Survey QC, Decision Making, and a Modest Proposal for Error Models

• Marc Willerth, MagVAR



Speaker Information

- Marc Willerth
- VP of Survey Technologies
- April 11, 2018
- MagVAR



Speaker Bio

- Marc Willerth
 - Magnetic Variation Services, LLC
 - Purdue University / BS Chem / Chem Eng
 - Denver, CO
 - Specializes in:
 - Talking about surveys, survey corrections, and survey quality
 - Talking about error models, & positional uncertainty
 - Honorary "Concerned Dutch Citizen"

Company / Affiliation Information



- High-accuracy Magnetic Models (MVHD, IFR1, IFR2)
- Survey Analysis and Real-time Survey Management
- Free QC Calculator: <u>http://fac.magvar.com/</u>
- Free QC API: <u>https://fac-api.magvar.com/</u>



Survey verification should not require expertise in surveying

Error-model-based QC should be possible using the Error model



Most people who drive cars are not mechanics



Most people who drive cars are not mechanics



There are warning signs when you need one



Expertise Requirement

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• Most who drill and survey wellbores are not survey experts

• Consumers of the data may be even less of an expert

• How do they know when there is a problem?

• Importance of error-model-based QC



Error-Model-Based QC A Brief History

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0.6 Survey Measurement 0.4 0.2 Error in Dip Angle 0 -0.2 -0.4 **Ideal Survey** -0.6 -800 -600 -400 -200 200 400 600 800 Error in Total Magnetic Field (Not shown – Error in Graviational Acceleration)

Pre-Error Model

- Measure deviation from references
- Many standards, usually fixed thresholds

Error-Model-Based QC A Brief History

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Pre-Error Model

- Measure deviation from references
- Many standards, usually fixed thresholds

SPE 103734, Ekseth, et al (2006)

- Define weighting functions, Root-Sum-Square
- Dynamic QC Changes with orientation



Error-Model-Based QC A Brief History

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Pre-Error Model

- Measure deviation from references
- Many standards, usually fixed thresholds

SPE 103734, Ekseth, et al (2006)

- Define weighting functions, Root-Sum-Square
- Dynamic QC Changes with orientation

Maus, et al (2017)

- Account for error covariance
- Compute "sigma distance"

SPE103734: **Root-Sum-Square** 0.2 Error in Dip Angle $\Rightarrow 1.14$ 0 -0.2 -0.4 Maus: Sigma Distance -0.6 800 -800 200 600 **Error in Total Magnetic Field**

Shortcomings of These Methods

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Focus on single survey evaluation

- User is interested in the set as a whole
- Exception: MSE in 103734, but use and interpretation requires a knowledgeable user

Real-World workflows can lead to complacency

- Once one survey fails, all the rest will likely fail
- "Drill ahead, this always happens near vertical!"

Escalation procedures often assume some level of expertise

- "If you identify interference from an offset well, notify town"
- Assumes that they already know if the survey is good or bad



When do I stop drilling?

When do I need to resurvey the well?



Move away from single surveys, towards survey sets

Use Propagation modes to build an expanded error covariance matrix

- Already contained in the Error Model
- Explains how errors should correlate *between* surveys in a set

Two New QC Values

- Marginal Sigma Distance
- Total Survey Confidence



Marginal Sigma Conditional Expectation and Survey QC

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First Survey – Normal QC

Acceptable envelope from error covariance



Marginal Sigma Conditional Expectation and Survey QC

Survey QC, Decision Making, and a Modest Proposal for Error Models presented by Marc Willerth

0.6 First Survey – Normal QC 0.4 Acceptable envelope from error covariance Angle 0.2 Second Survey – Conditional QC based on first 0 Error in Dip Drilling straight, large errors are correlated 0 Whole ellipse no longer acceptable -0.2 **Conditional Error** -0.4 Covariance

-0.6 -800

-600

-400



Marginal Sigma Conditional Expectation and Survey QC

Survey QC, Decision Making, and a Modest Proposal for Error Models presented by Marc Willerth

0.6 First Survey – Normal QC 0.4 Acceptable envelope from error covariance Marginal Sigma 0.2 gle €.1.52 Second Survey – Conditional QC based on first Ang Distance Error in Dip Drilling straight, large errors are correlated 0 Whole ellipse no longer acceptable -0.2 Marginal Sigma Conditional Error Sigma Distance from the conditional expectation -0.4 Covariance How much "new error" is in this survey? Does *this survey* require escalation? -0.6 -800 -600 -400 200 400 600 800 **Error in Total Magnetic Field**

Still Accounts for Orientation Change Two Possibilities for Survey #3

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Sigma distance can be computed for a group of surveys

• With residuals and the expanded covariance matrix

Direct Interpretation is not as straightforward

Larger survey sets will have a larger "total sigma"

Can convert this sigma distance into a P-value

• Set a threshold for when you should reject a survey as invalid





The probability that data at least this extreme would be produced by random chance given a certain set of assumptions



"If my survey instrument meets the assumptions of the error model, how often do I expect to see data like this?"



