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Web-based Technologies for Real-time Directional Survey Quality Improvement

Jarrod S. DeVerse*, Surcon Ltd., Denver, CO, United States;
Stefan Maus, Magnetic Variation Services LLC, Westminster, CO, United States.

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Summary

Directional surveys acquired by Measurement While Drilling (MWD) are subject to many errors that are not easily recognized by traditional Quality Control (QC) procedures. This commonly leads to inaccurate wellbore placement and greater positional uncertainty. Common sources of MWD survey error are inaccurate geomagnetic references, localized distortions in the natural magnetic field, poor instrument calibration, random sensor noise, magnetic mud, and human error. Often times, such errors go unrecognized due to limitations in traditional single-station QC tests. This is a significant problem because wellbore collision avoidance, geological modeling, and reservoir drainage are all greatly affected by wellbore placement accuracy. Fortunately, most sources of MWD error can now easily be identified and corrected through implementation of robust independent survey quality control processes. By using web-based systems to facilitate this process, drillers can benefit from the most powerful quality assurance practices which can be standardized across the industry regardless of service provider or vendor specific technologies.

Introduction

Well placement by MWD employs the use of orthogonally positioned accelerometers and magnetometers to measure the orientation of the bottom-hole assembly (BHA) relative to the Earth's gravitational and magnetic fields as shown in Figure 1. Taking survey measurements at regular intervals along the well path enables computation of the wellbore trajectory through minimum curvature interpolation.

Standard MWD surveying is subject to numerous error sources which can lead to inaccurate wellbore placement. These sources of error are divided into three categories: gross, random, and systematic. Gross errors occur from human mistakes, instrument failure, or environmental factors that cannot be predicted or estimated. Random and systematic errors occur with some measure of predictability and can therefore be estimated and quantified. The standard approach for estimating positional uncertainty in the wellbore caused by random and systematic survey error is to use instrument performance models called tool codes. Tool codes provide the mathematical framework to compute Ellipsoids of Uncertainty (EOUs) which represent positional uncertainty evaluated at a particular sigma, or confidence level (Grindrod 2016). Figure 2 shows how EOUs form an elliptical tunnel when propagated along the well path which characterizes the statistical distribution of where the actual wellbore could exist. Quantifying positional

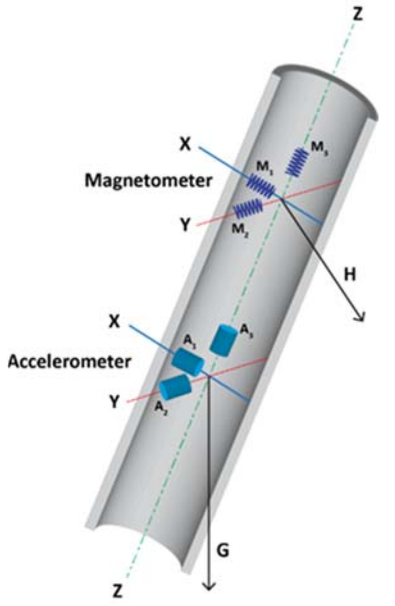


Figure 1: Three orthogonal accelerometers and three orthogonal magnetometers measure the Earth's gravitational field vector (G) and magnetic field vector (H).

uncertainty is a critical step in the well planning and drilling processes because it enables drillers to evaluate collision risk and understand wellbore placement.

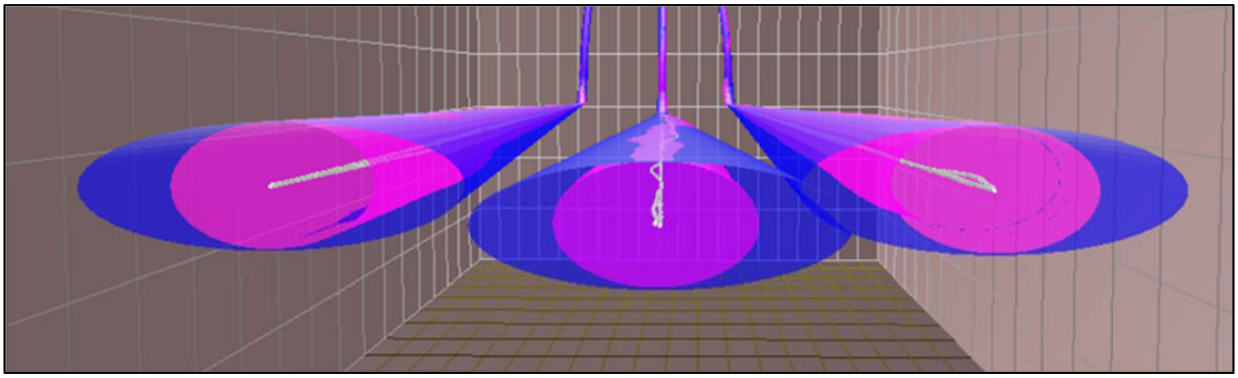


Figure 2: Ellipsoids of uncertainty computed by the IPM at each survey station propagate along the well path creating an elliptical tunnel of positional uncertainty.

It is important to note that the MWD tool code used for EOU and anti-collision calculations specifies the permissible magnitudes of the various error terms. Another assumption also made is that surveys are free of gross error, since gross error cannot be predicted or modeled (Torkildsen 1997). To validate EOUs and anti-collision scans, it is therefore essential to quality control MWD survey measurements to verify that they are free of gross error and do not contain excessive random or systematic error. If the quality control step is not performed, then there can be very little confidence that the tool code is representative of the actual errors in the wellbore position.

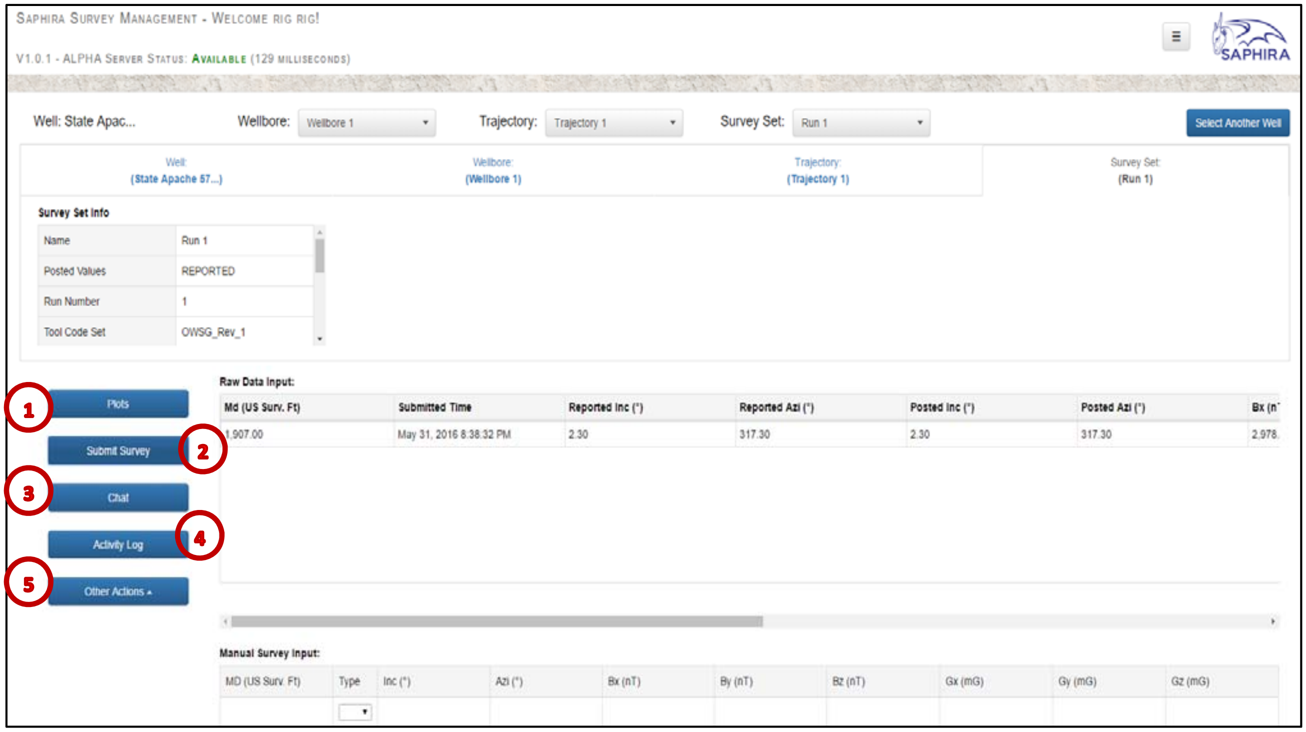
There are three values computed from MWD survey measurements which can be used for quality control purposes. They are B total (strength of the magnetic field), Dip (direction of magnetic field with respect to horizontal plane), and G total (strength of the gravity field) (Ekseth 2010). These measurements are used as metrics for survey quality, because regardless of the orientation of the wellbore and BHA, the measured B total, Dip, and G total should be equal to the values provided by the geomagnetic and gravity reference models. Therefore, any differences between the measured values vs reference values (Δ B total, Δ Dip, and Δ G total) can be attributed to some combination of measurement error and reference error. This concept is the basis for standard single-station MWD survey quality control tests.

