Are You Using the Correct EOU?

Introducing an Industry Standard Process to Validate the Accuracy of Survey Correction Software

Why Validation of Survey Correction Algorithms is Overdue

Industry Papers/Presentations Detailing Problems with MSA & IFR

1. SPE/IADC 96211, "Analyses of the Accuracy and Reliability of Magnetic Directional Surveys," Nyrnes, E. and Torkildsen, T, 2005.
2. SPWLA 46th Annual Logging Symposium, "Error Properties of Magnetic Directional Surveying Data," Nyrnes, E., Torkildsen, T., and Nahavandchi, H., June 26-29, 2005.
3. SPE/IADC 125677, "Minimum Requirements for Multi-Station Analysis of MWD Magnetic Directional Surveys," Nyrnes, E., Torkildsen, T., and Wilson, H., 2009.
4. SPE/IADC 128217, "Wellbore Positions Obtained While Drilling by the Most Advanced Magnetic Surveying Methods May Be Less Accurate than Predicted," Ekseth, R. and Weston, J., 2010.
5. ISCWSA 37th General Meeting, "Combined use of MWD and gyro surveying to reduce wellbore positioning uncertainties," Maus, S. and McCulloch, S., March 8, 2013.
6. SPE/IADC 173098, "Assessment of the Validity of MWD Survey Accuracy Following Multistation Analysis," Hanak, C., Wilson, H., Gjertsen, M., 2015.
7. ISCWSA 44th General Meeting, "East-West Exclusion Zones: Why Do We Have Them and How Can We Eliminate Them?" Hanak, C. September 22, 2016.
8. Bergstrom, N., "High Accuracy Wellbore Surveys Multi-Station Analysis (MSA)," IADD Roadmap to the Future, September 28-29, 2016.
9. ISCWSA 48th General Meeting, "Declination Error at Depth: A Comparison Study of Gyro vs. MWD Surveys," Hanak, C., September 27, 2018.
10. SPE 194130, "Combined Gyroscopic and Magnetic Surveys Provide Improved Magnetic Survey Data and Enhanced Survey Quality Control," Weston, J. and Ledroz, A., 2019.

Past performance is not a guarantee of future results. Results may vary.

Comparison to the Aerospace Industry

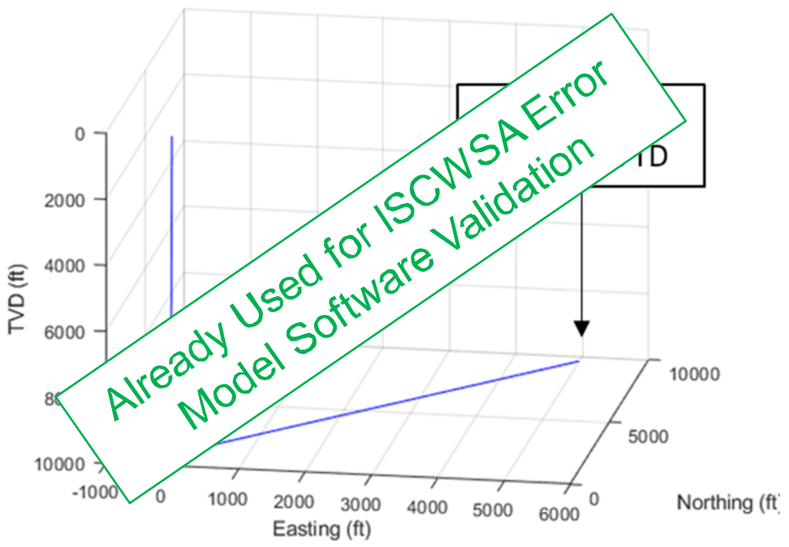
Step 1
Create Flight
Software

???

