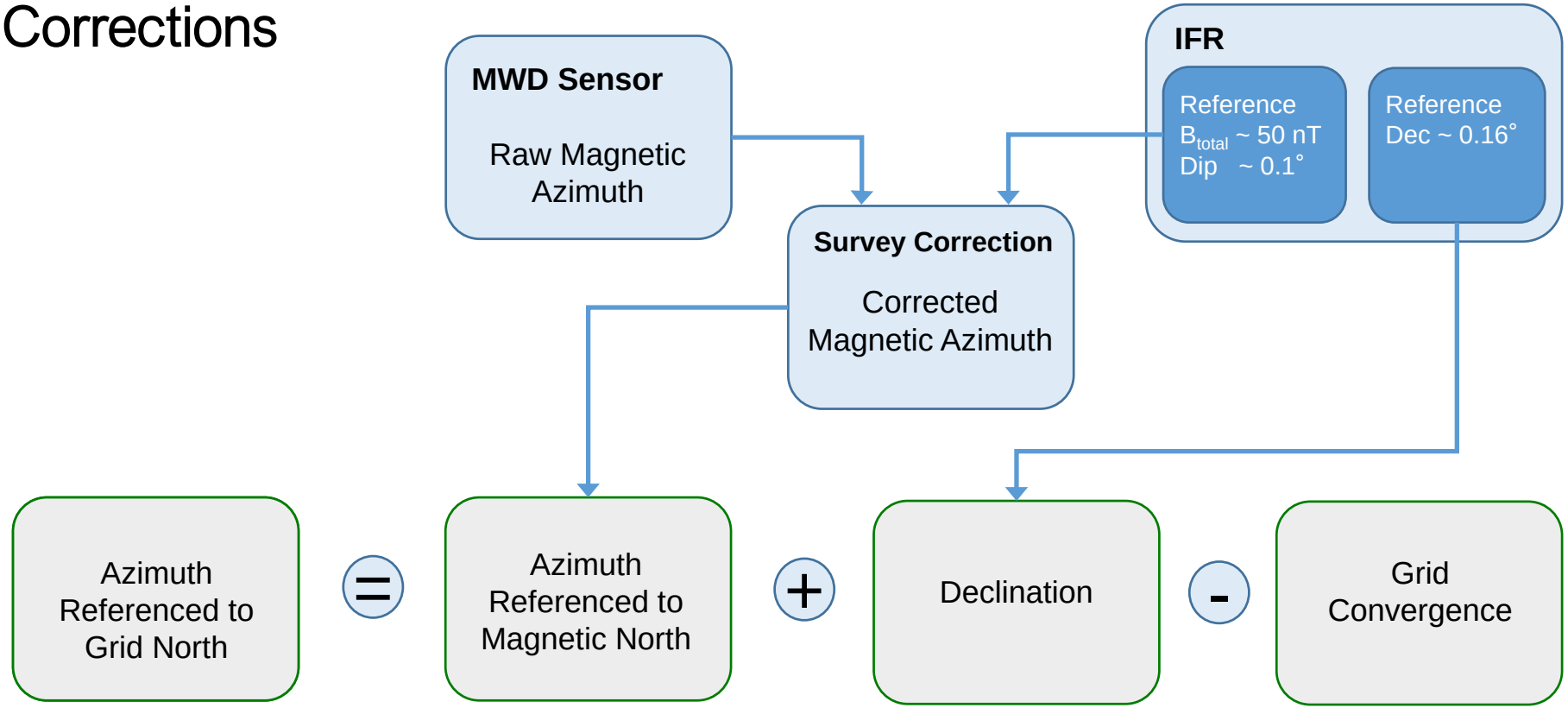
# Declination Error at Depth

## How Do the IFR and BGGM Error Models Fare?

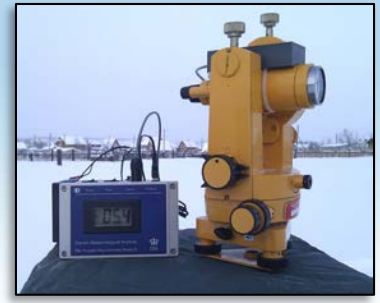
# Standard MWD



# Magnetic Survey Corrections



# How Accurate is IFR Data at Depth?

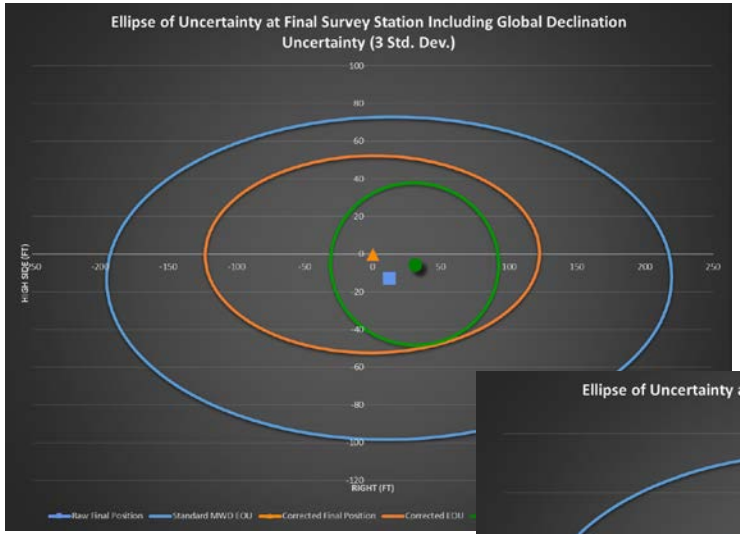