It is common in standard MWD surveying practice to rely on these single-station tests as the only metric for survey quality assurance. However, these tests are considerably lacking in their ability to fully validate the assumptions made by the tool code. For instance, typical QC tolerances used by MWD contractors for passing or failing surveys are often arbitrary limits based on legacy practices. A more informative and standardized approach would be to use QC tolerances that are derived from the same tool code used to compute the EOUs. Furthermore, it is not enough to evaluate each survey individually because single-station QC tests are extremely limited in their ability to distinguish different types of error. It is preferable to evaluate single survey points against the entire survey data set in order to identify trends that could indicate what types of errors are occurring and to gain a better understanding of how the various errors may actually impact the wellbore position. Finally, single-station QC tests are not capable of detecting certain types of gross human errors such as applying an incorrect north reference or misreporting the final survey measurement. This makes it critical to independently calculate survey inclination and azimuth from the raw sensor measurements and to independently compute reference values to verify against human mistakes that would otherwise go unnoticed.

Web Application for Independent Survey QC and Validation

Independent survey quality validation and analysis requires specialized tools and skillsets which are not readily available to most rig-site personnel. As a result, the most powerful form of survey quality assurance comes from independent and expert analysis by specialized professionals in remote operating centers. Historically, it has been challenging to transfer the necessary MWD survey data to remote centers without compromising data integrity or adding cumbersome and time consuming steps to the drilling process. A web-based application was developed to provide an interface between rig-site users and remote operating centers that optimizes the transfer of directional survey data in such a way that minimizes time consuming steps while simultaneously providing automatic data validation ensuring data integrity. The web application is a leap forward from traditional methods of emailing text files and spreadsheets between end users because it not only speeds up the entire process, but it significantly reduces the occurrence of transcription and clerical errors. Another benefit to web technology is that it is easily accessible by almost anywhere on the globe by simply logging in through a standard internet browser. This eliminates the need for specialized software. An intuitive rig-site user interface enables the user to upload, visualize, and receive survey data with minimal training. User permissions can be customized to ensure that drilling data is secure and only accessible by authorized individuals. Well data is organized in a standardized hierarchical structure as follows:

1. Company: operator or owner of data
    a. anti-collision rules and parameters
2. Field: area of drilling operations
    a. geodetic and coordinate information
    b. north reference
3. Pad: drilling site with multiple wellheads
4. Well: designated by a single wellhead
    a. drilling rig and TVD reference
    b. surface location
5. Wellbore: represents each physical hole in the subsurface
    a. magnetic reference information
6. Trajectory: definitive surveys characterizing a particular wellbore geometry
    a. can be made up from multiple survey sets
7. Survey Set: survey station data specific to an individual tool run
    a. survey type, sensor orientation, and units
    b. correction type (i.e. IFR1, IFR2, MSA, Sag, etc.)
    c. survey validation tolerances
    d. survey tie-in point
    e. survey analysis tolerances



Well: State Apac... Wellbore: Wellbore 1 Trajectory: Trajectory 1 Survey Set: Run 1

Well: (State Apache 57...) Wellbore: (Wellbore 1) Trajectory: (Trajectory 1) Survey Set: (Run 1)

Survey Set Info

Name	Run 1
Posted Values	REPORTED
Run Number	1
Tool Code Set	OWSG_Rev_1

Raw Data Input:

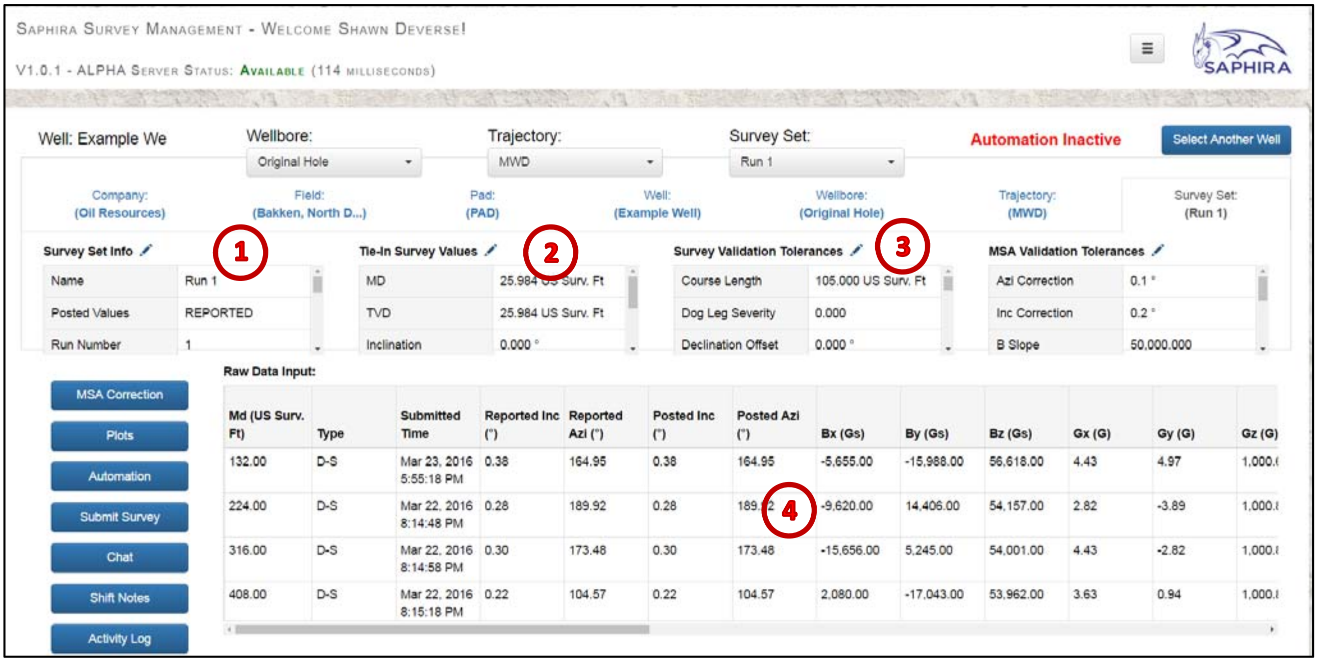
Md (US Surv. Ft)	Submitted Time	Reported Inc (°)	Reported Azi (°)	Posted Inc (°)	Posted Azi (°)	Bx (n
1,907.00	May 31, 2016 8:38:32 PM	2.30	317.30	2.30	317.30	2,978.

Manual Survey Input:

MD (US Surv. Ft)	Type	Inc (°)	Azi (°)	Bx (nT)	By (nT)	Bz (nT)	Gx (mG)	Gy (mG)	Gz (mG)
	▾								

Figure 3: Rig-site web interface is simplified for ease of use.

1. Plots: enables rig user to visualize MWD survey data
2. Submit Survey: surveys can be submitted by uploading direct files or by manual entry
3. Chat: facilitates communication between rig user and remote operating center
4. Activity log: tracks results from QC tests and other validation checks
5. Other actions: additional functionality including survey import/export and file storage



Well: Example We Wellbore: Original Hole Trajectory: MWD Survey Set: Run 1

Company: (Oil Resources) Field: (Bakken, North D...) Pad: (PAD) Well: (Example Well) Wellbore: (Original Hole) Trajectory: (MWD) Survey Set: (Run 1)

Survey Set Info

Name	Run 1
Posted Values	REPORTED
Run Number	1

Tie-In Survey Values

MD	25.984 US Surv. Ft
TVD	25.984 US Surv. Ft
Inclination	0.000 °

Survey Validation Tolerances

Course Length	105.000 US Surv. Ft
Dog Leg Severity	0.000
Declination Offset	0.000 °

MSA Validation Tolerances

Azi Correction	0.1 °
Inc Correction	0.2 °
B Slope	50,000.000

Raw Data Input:

Md (US Surv. Ft)	Type	Submitted Time	Reported Inc (°)	Reported Azi (°)	Posted Inc (°)	Posted Azi (°)	Bx (Gs)	By (Gs)	Bz (Gs)	Gx (G)	Gy (G)	Gz (G)
132.00	D-S	Mar 23, 2016 5:55:18 PM	0.38	164.95	0.38	164.95	-5,655.00	-15,988.00	56,618.00	4.43	4.97	1,000.
224.00	D-S	Mar 22, 2016 8:14:48 PM	0.28	189.92	0.28	189.[illegible]2	-9,620.00	14,406.00	54,157.00	2.82	-3.89	1,000.
316.00	D-S	Mar 22, 2016 8:14:58 PM	0.30	173.48	0.30	173.48	-15,656.00	5,245.00	54,001.00	4.43	-2.82	1,000.
408.00	D-S	Mar 22, 2016 8:15:18 PM	0.22	104.57	0.22	104.57	2,080.00	-17,043.00	53,962.00	3.63	0.94	1,000.