P-value is a uniform threshold that can apply to all survey sets

• Normalizes for amount and quality of data

Operators can set their own false positive rate

• E.g. if P<= 0.10, escalate for further investigation

Can analyze arbitrarily large amounts of data

• Single survey, set of surveys, entire pad of wells with surveys, etc





New QC in Action

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One more time – Same Survey

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New QC methods

- Marginal Sigma (<2-sigma threshold)
- Total Confidence (P-Value, >0.10 threshold)

Survey passes QC until 1300m

- High confidence, low marginal sigma
- Errors are consistent with the Error-Model

Magnetic storm for ~8 hours

- Affected 10-12 surveys, not just 1
- Accelerometers not a big issue

May need to investigate azimuths deeper than 1300m



How Does This Work?

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Marginal Sigma and Total Survey confidence remove the expertise requirement to perform error-model based QC on a survey

Corrective action & remediation may still require expert evaluation, but *decision to escalate* does not and should not



Why has error-model based QC seemed so challenging up to now?



Why has error-model based QC seemed so challenging up to now?

Because it's not actually in the Error Model!



Fixing the Error Models Enable QC on All Surveys

Step 1: Add fields to the header

- Number of QC Criteria
- Names of the QC Criteria

47th General Meeting April 11th, 2018 Inverness, Scotland Survey QC, Decision Making, and a Modest Proposal for Error Models presented by Marc Willerth

| OWSG Prefix: | А005МЬ |
|-------------------------|---|
| Short Name: | MWD+IFR1 |
| Long Name: | OWSG MWD + IFR1 |
| Revision No: | 2 |
| Revision Date: | 18-May-15 |
| Revision Comment: | Rev 2 DBHR increased from 1500 to 3000 deg.nT. AMIL reduced from 300 to 220 |
| Source: | SPE 67616 and 63275 |
| Application: | MWD with IFR1 (IFR or Crustal Anomaly Correction) |
| Tool Type: | Magnetic |
| Status: | Agreed |
| Checked: | |
| Approved: | |
| Notes: | Based on ISCWSA MWD Rev 3 - Toolface Independent Sliding |
| Revision History: | Rev 0.1 05-Jun-2013 Draft Release for Comment. Rev 1.0 01-Nov-2013 Initial Re |
| Replaces / Replaced By: | OWSG_A005Ma_MWD+IFR1 / |
| Inclination Range Min: | 0 deg |
| Inclination Range Max: | 180 deg |
| Hor East/West Exclusion | 0 deg |
| Range Comment: | None |
| Tool Parameters | |
| Number of QC Criteria: | 3 |
| Q1 | Error in Magnetic Field Strength |
| Q2 | Error in Magnetic Dip Angle |
| Q3 | Error in Gravitational Field Strength |



Fixing the Error Models Enable QC on All Surveys

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Step 2: Add weighting functions for the QC Criteria

- The same as for Inc, Azi, and Depth
- Relate each error to its relevant QC parameters

| No | Code | Term Description | Wt.Fn. | Q1 Formula | Q2 Formula | Q3 Formula | |
|----|------|-------------------------------------|--------|------------|---|------------|--|
| 22 | AMIL | MWD: Axial Interference - SinI.SinA | AMIL | Bz/Bfield | (cos(Dip)*cos(Inc)-sin(Dip)*sin(Inc)*sin(AzM))/Bfield | 0 | |
| 23 | SAG | MWD: Sag | SAG | 0 | 0 | 0 | |



Fixing the Error Models Enable Simple QC on All Surveys

Step 1: Add fields to the header

- Number of QC Criteria
- Names of the QC Criteria

Step 2: Add weighting functions for the QC Criteria

- The same as for Inc, Azi, and Depth
- Relate each error to its relevant QC parameters

Step 3: Add errors that impact QC, but not surveys

- Include relevant propagation modes
- Raise awareness of external factors that impact QC