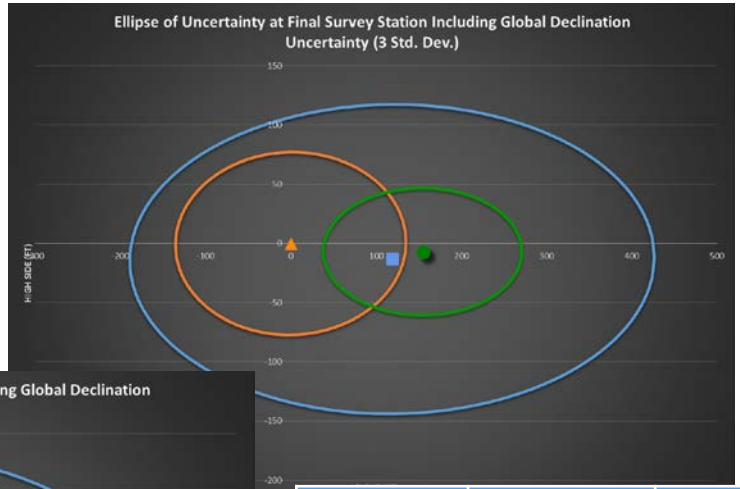
*May* be checked at ground level for accuracy.

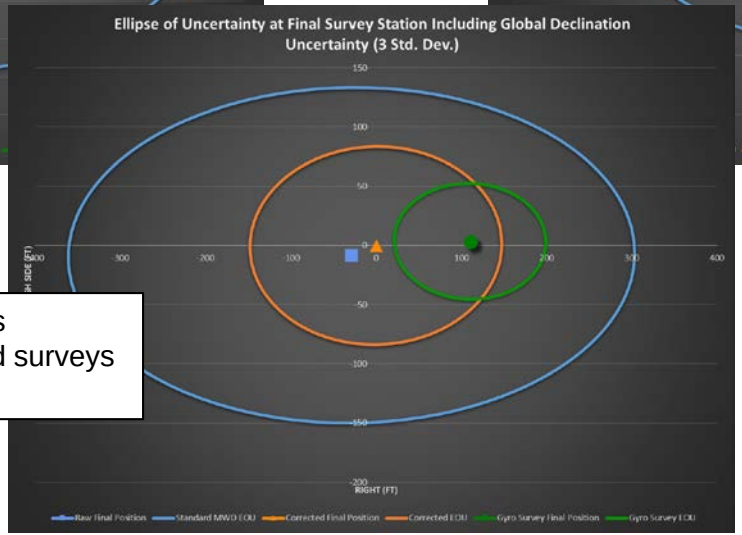
IFR data frequently comes from aero-mag surveys, hundreds of feet above the ground.

IFR error level at depth is not well known.