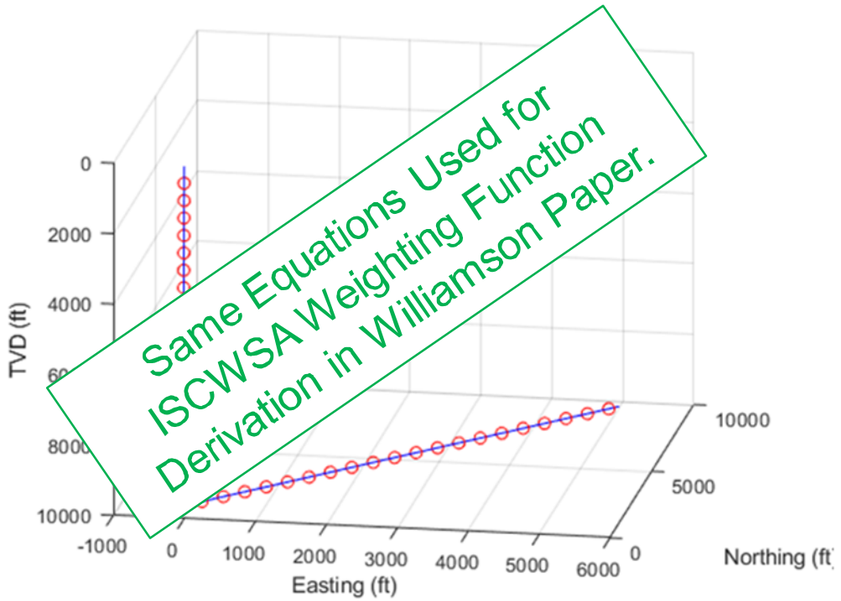
Step 3
Develop Procedures
for Implementation

Simulated Test Well Creation Process

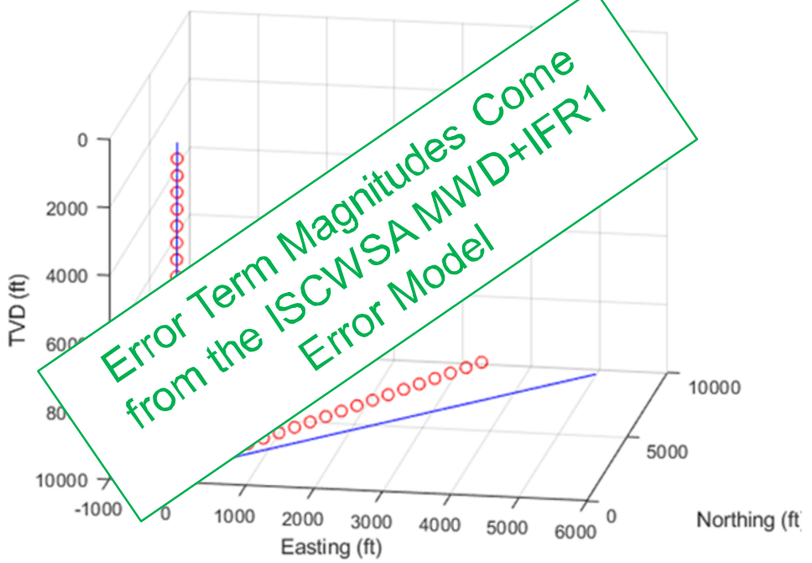
Step 1: Create Synthetic Well Profile



Step 2: Sample the Well & Calculate Perfect Surveys



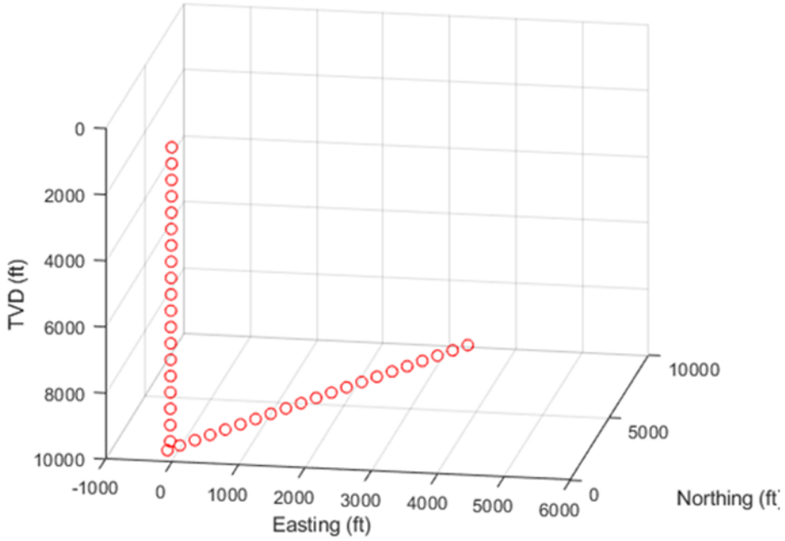
Step 3: Add Typical Measurement Errors to the Surveys