Figure 4: Expert user interface for advanced survey analysis.

1. Survey set info: metadata used to describe survey data, units, run number, and other parameters
2. Tie-in survey: used to initialize position of first survey in data set
3. Survey validation tolerances: parameters used to qualify survey data upon initial data entry
4. Raw survey data: all data associated with each MWD survey station

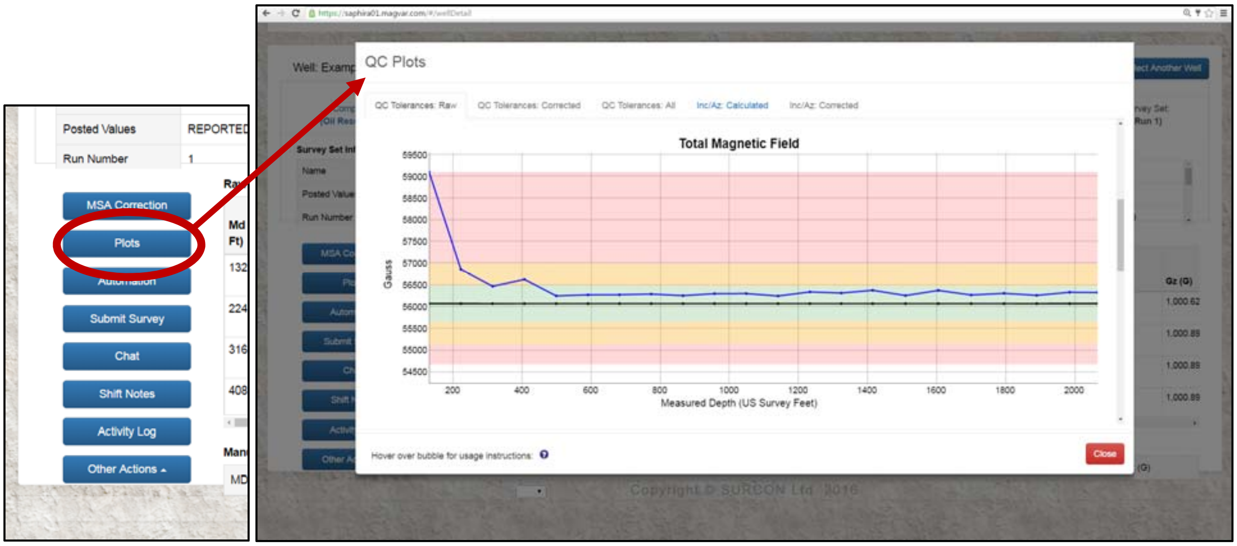
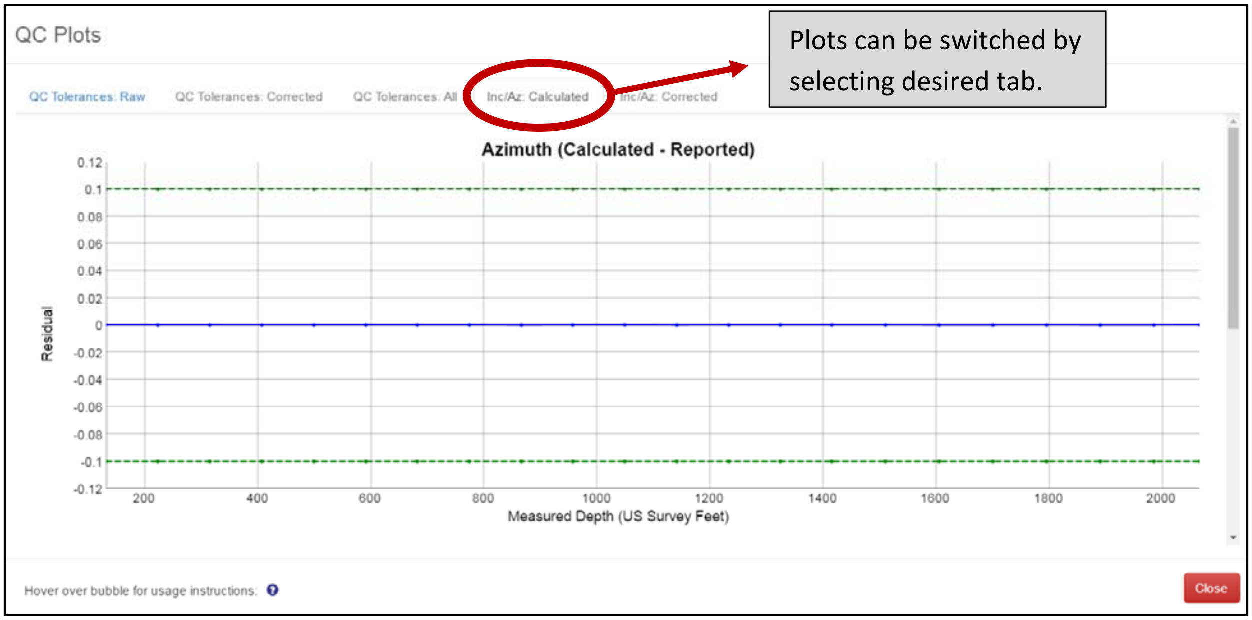


Figure 5: Plots are available to all users for MWD survey data visualization. QC plots of B total, Dip, and G total are helpful for evaluating trends in data, verifying reference value accuracy, and identifying sources of error. This plot shows B total (total magnetic field) plotted vs. measured depth. The outlier survey at the beginning of the wellbore is a result of magnetic distortion caused by conductor casing and the drilling rig.



Plots can be switched by selecting desired tab.

Figure 6: Plot showing the difference between calculated and reported inclination/azimuth are a helpful tool to verify accuracy of raw MWD 6 axis data. In this plot, there is perfect agreement between reported and calculated azimuth. If a disagreement is observed, then the likely cause can be determined such as incorrect north reference, miscorrelated raw data, clerical errors, or incorrect reference declination.

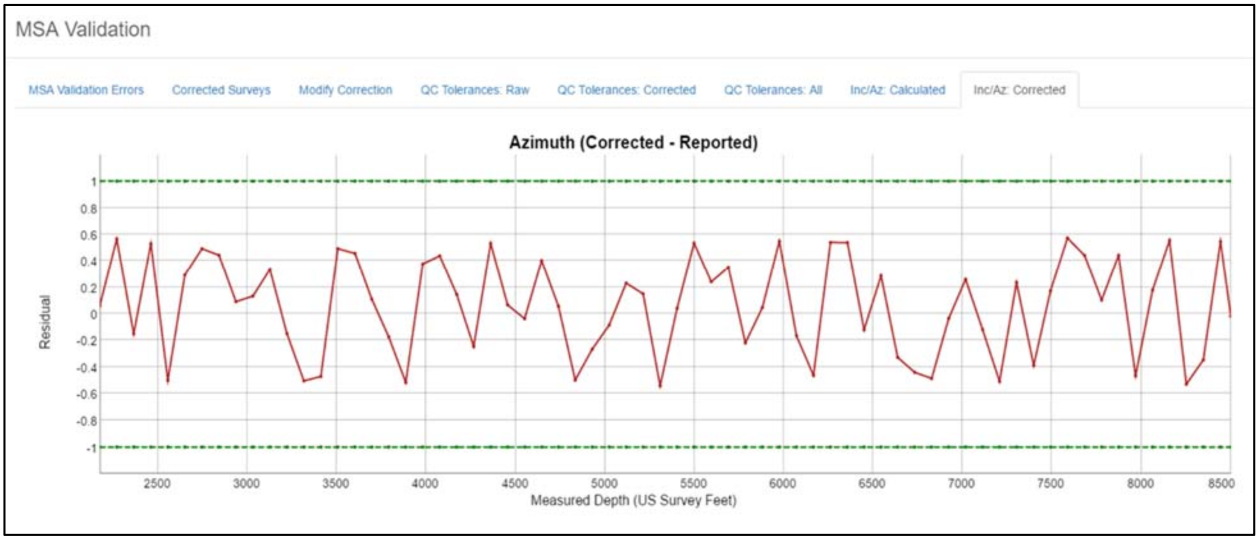


Figure 7: Plot showing the difference between corrected and reported inclination/azimuth helps users QC and understand survey corrections that are being applied. This plot shows an example of survey data corrected for large cross axial errors which cause variation in azimuth correlated with tool face.