# Raw MWD, Corrected MWD, and Gyro Final Positions (Downhole View)



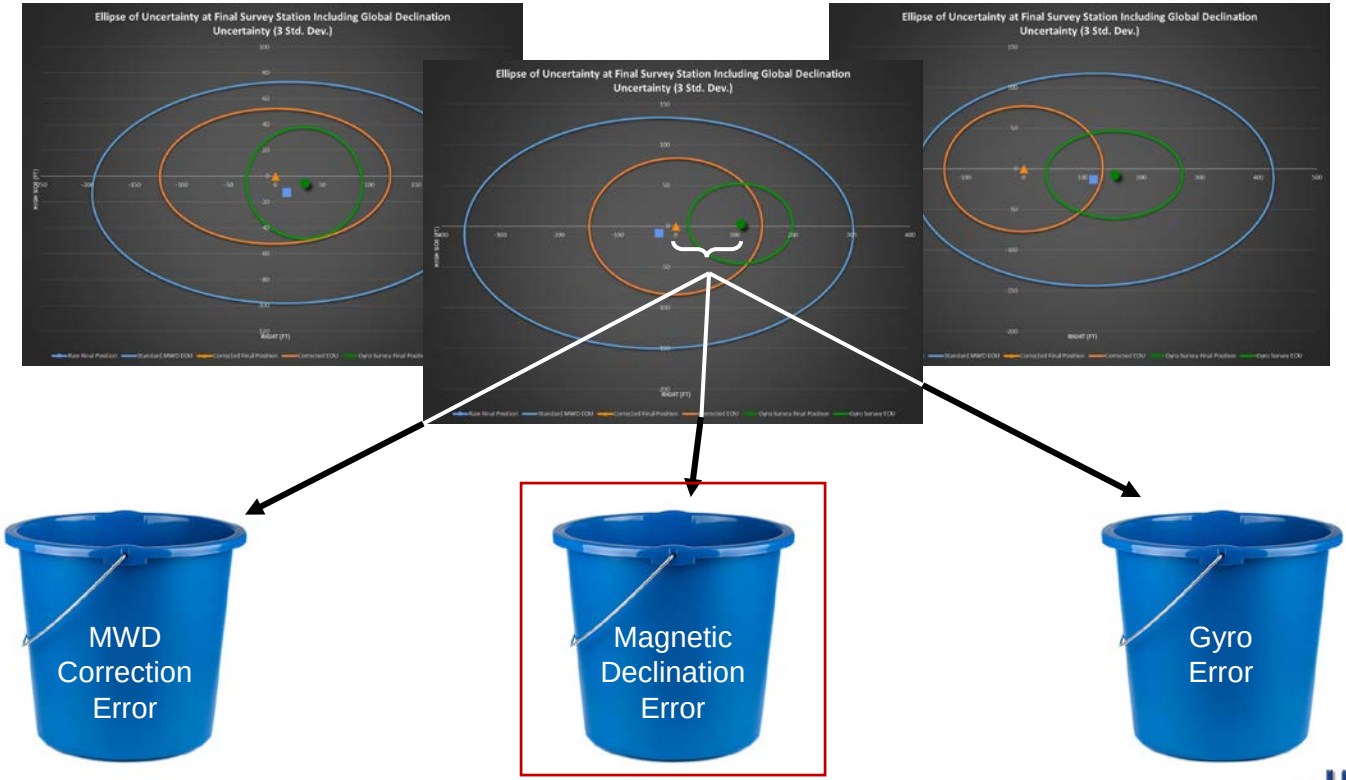




- **Blue** represents raw MWD surveys
- **Orange** represents FDIR corrected surveys
- **Green** represents gyro surveys

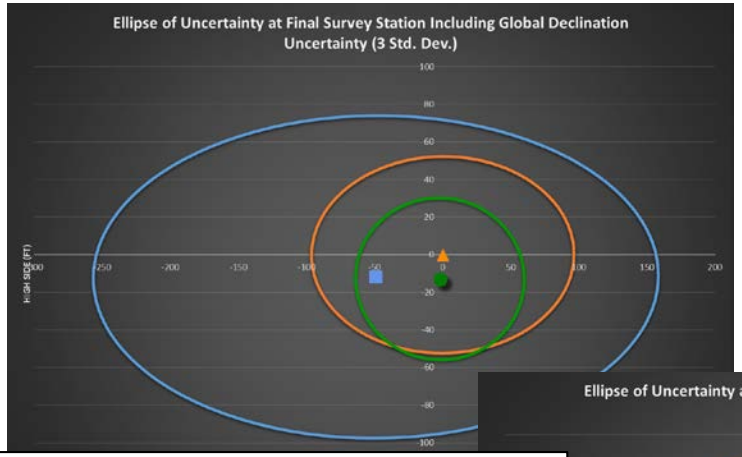
| | Gyro TD | MWD TD |
|---|---|---|
| Upper Left | 12,545 ft | 17,886 ft |
| Upper Right | 16,907 ft | 19,016 ft |
| Bottom | 14,976 ft | 19,957 ft |