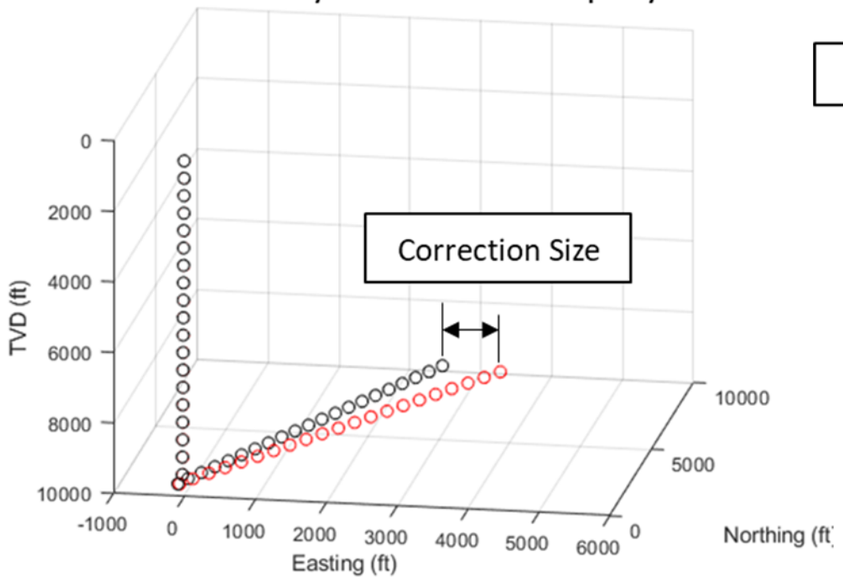
[Williamson(2000)] H. S. Williamson. Accuracy prediction for directional measurement while drilling, SPE 67616. *SPE Drilling and Completion*, 15(4), December 2000.

Test Data Corrected by Survey Correction Company

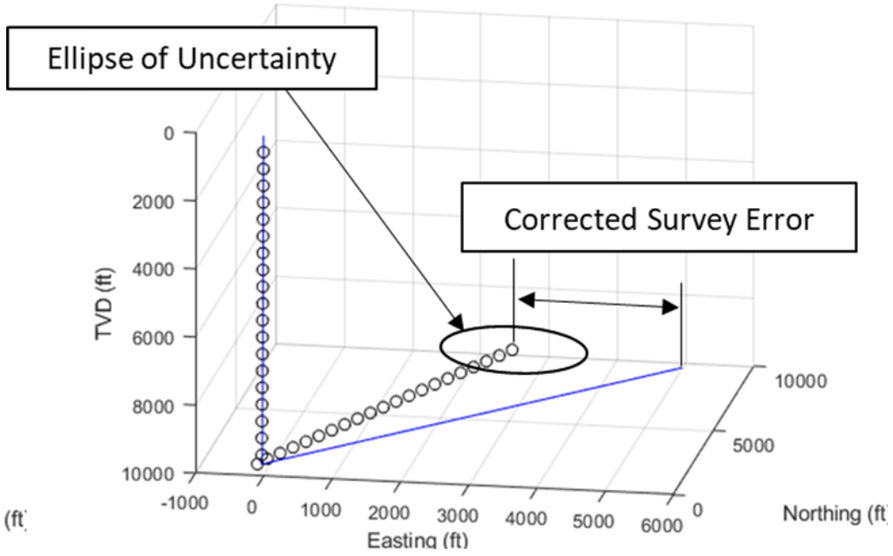
Step 4: Give Survey Data, Including Errors, to Survey Correction Company