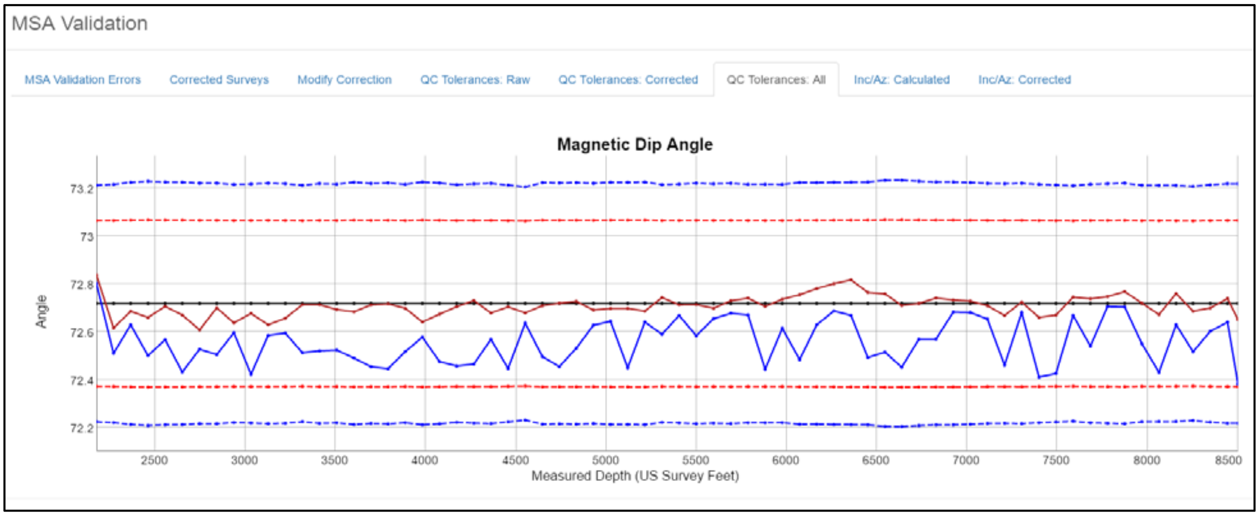


Figure 8: QC plot shows raw survey data (blue) overlaid with MSA corrected data (red) to help user verify that applied corrections are improving survey quality. This plot shows a reduction in variance and offset from the reference dip angle signifying an improvement in survey quality.

Surveying professionals at the rig site upload MWD survey data into a web application in real-time. The survey measurements are then automatically validated through independent quality checks to prevent clerical mistakes and identify gross errors. Remote survey analysts can then access the verified MWD data and evaluate it for systematic or random error that could indicate non-compliance with the instrument performance model, or tool code. Surveys can also be corrected in real-time when systematic errors are identified and provided back to the rig site personnel for accurate steering and wellbore placement. Figure 9 shows the process workflow as it is implemented in drilling operations.

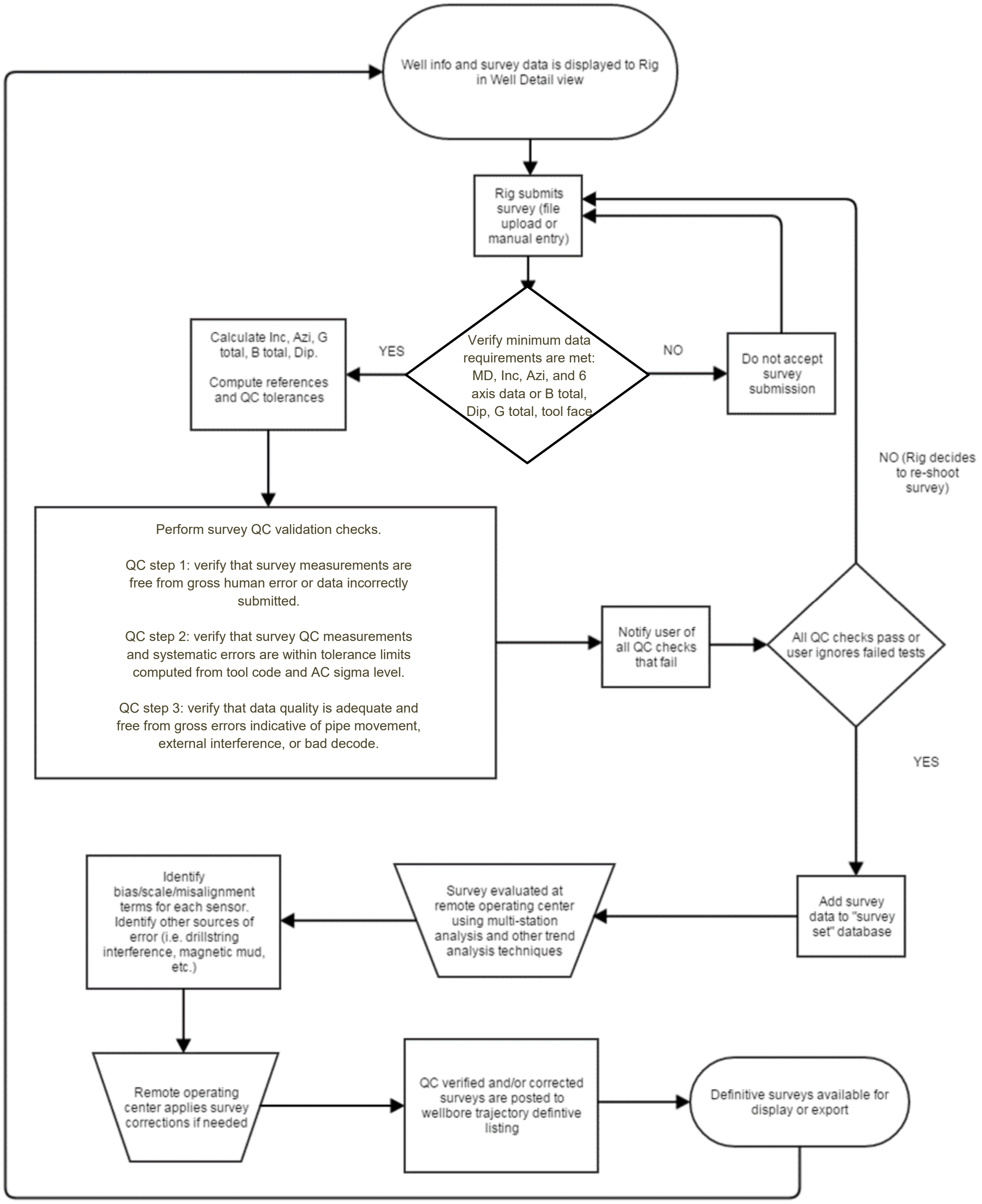
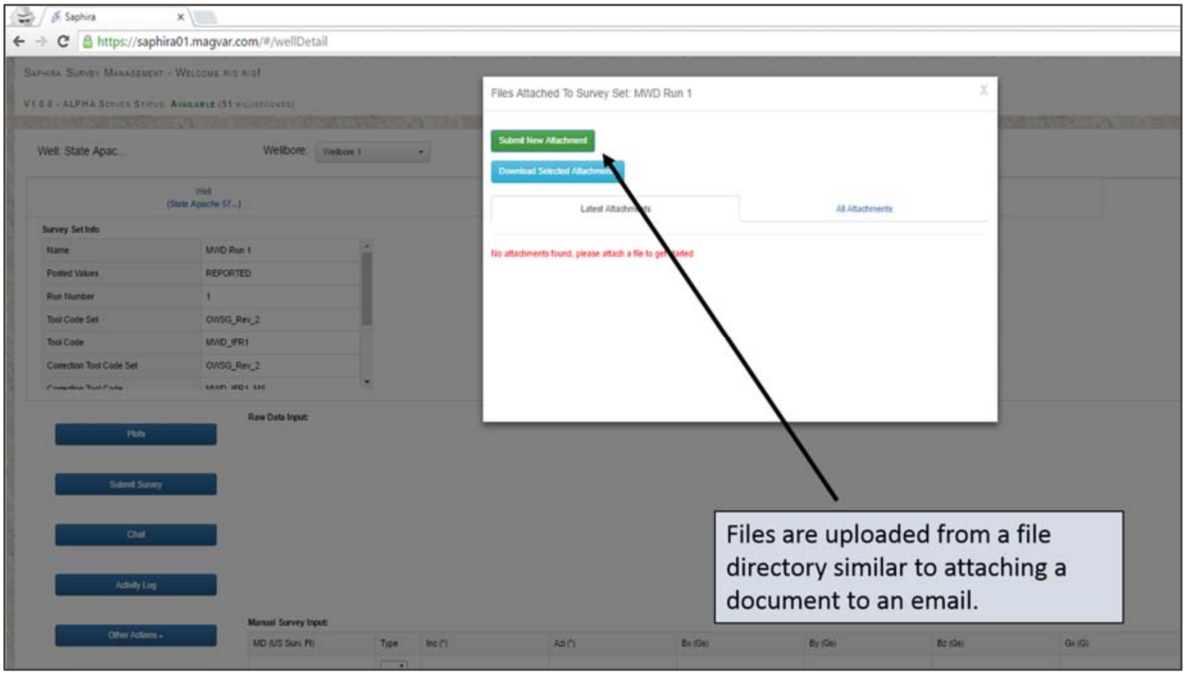


Figure 9: Process workflow for MWD data transfer and independent survey quality assurance.