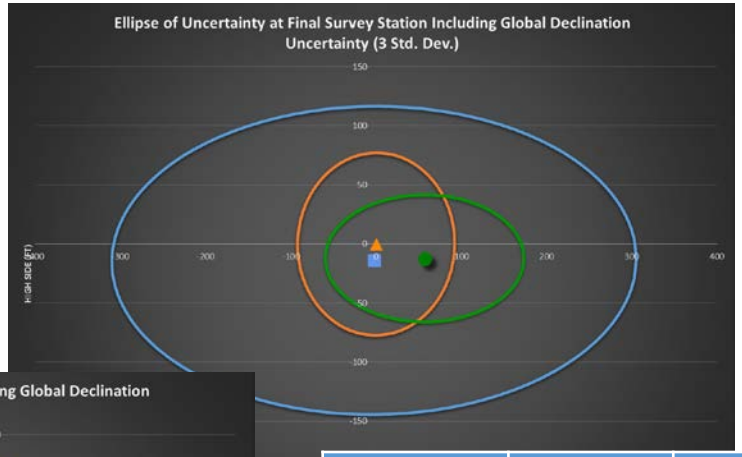
# Disagreement Between Gyro and Corrected MWD Can be Attributed to Three Sources

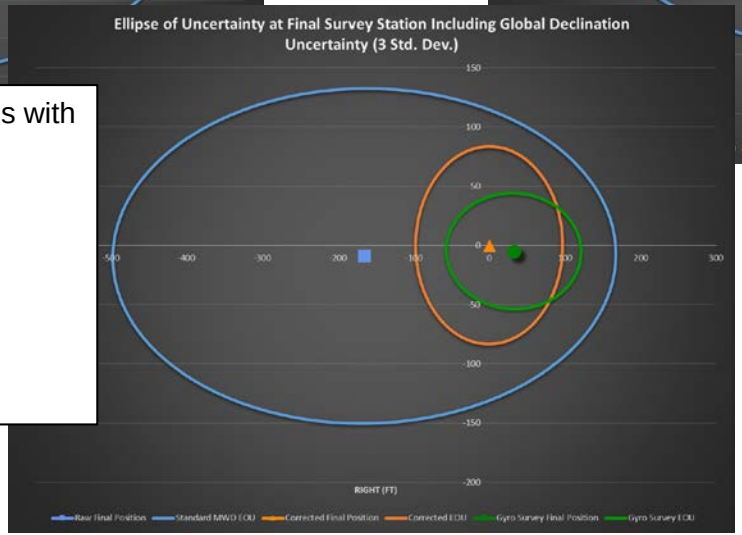



Only one error source is global to all the wells on a pad

# After Removing Declination Error




- **Orange** represents MWD Corrections with declination error removed based on downhole measurement with gyro comparison
- **Green** represents gyro surveys
- **IFR Declination error estimated at 0.28˚**

| | Dec. | Diff. from HDGM |
|---|---|---|
| HDGM | 4.98 deg | -- |
| IFR | 4.95 deg | -0.03 deg |
| Estimated from Gyro | 5.23 deg | 0.25 deg |

# Declination Error Study (5 Multi-Well Pads & 3 Individual Wells)

| Well/Pad | Number of Wells/Gyros | Azimuth | IFR Dec. Error | BGGM Dec. Error | Dec. Agreement (IFR-BGGM) |
|---|---|---|---|---|---|
| Pad 1 | 3 | 290° | 0.29° | 0.55° | -0.33° |
| Pad 2 | 3 | 280° | 0.28° | 0.24° | -0.11° |
| Pad 3 | 4 | 305° | 0.01° | -0.17° | -0.03° |
| Pad 4 | 3 | 90° | -0.59° | -0.64° | -0.04° |
| Pad 5 | 2 | 320° | 0.17° | 0.22° | -0.14° |
| Well 1 | 1 | 165° | 0.16° | 0.21° | -0.05° |
| Well 2 | 1 | 90° | -0.11° | -0.02° | -0.12° |
| Well 3 | 1 | 270° | -0.79° | -1.36° | 0.08° |

| IFR Error Model Dec. 1-σ | BGGM Error Model Dec. 1-σ |
|---|---|
| 0.16° | 0.42° |