Step 5: Receive Corrected Survey Log from Survey Correction Company

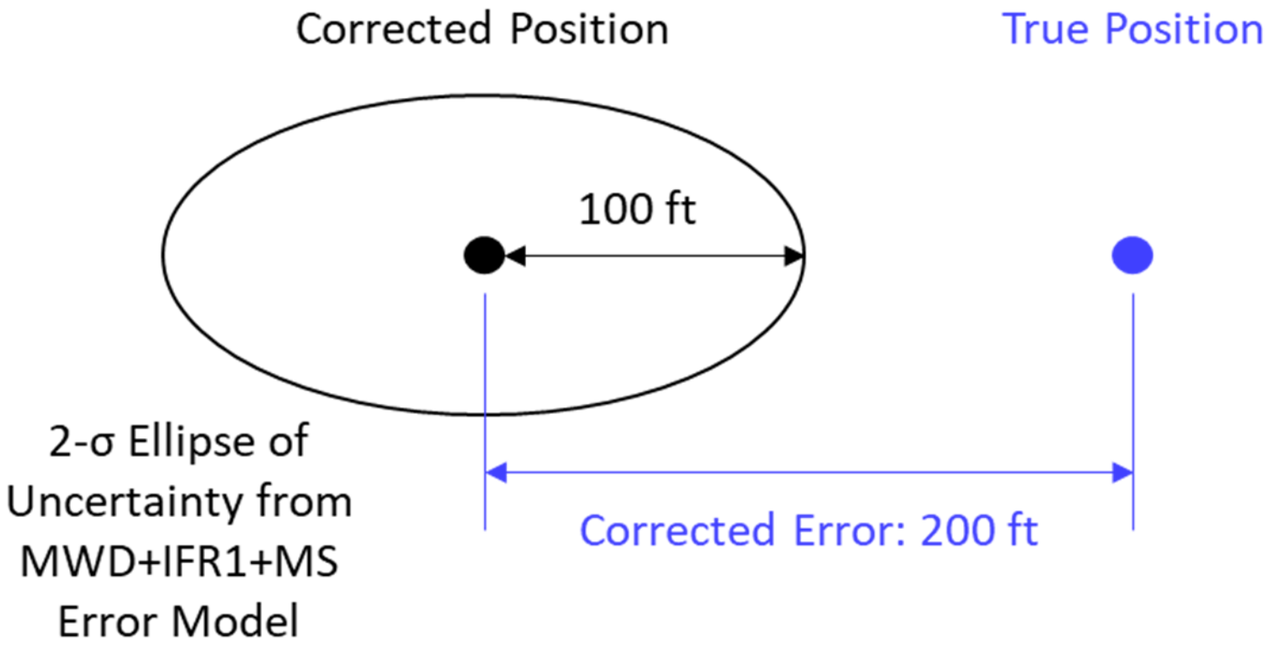


Step 6: Calculate Error