The first step is for the MWD operator to upload the MWD data to the web application after taking a survey measurement as shown in Figure 10. At a minimum, the data should include the reported measured depth, inclination, and azimuth and the corresponding B total, G total, and Dip or the 6 axis data (accelerometer and magnetometer measurements). When the survey file is uploaded to the web application, the data processor will read the survey file and extract the relevant MWD data. By uploading a direct survey export file, one can minimize the occurrence of transcription errors. However, sometimes the surveying contractor is limited by their surveying software capabilities and must enter the MWD data manually into the web application. Once MWD data is entered, the web application re-computes inclination and azimuth from the corresponding 6 axis measurements when available and compares the results to the rig reported inclination and azimuth. This step ensures that the data is free of clerical errors and also provides an independent check against the north reference, grid correction, and magnetic reference values being applied.



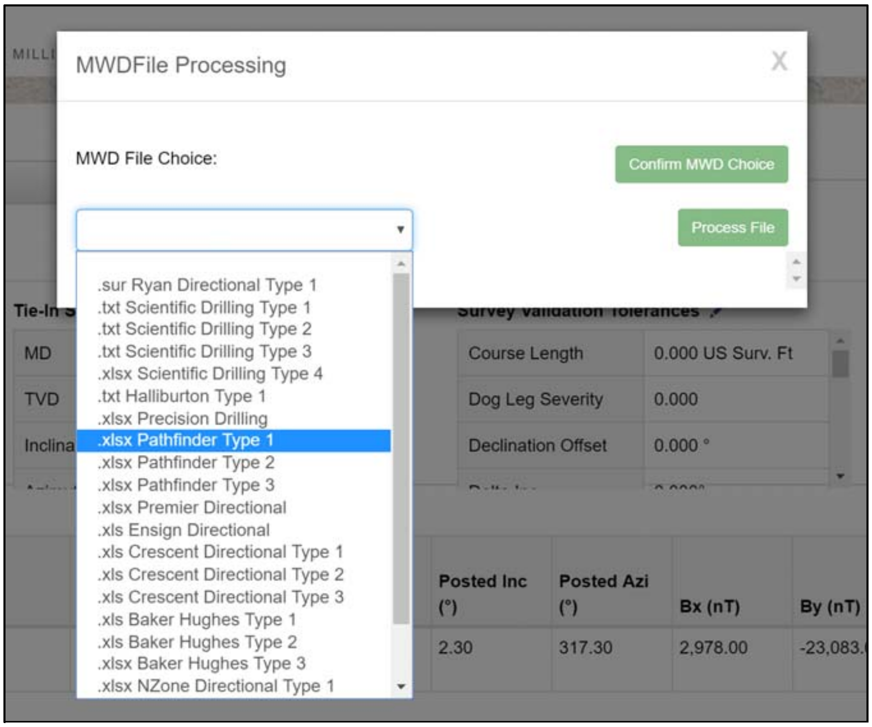
Survey Set Info

Name	MWD Run 1
Posted Values	REPORTED
Run Number	1
Tool Code Set	OWSG_Rev_2
Tool Code	MWD_IFR1
Correction Tool Code Set	OWSG_Rev_2

No attachments found, please attach a file to get started

Files are uploaded from a file directory similar to attaching a document to an email.

Figure 10: User uploads survey file to web application via rig interface.



Course Length	0.000 US Surv. Ft
Dog Leg Severity	0.000
Declination Offset	0.000 °

Posted Inc (°)	Posted Azi (°)	Bx (nT)	By (nT)
2.30	317.30	2,978.00	-23,083.

Figure 11: User selects survey file format type from available list. The MWD reader is already compatible with most custom surveying contractor file types, but can be updated to include additional file types as long as the minimum data requirements are met.

Next, the survey measurement is validated against the tool code by evaluating the Δ B total, Δ Dip, and Δ G total using the appropriate QC tolerances. The QC tolerances are computed from the error coefficients specified in the tool code and scaled to the same sigma level used for collision avoidance planning. QC tolerances are also dependent on inclination and azimuth and therefore change with wellbore geometry. If the Δ B total, Δ Dip, or Δ G total fall outside the calculated QC tolerance limits, then the survey measurement has greater error than what was modeled by the tool code EOUs and the anti-collision assessment may be invalid. However, it is not enough to evaluate each survey individually without comparing it to the entire data set. For instance, if there is a systematic error present that is causing every survey to fail the B total and Dip QC tolerances, then the possibility of a gross error occurring without recognizing it as such becomes very likely. Therefore, it is useful to evaluate the surveys against the entire data set in order to identify trends that could alert the driller to gross errors indicative of external magnetic interference from offset well casing or a failing instrument. To accomplish this, another validation check is compare the deviation of the survey measurement with the standard deviation of the preceding MWD data. If the measurement exceeds a certain threshold, such as 3 sigma, then the survey could be considered a statistical outlier and suggests that there is particular problem such as a poor telemetry decode or the BHA is in near proximity to an offset wellbore. Figure 5 is an example QC plot available within the web application to provide users with visualization of the MWD data.

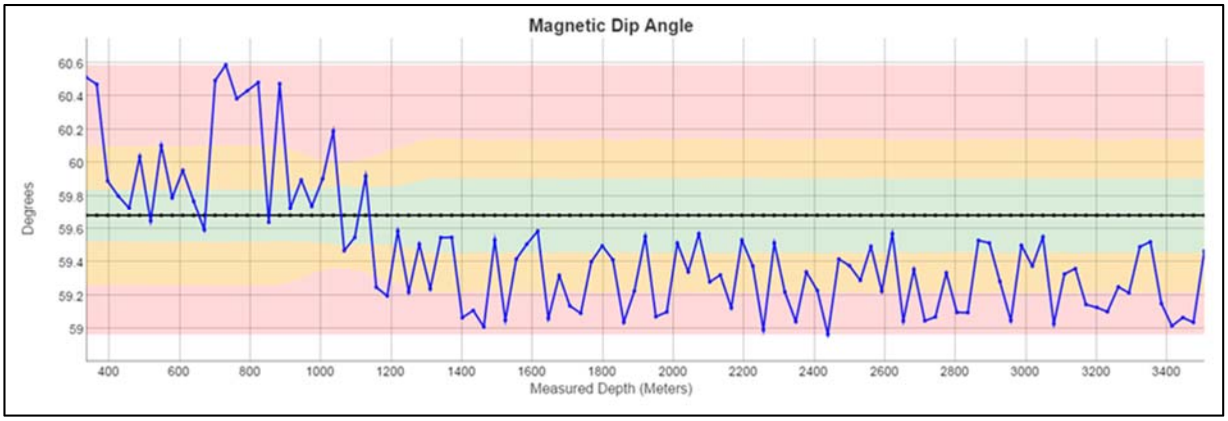
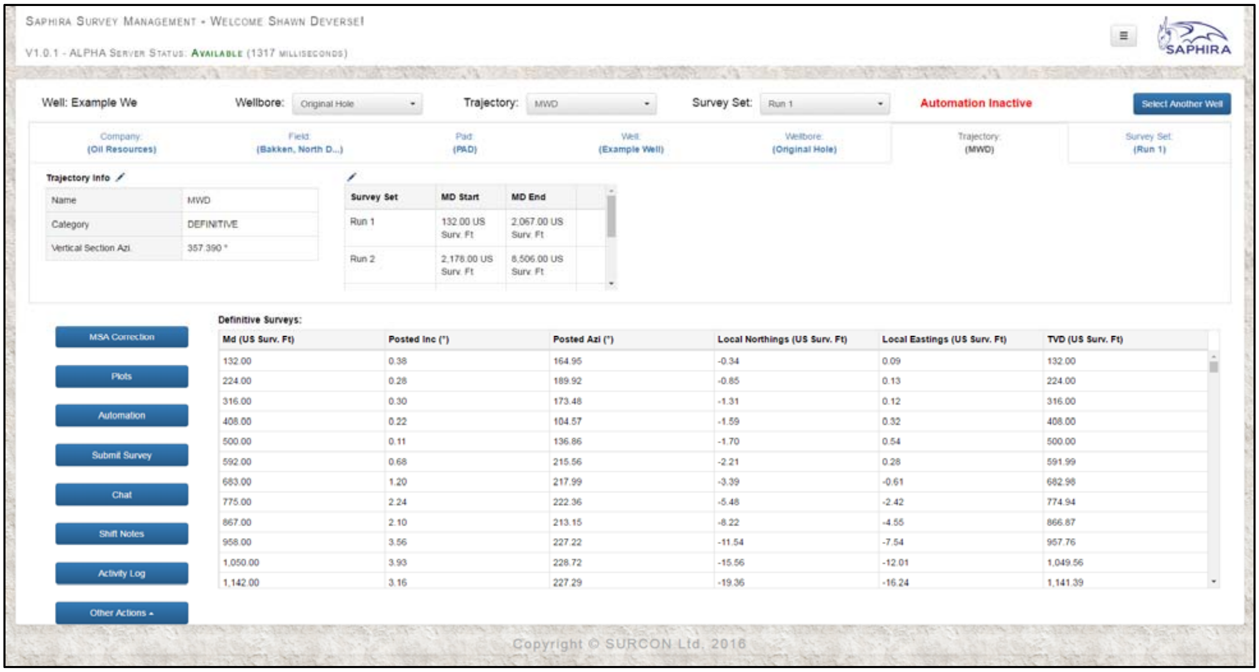


Figure 12: QC plot of measured Dip angle with baseline centered on Dip reference value. This plot shows significant variation in dip measurement between survey stations caused by a misalignment between the magnetometers and the accelerometers.