# Are the Downhole Results Consistent with the Error Model Declination Magnitudes

- Chi-Square metric with known mean and variance
- Rejection of the Null Hypothesis at 1% probability or less

IFR: from error model, $\mu = 0$, $\sigma = 0.16^\circ$

| | Chi-Square Metric | Probability of Agreement with Error Model |
|---|---|---|
| Full Data Set | 46.73 | 0.000017% |
| Worst Point Removed | 22.35 | 0.22% |

Downhole declination disagreement with IFR error model is statistically significant

Downhole declination disagreement with BGGM error model not statistically significant

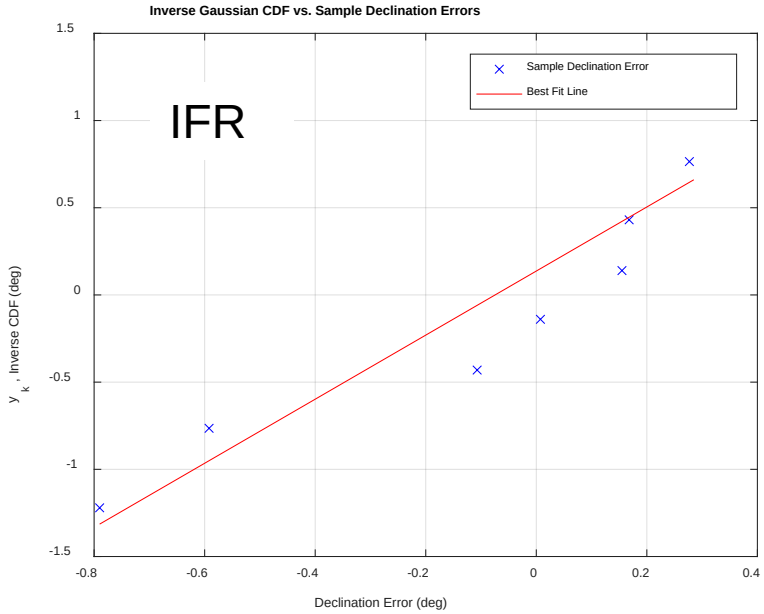
BGGM: from error model, $\mu = 0$, $\sigma = 0.42^\circ$

| | Chi-Square Metric | Probability of Agreement with Error Model |
|---|---|---|
| Full Data Set | 15.79 | 4.5% |
| Worst Point Removed | 5.13 | 64% |

# Fitting the Data to a Gaussian Cumulative Distribution Function (CDF)

$$F_X(x) = \Phi\left(\frac{x-\mu_X}{\sigma_X}\right)$$

$$\begin{aligned}\Phi^{-1}(F_X) &= \left(\frac{1}{\sigma_X}\right)x + \left(-\frac{\mu_X}{\sigma_X}\right) \\ &= ax + b\end{aligned}$$




$$y_k = \Phi^{-1}(F_X) = \Phi^{-1}\left(\frac{k}{n+1}\right), \text{ where } n = \text{the number of data points}$$

# Comparison to Error Model Magnitudes Based on CDF Fit

CDF Fitting Results

| | IFR Declination 1-σ | BGGM Declination 1-σ |
|---|---|---|
| Error Model Value | 0.16° | 0.42° |
| Estimated Value | 0.54° | 0.82° |
| % of EM Value | 3.4x | 2.0x |