in Corrected Position from Known True Position

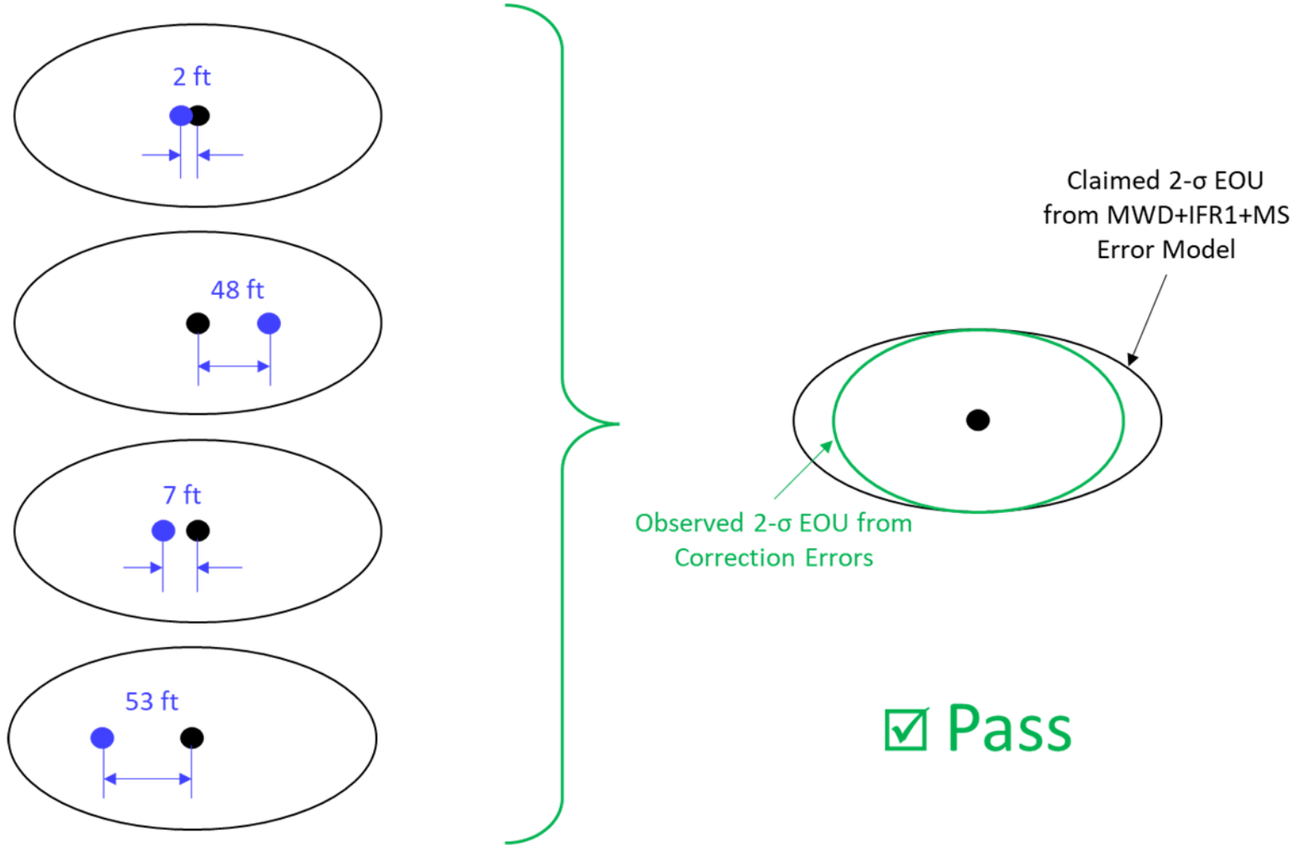


How Large is the Error Compared to the EOU?