The initial validation steps are fully automated and occur almost instantly thus giving the rig-site personnel immediate feedback if there is a problem. Alerting rig users to potential survey problems in a timely manner creates an opportunity to re-shoot the survey or elevate the concern to management before drilling begins again. Once the initial survey validation is passed, the MWD data is automatically uploaded into a cloud database where it is permanently stored and managed. This is a central step because storing the data on a cloud server makes it easily accessible by survey specialists in remote operating centers who can perform expert analysis in real-time. While the initial QC validation works well to detect potential problems in the survey quality, it does very little to identify the underlying cause of the problem or distinguish between the various sources of error. Alternatively, the survey data can be further evaluated using advanced MSA (multi-station analysis) techniques to determine individual error components attributed to sensor bias, scale, and misalignment. Trend analysis is also useful for recognizing patterns characteristic of magnetic drillstring interference, magnetic mud, and other environmental factors that contribute to survey error. Survey analysis is performed in real-time in order to estimate the potential impacts on wellbore position and to determine the most cost effective approach to managing or reducing survey errors before making operational decisions. If survey corrections are required, they can be applied through the same web tool used for processing and managing the MWD data. Corrected surveys are then displayed to the rig-site user on the same interface and made available for download or export as shown in Figure 10.



SAPHIRA SURVEY MANAGEMENT - WELCOME SHAWN DEVERSE!

V1.0.1 - ALPHA SERVER STATUS: AVAILABLE (1317 MILLISECONDS)

Well: Example We Wellbore: Original Hole Trajectory: MWD Survey Set: Run 1 Automation Inactive

Company:	Field:	Pad:	Well:	Wellbore:	Trajectory:	Survey Set:
(Oil Resources)	(Bakken, North D...)	(PAD)	(Example Well)	(Original Hole)	(MWD)	(Run 1)

Trajectory Info

Name	MWD
Category	DEFINITIVE
Vertical Section Azi	357.390 °

Survey Set	MD Start	MD End
Run 1	132.00 US Surv. Ft	2,067.00 US Surv. Ft
Run 2	2,178.00 US Surv. Ft	8,506.00 US Surv. Ft

Definitive Surveys:

Md (US Surv. Ft)	Posted Inc (°)	Posted Azi (°)	Local Northings (US Surv. Ft)	Local Eastings (US Surv. Ft)	TVD (US Surv. Ft)
132.00	0.38	164.95	-0.34	0.09	132.00
224.00	0.28	189.92	-0.85	0.13	224.00
316.00	0.30	173.48	-1.31	0.12	316.00
408.00	0.22	104.57	-1.59	0.32	408.00
500.00	0.11	136.86	-1.70	0.54	500.00
592.00	0.68	215.56	-2.21	0.28	591.99
683.00	1.20	217.99	-3.39	-0.61	682.98
775.00	2.24	222.36	-5.48	-2.42	774.94
867.00	2.10	213.15	-8.22	-4.55	866.87
958.00	3.56	227.22	-11.54	-7.54	957.76
1,050.00	3.93	228.72	-15.56	-12.01	1,049.56
1,142.00	3.16	227.29	-19.36	-16.24	1,141.39

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Figure 13: Corrected surveys are posted on web interface and available for download or direct export.

Examples of Survey QC Tolerances

Survey QC tolerances can be calculated similarly to how MD, Inc, and Azi error are calculated from a tool code (Maus 2014). Weighting functions for B total, Dip, and G total can be derived for each error coefficient identified within the tool code. The weighting function computes how the magnitude of the error coefficient affects the final QC parameter (i.e. Δ B total, Δ Dip, and Δ G). The expected errors in B total, Dip, and G total are computed based off the same assumptions made by the tool code. QC tolerances are dependent on numerous variables such as wellbore geometry, strength and direction of the geomagnetic field, confidence level (sigma multiplier), and the magnitudes and weighting functions of the various error coefficients associated with the surveying method being applied. Ekseth et. al. (2007) provides a detailed explanation for how to derive error model based QC tests. Calculating QC tolerances from tool codes manually can be quite challenging due to the numerous variables and the complexity of deriving the individual weighting functions. QC tolerances will also change throughout the wellbore due to geometry variation and differences in surveying methods. However, web-based software facilitates practical implementation of error model based QC into drilling operations. Table 1 provides example tolerance limits for a typical horizontal wellbore planned with at 2.79 sigma confidence level and drilled using standard MWD survey measurements in the Eagle Ford Basin, Texas. Table 2 provides an example of how QC tolerances for the same wellbore would change if IFR1 (in-field referencing) and MSA corrections were both applied to the MWD surveys.

Table 1: QC tolerances for MWD tool code (OWSG Rev 1) at 2.79 sigma confidence level

Inclination (°)	Azimuth (°)	B total (nT)	Dip (°)	G total (mill-G)
0	45	825.7	0.85	4.9
20.75	45	899.5	0.66	4.85
45.25	45	865.4	0.73	4.79
90	45	562.6	0.92	4.9

Table 2: QC tolerances for MWD+IFR1+MS tool code (OWSG Rev 1) at 2.79 sigma confidence level

Inclination (°)	Azimuth (°)	B total (nT)	Dip (°)	G total (mill-G)
0	45	298.4	0.37	4.9
20.75	45	323.3	0.32	4.85
45.25	45	311.6	0.35	4.79
90	45	220.1	0.39	4.9

The QC tolerances are different in these two cases because application of IFR1 and MSA corrections will reduce the uncertainty, or expected error, in several error coefficients. When QC tolerances for the MWD+IFR1+MS tool code is computed using the reduced error coefficients, then the resulting error in B total and Dip is also reduced. However, the QC tolerances for G total are identical in both cases, because IFR1 and MSA do not yield any reduction in error associated with G total measurements.

Another observation from these two tables is that QC tolerances change with respect to inclination. This is a result of how certain error coefficients affect B total, Dip, and G total measurements at different geometries. For example, it is evident that the B total QC tolerance increases through the build section of the wellbore then decreases to a minimum in the lateral section. This is understood by looking at how axial magnetic interference affects B total measurements. When the drillstring aligns with the natural magnetic field vector, which it does in this case through the build section, or at inclinations that are complementary to the dip angle, then the resulting effect on measured B total is greatest. However, once the drillstring is horizontal, then the effect on measured B total is reduced to a minimum. Figure 14 and Figure 15 demonstrate this concept for B total measurements at 45° and at 90° inclination.

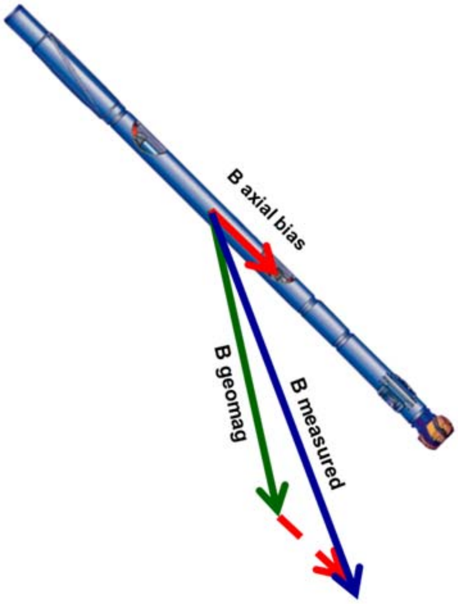

Figure 14: Axial magnetic interference has a greater effect on measured B total when the drillstring is at 45 degrees and closely aligned with the natural geomagnetic field.

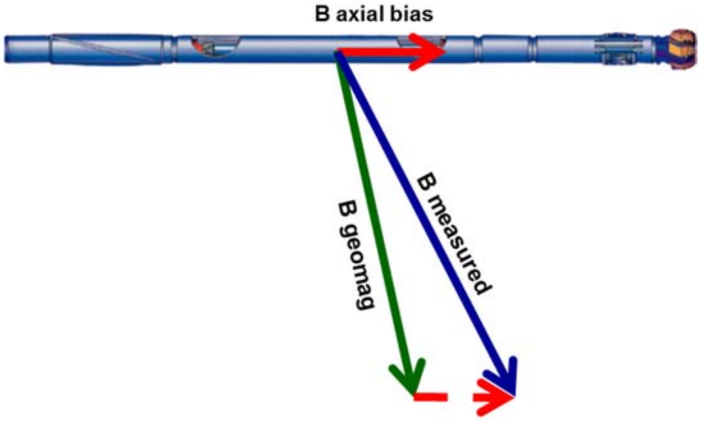

Figure 15: Axial magnetic interference has a reduced effect on measured B total when the drillstring is at 90 degrees.