IFR error model appears optimistic in terms of declination by about 3x

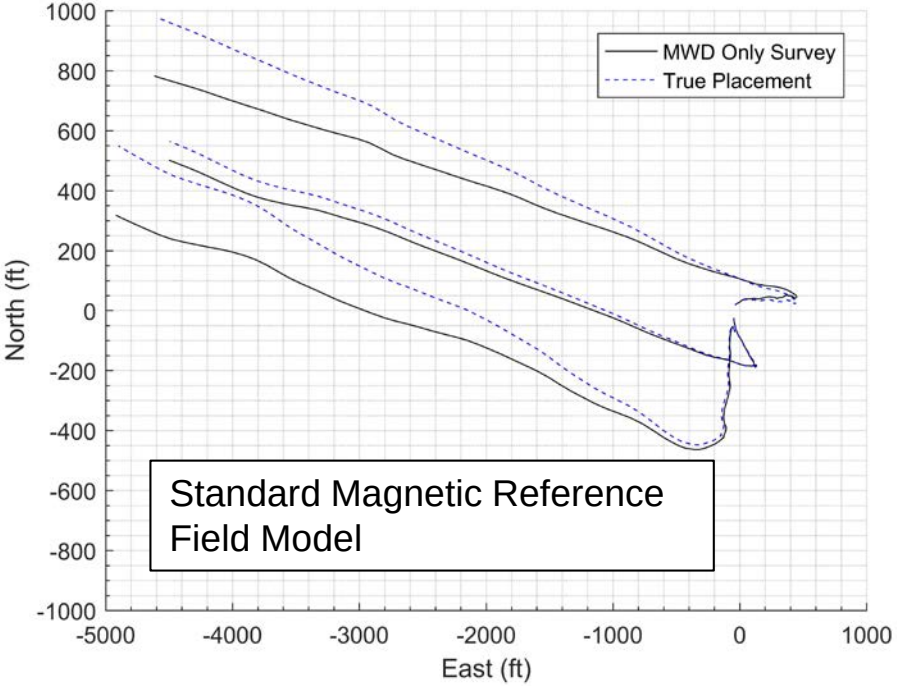
BGGM error model may be somewhat optimistic in terms of declination

IFR shown to be an improvement over BGGM (recent BGGM improvements not considered)

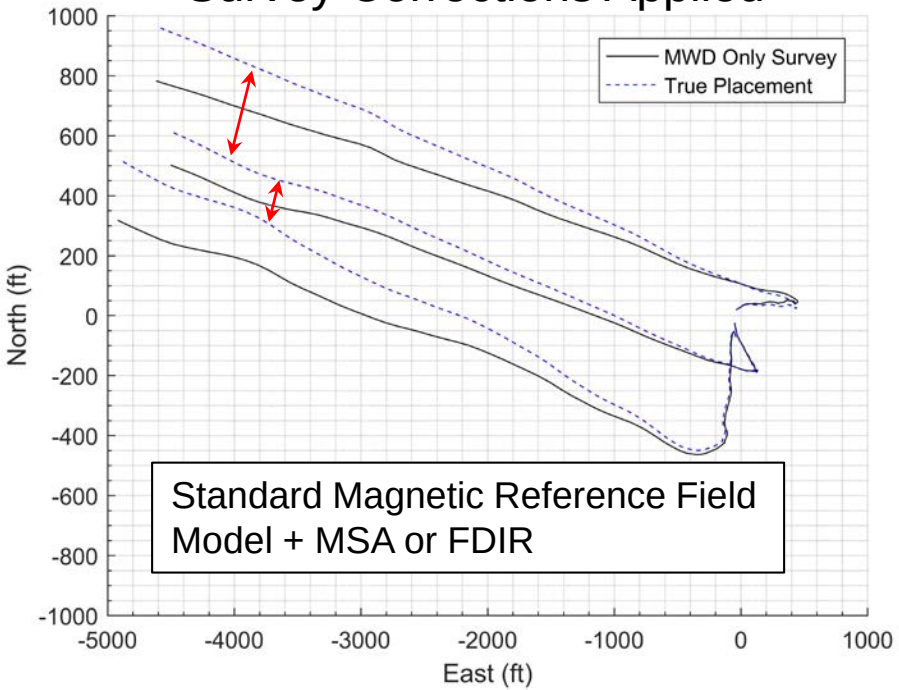
CDF Fitting Results, Excluding Worst Point

| | IFR Declination 1-σ | BGGM Declination 1-σ |
|---|---|---|
| Error Model Value | 0.16° | 0.42° |
| Estimated Value | 0.43° | 0.50° |
| % of EM Value | 2.7x | 1.2x |