Correction Error Compared to Claimed EOU Size

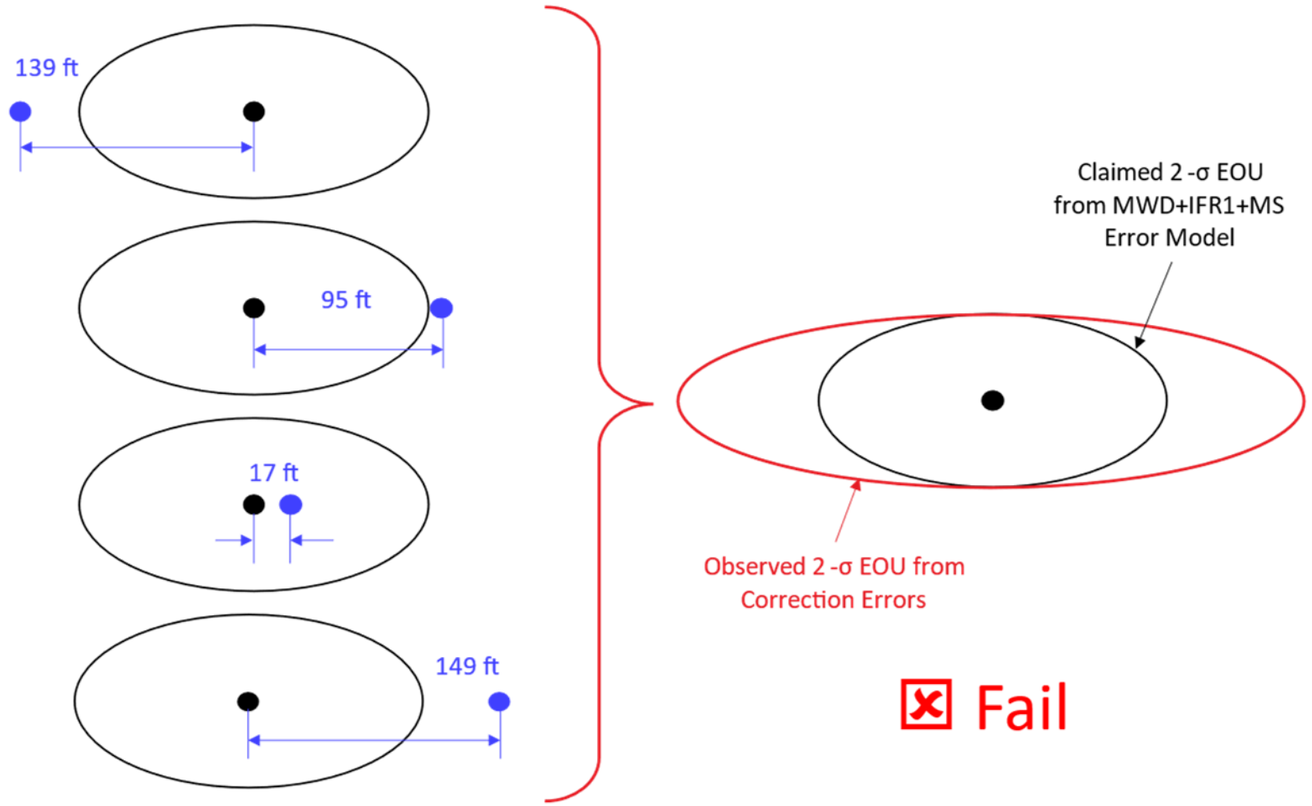


Correction Error Compared to Claimed EOU Size



**Use Chi-Squared distribution to determine pass/fail threshold for horizontal EOU*

Correction Error Compared to Claimed EOU Size



**Use Chi-Squared distribution to determine pass/fail threshold for horizontal EOU*

Error Sources (The "Controversial" Part)

Error Type	Symbols	Source	ISCWSA Mnemonics
Accelerometer Biases	b_{ax}, b_{ay}, b_{az}	ISCWSA	ABX, ABY, ABZ
Magnetometer Biases	b_{mx}, b_{my}, b_{mz}	ISCWSA	MBX, MBY, MBZ
Axial Magnetic Interference	AMI	ISCWSA	AMIL
Accelerometer Scale Factor Errors	s_{ax}, s_{ay}, s_{az}	ISCWSA	ASX, ASY, ASZ
Magnetometer Scale Factor Errors	s_{mx}, s_{my}, s_{mz}	ISCWSA	MSX, MSY, MSZ
Twist	ϕ	Calibration Model	(lumped term)
Bend	ψ_{xz}, ψ_{yz}	Calibration Model	(lumped term)
Accelerometer Non-Orthogonality	$\gamma_{axy}, \gamma_{axz}, \gamma_{ayz}$	Calibration Model	(lumped term)
Magnetometer Non-Orthogonality	$\gamma_{mxy}, \gamma_{mxz}, \gamma_{myz}$	Calibration Model	(lumped term)
Reference B_total Error	$\tilde{B}_{ref}$	ISCWSA	MFIG (+AX model only)
Reference Dip Error	$\tilde{Dip}_{ref}$	ISCWSA	MFDG (+AX model only)

"Andy Brooks has demonstrated that if a sensor is subject to a scale error and two orthogonal misalignments, all independent and of similar magnitude, the combination of the three error terms is equivalent to a single bias term. This term need not appear explicitly in the error model, but may be added to the existing bias term to create a **"lumped" error**. This eliminates the need for 20 extra weighting functions corresponding to **sensor misalignments**."