The dependency B total has on inclination with respect to axial magnetic interference is just one example of how wellbore geometry affects MWD measurement error. However, one must look at the individual weighting functions of each error source to see their specific dependencies. Figure 16, Figure 17, and Figure 18 show a graphical representation of how some tool code error terms affect B total, Dip, and G total, respectively, throughout the entire wellbore. The plotted measurements for the Raw Measured series were calculated from synthetic MWD data with the following error terms applied: 700 nT axial magnetic interference, 2 mill-G reference G total error, 120 nT reference B total error, and 50 nT cross-axial magnetometer biases. The plotted measurements for the IFR 1+MS Corrected series were calculated after IFR 1 and MSA corrections were applied to the synthetic data, which effectively reduced the magnitude of the error terms to <50 nT, <0.5 mill-G, <60 nT, and <10 nT, respectively.

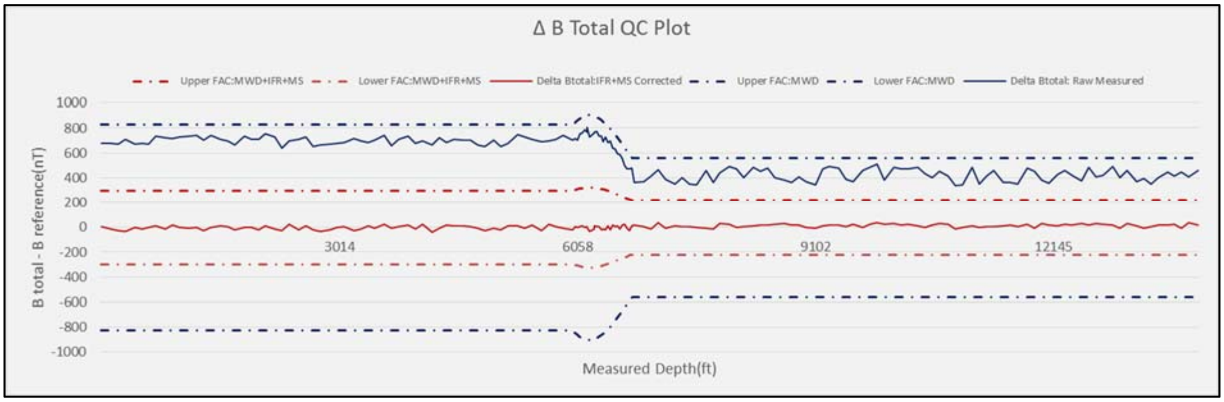

Figure 16: Delta B total plot for synthetic data with 700 nT axial magnetic interference, 50 nT cross-axial magnetic biases, and 120 nT B reference error. QC tolerances are reduced for MWD+IFR1+MS because IFR 1 and MSA reduces error in measured B total.

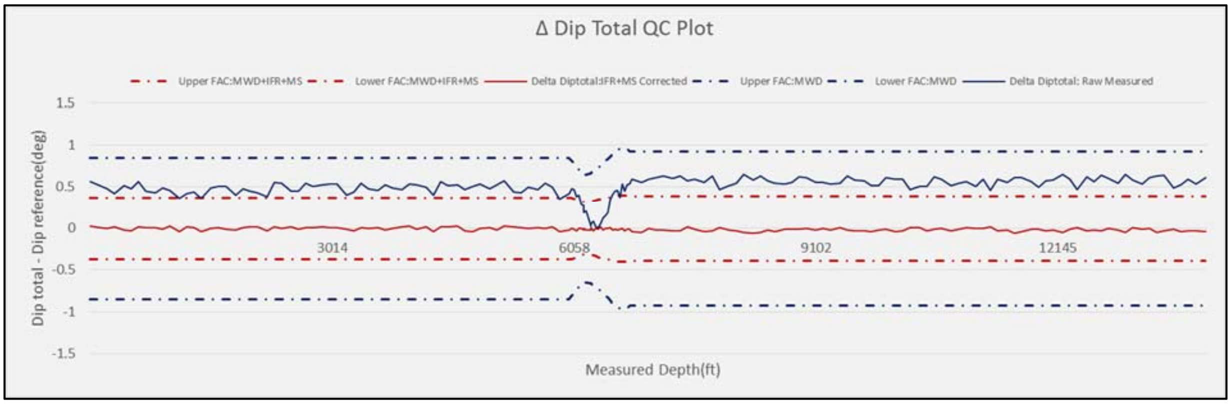

Figure 17: Delta Dip plot for synthetic data with 700 nT axial magnetic interference, 50 nT cross-axial magnetic biases. QC tolerances are reduced for MWD+IFR1+MS because IFR 1 and MSA reduces error in measured dip.

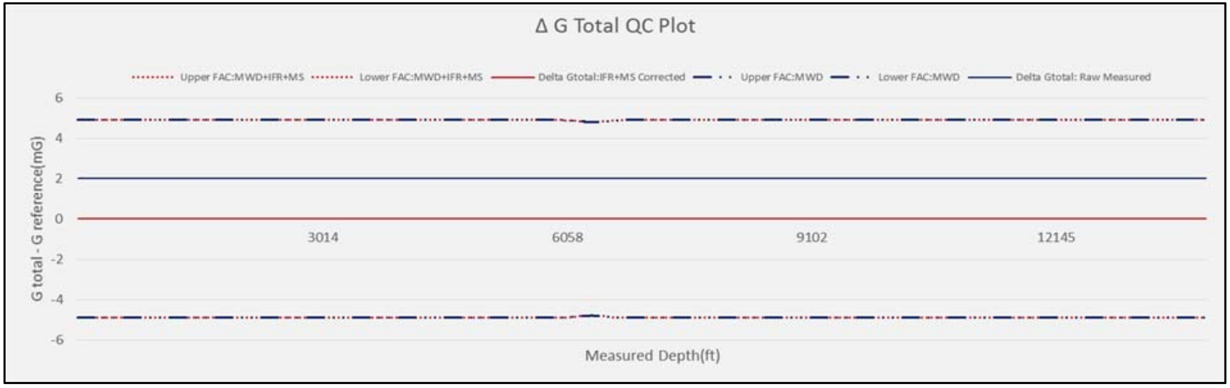

Figure 18: Delta G total plot for synthetic data with 2 mill-G G reference error. QC for MWD is the same as MWD+IFR1+MS because IFR and MSA corrections do not affect G total measurements.

Results

This web-based technology has successfully been implemented across numerous drilling rigs in many of the major U.S. shale plays including the Bakken, Marcellus/Utica, Niobrara, Permian, and Eagle Ford. Examples for common types of errors that were prevented and/or corrected were miscalculated grid correction, incorrect north reference, excessive drillstring interference, poor instrument calibration, misaligned sensors, magnetic mud, and incorrect survey order. The impact of these errors, if not prevented, could easily have caused hundreds of feet of positional error at the bottom hole location. Figure 19 shows one of these examples where the rig reported azimuth was observed to be offset from the azimuth calculated independently from the raw MWD measurements. The observed offset was a result of the surveying contractor applying a grid correction even though the wellbore was supposed to be referenced to true north. This particular azimuth error of 1.1 degrees would have caused over 170 feet of lateral error (shown in Figure 20) that would not have been caught by standard survey QC practices. Furthermore, the MWD tool code used to model the wellbore uncertainty does not account for these types of errors, which means that the anti-collision analysis would have been completely invalidated had this error not been corrected. However, it was quickly recognized during the independent validation process facilitated by the web application discussed throughout this paper and corrected in real-time thus mitigating any adverse consequences.

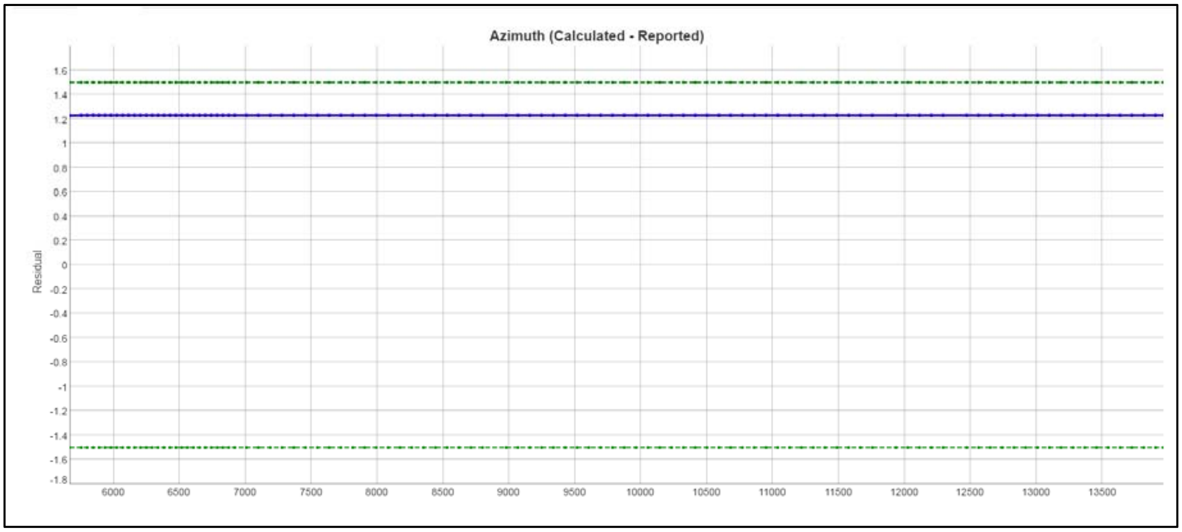

Figure 19: Plot showing consistent difference of 1.1 degrees between calculated azimuth vs. reported azimuth as a result of incorrect grid correction.