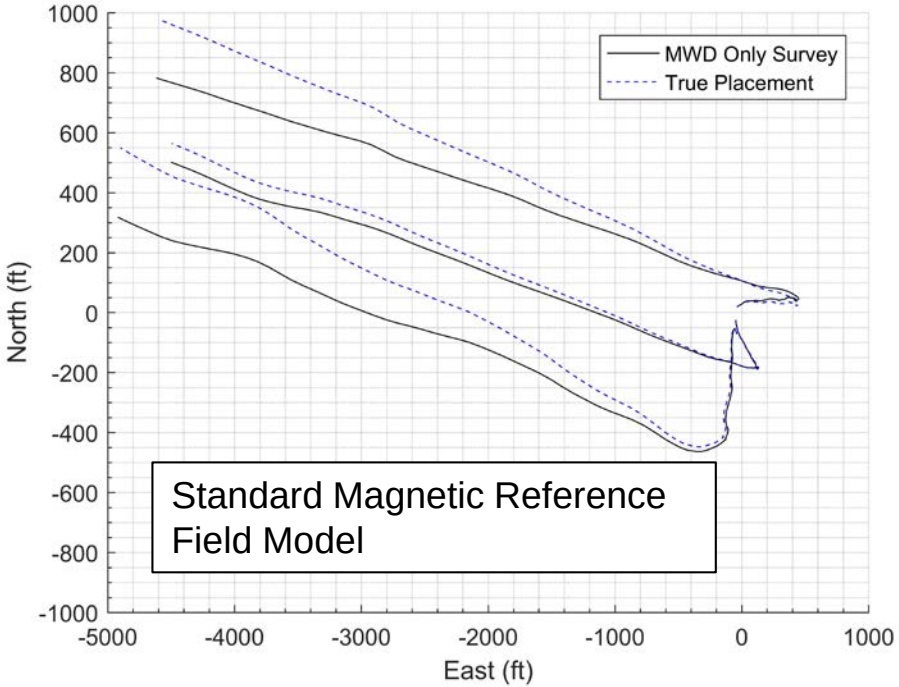
# Survey Corrections are Used to Fix Spacing Between Parallel Wells Originating from the Same Surface Location

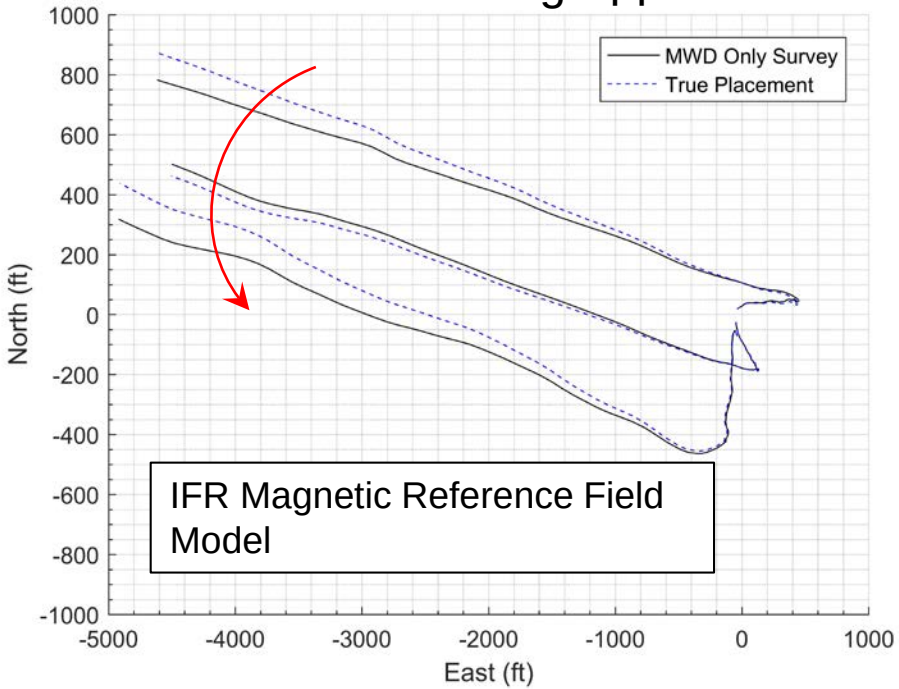



Survey Corrections Applied



# IFR is Used to Fix Global Rotational Shift of All Wells Originating from the Same Surface Location



# Conclusion Regarding Downhole Declination Uncertainty

- IFR error model
  - Appears to be optimistic based on downhole data
  - Statistically significant result
  - Uncertainty may be 3x the modeled value
- BGGM error model
  - No statistically significant disagreement with downhole data
  - May still be somewhat optimistic
- Results call into question anti-collision scans (IFR especially)
- IFR still shown to be more accurate than BGGM
  - Recent BGGM improvements not considered