[Williamson(2000)] H. S. Williamson. Accuracy prediction for directional measurement while drilling, SPE 67616. *SPE Drilling and Completion*, 15(4), December 2000.

Levels of Validation

(What Errors Can the Software Handle and Still Deliver Claimed Accuracy?)

- Educational Validation – All Error Sources Randomized According to Spec
- Operational Validation – Some Error Sources Randomly Out of Spec
- Robust Operational Validation – Operational Validation + Data Entry Problems

*Validation test should be run per standard operational procedure. If no checkshots are claimed necessary, none should be provided.
**Tests should be limited to 1.5 hours to capture standard performance.

Proof of Concept

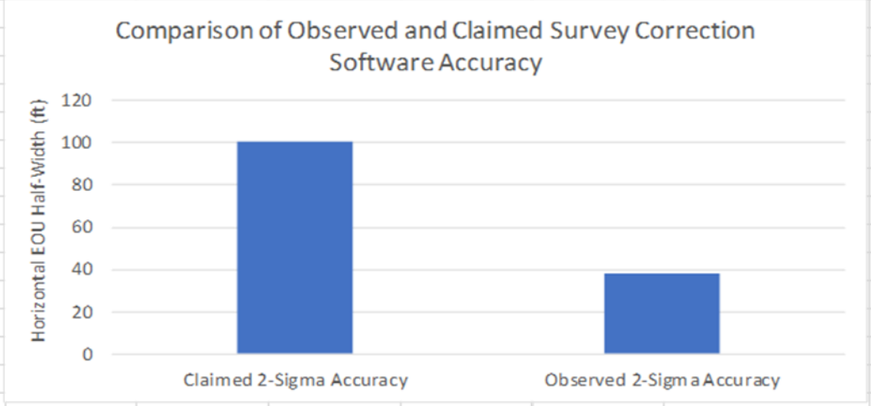
Robust Operational Validation

Survey Correction Software Validation Spreadsheet

Well Number	Approx. Azimuth	True (Simulated) Bottom Hole Location			Corrected Bottom Hole Location (from Survey Correction Company)			MWD+IFR1+MS (or MWD+IFR1+FDIR) 2σ EOU Half-Width	Survey Correction Error	Survey Correction Error Expressed in Terms of σ
		Northing	Easting	TVD	Northing	Easting	TVD			
1	0	10348.56684	792.5737685	9783.932962	10347.99	820.96	9783.2	89.33	28.40	0.64
2	0	10365.86726	-108.9944219	9786.46623	10363.99	-96.3	9789.67	89.33	13.23	0.30
3	30	8785.607469	5533.803041	9786.157077	8779.35	5541.92	9787.93	93.53	10.40	0.22
4	30	8831.752142	5429.286143	9783.683458	8829.35	5436.34	9786.41	93.53	7.93	0.17
5	60	5539.730349	8779.709808	9785.244844	5523.71	8789.59	9785.42	106.27	18.82	0.35
6	60	3688.439441	9694.119788	9785.518792	3669.8	9699.82	9783.38	106.27	19.61	0.37
7	90	507.0738454	10361.77356	9786.480478	493.73	10362.87	9782	113.20	14.12	0.25
8	90	320.8022422	10360.54644	9782.744715	291.94	10362.5	9785.74	113.20	29.08	0.51

Degrees of Freedom:	8
χ2 Probability of Success at Which to Fail Software:	10%

Average Error Model EOU Half-Width (2σ):	101
Survey Correction Error Sample Standard Deviation (2σ):	38
Pass (if under) / Fail (if over) Threshold:	130
Validation Result:	*PASS*



Start Time	12:20
End Time	13:03
Elapsed Time	0:43

Results for Superior QC, with Philip Gurden Proctoring on 9/26/22

Thank You To…

- Bill Allen – BP
- Pete Clark – Chevron
- Dalis Deliu - ConocoPhillips
- Jonathan Lightfoot – Oxy
- Heather Vannoy – EOG