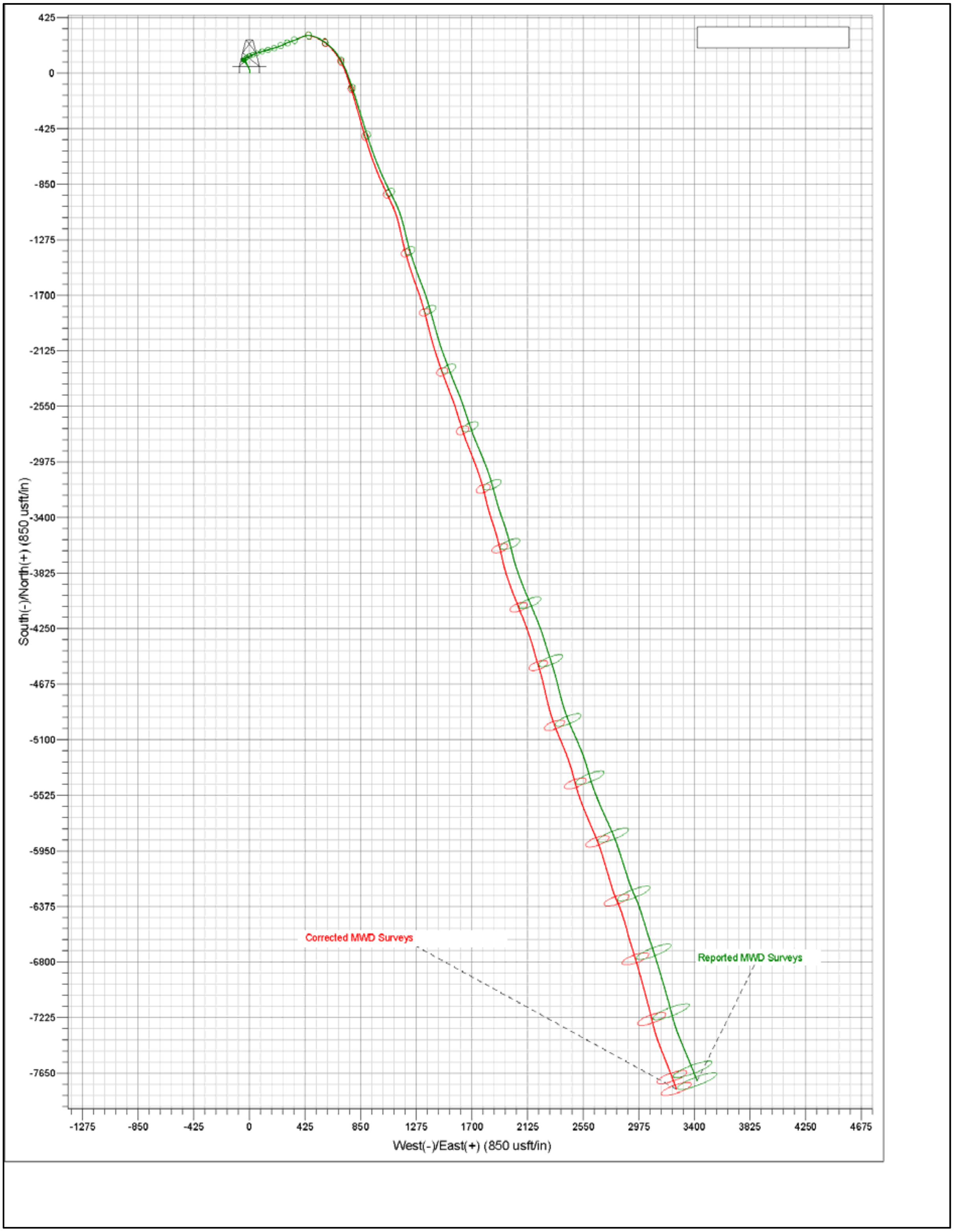

Figure 20: Plan view plot comparing reported MWD surveys against surveys corrected for north reference error.

Prevention of human errors and systematic errors which can cause significant misplacement of the bottom hole location is an important role of independent survey quality analysis. Another important benefit is detection of anomalous MWD data that could indicate a serious concern such as shown in Figure 21. In the example data set, one can see the last three data points appear to be outliers as compared to the rest of the data set. Without proper analysis of the data, it is impossible to determine if these apparent outliers are a result of changing wellbore geometry, a failing instrument, or magnetic distortions caused by offset well casing. After careful analysis, the survey outliers were determined to be caused by external magnetic interference. The decision was made to stop drilling and run gyro surveys in the offset well which showed that it was significantly closer than what was depicted by the original surveys. In this example, independent QC of the surveys in real-time was a key factor in preventing a possible wellbore collision that could have resulted in significant cost.

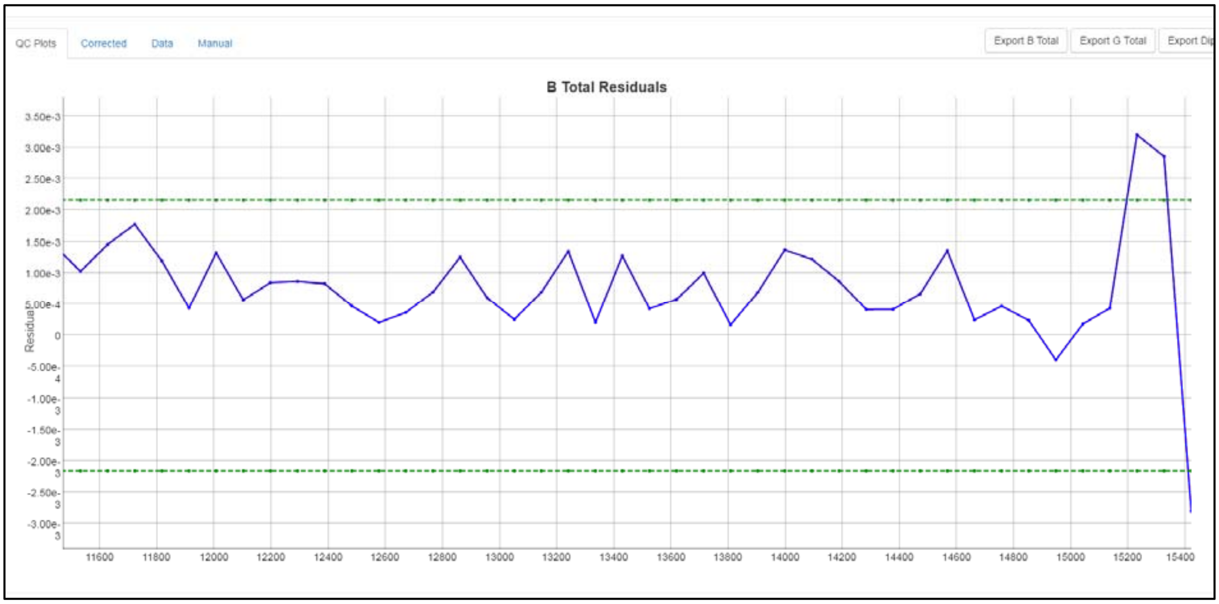

Figure 21: B total residual plot (Δ B total) shows outlier surveys indicative of external magnetic interference caused by close proximity to an offset wellbore.

Conclusion

Well planning with EOUs computed from standardized tool codes is generally accepted as a safe and effective method for avoiding wellbore collisions. However, it is critical to understand that tool codes are based on assumed magnitudes of error, and if survey measurements have greater error than what was assumed, then the actual wellbore position can fall outside the planned EOUs. In order to reduce this risk, it is recommended to perform independent survey QC validation on all survey measurements. The most effective method for MWD survey validation is to use web-based technology to independently calculate surveys from raw 6 axis data using independent reference values and to test QC parameters against tolerances derived from the tool code associated with the surveying methodology. Furthermore, surveys should be evaluated against the entire MWD data set for a particular tool run in order to identify statistical significance and perform multi-station analysis. When a survey fails to pass QC tolerance limits, then it is reasonable to assume that the survey has greater error than what was modeled by the tool code for anti-collision planning. Evaluating survey quality by offsite professionals with specialized expertise provides the most powerful form of quality assurance. Using web-based technology, this highest tier of survey QC can be effectively integrated into most drilling operations at reasonable cost and standardized across the industry which will ultimately reduce the number of wellbores drilled outside the planned EOUs.

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