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| P | lo Code | Term Description | Wt.Fn. | Wt.Fn. Source | Туре | Magnitude | Units | Prop. | P1 | P2 | P3 |
|---|--------------|--|----------|-------------------------|--------|-----------|--------|-------|----|----|----|
| | 1 DRFR | Depth: Depth Reference - Random | DREF | SPE 67616 | Depth | 0.35 | m | R | 0 | 0 | 0 |
| | 2 DSFS | Depth: Depth Scale Factor - Systematic | DSF | SPE 67616 | Depth | 0.00056 | - | s | 1 | 0 | 0 |
| | 3 DSTG | Depth: Depth Stretch - Global | DST | SPE 67616 | Depth | 2.5E-07 | 1/m | G | 1 | 1 | 1 |
| | 4 ABXY-TI1S | MWD TF Ind: X and Y Accelerometer Bias | ABXY-TI1 | SPE 63275 + Andy Brook | Sensor | 0.004 | m/s2 | s | 1 | 0 | 0 |
| | 5 ABXY-TI2S | MWD TF Ind: X and Y Accelerometer Bias | ABXY-TI2 | SPE 63275 + Andy Brook | Sensor | 0.004 | m/s2 | s | 1 | 0 | 0 |
| | 6 ABZ | MWD: Z-Accelerometer Bias | ABZ | SPE 67616 Table 1 | Sensor | 0.004 | m/s2 | s | 1 | 0 | 0 |
| | 7 ASXY-TI1S | MWD TF Ind: X and Y Accelerometer Scale Fact | ASXY-TI1 | SPE 63275 + Andy Brook | Sensor | 0.0005 | - | s | 1 | 0 | 0 |
| | 8 ASXY-TI2S | MWD TF Ind: X and Y Accelerometer Scale Fact | ASXY-TI2 | SPE 63275 + Andy Brooks | Sensor | 0.0005 | - | s | 1 | 0 | 0 |
| | 9 ASXY-TI3S | MWD TF Ind: X and Y Accelerometer Scale Fact | ASXY-TI3 | SPE 63275 + Andy Brook | Sensor | 0.0005 | - | s | 1 | 0 | 0 |
| 1 | LO ASZ | MWD: Z-Accelerometer Scale Factor | ASZ | SPE 67616 Table 1 | Sensor | 0.0005 | - | s | 1 | 0 | 0 |
| 1 | 1 MBXY-TI15 | MWD TF Ind: X and Y Magnetometer Bias | MBXY-TI1 | SPE 63275 + Andy Brook | Sensor | 70 | nT | s | 1 | 0 | 0 |
| 1 | L2 MBXY-TI25 | MWD TF Ind: X and Y Magnetometer Bias | MBXY-TI2 | SPE 63275 + Andy Brook | Sensor | 70 | nT | s | 1 | 0 | 0 |
| 1 | L3 MBZ | MWD: Z-Magnetometer Bias | MBZ | SPE 67616 Table 1 | Sensor | 70 | nT | s | 1 | 0 | 0 |
| 1 | 4 MSXY-TI1S | MWD TF Ind: X and Y Magnetometer Scale Fac | MSXY-TI1 | SPE 63275 + Andy Brook | Sensor | 0.0016 | - | s | 1 | 0 | 0 |
| 1 | L5 MSXY-TI2S | MWD TF Ind: X and Y Magnetometer Scale Fac | MSXY-TI2 | SPE 63275 + Andy Brook | Sensor | 0.0016 | - | s | 1 | 0 | 0 |
| 1 | L6 MSXY-TI3S | MWD TF Ind: X and Y Magnetometer Scale Fac | MSXY-TI3 | SPE 63275 + Andy Brook | Sensor | 0.0016 | - | s | 1 | 0 | 0 |
| 1 | I7 MSZ | MWD: Z-Magnetometer Scale Factor | MSZ | SPE 67616 Table 1 | Sensor | 0.0016 | - | s | 1 | 0 | 0 |
| 1 | L8 DECG | MWD: Declination - Global | AZ | SPE 67616 | AziRef | 0.15 | deg | G | 1 | 1 | 1 |
| 1 | L9 DECR | MWD: Declination - Random | AZ | SPE 67616 | AziRef | 0.1 | deg | R | 0 | 0 | 0 |
| 2 | 20 DBHG | MWD: BH-Dependent Declination - Global | DBH | SPE 67616 | AziRef | 1500 | deg.nT | G | 1 | 1 | 1 |
| | | MWD: BH-Dependent Declination - Random | DBH | SPE 67616 | AziRof | 3000 | des oT | R | 0 | 0 | 0 |
| 2 | 22 MDIG | MWD: Magnetic Dip - Global | MDI | SPE 67616 Table 1 | Mgntcs | 0.1 | deg | G | 1 | 1 | |
| | 3 MDIR | MWD: Magnetic Dip - Random | MDI | SPE 67616 Table 1 | Mgntcs | 0.08 | deg | R | 0 | 0 | |
| 2 | 4 MFIG | MWD: Total Magnetic Field - Global | MFI | SPE 67616 Table 1 | Mgntcs | 50 | nT | G | 1 | 1 | |
| | 5 MFIR | MWD: Total Magnetic Field - Random | MFI | SPE 67616 Table 1 | Mgntcs | 60 | nT | R | 0 | 0 | |
| 2 | 26 AMIL | MWD: Axial Interference - Sinl.SinA | AMIL | Halliburton | Mgntcs | 220 | nT | S | 1 | 0 | 0 |
| 2 | 27 SAG | MWD: Sag | SAG | SPE 67616 | Align | 0.2 | deg | s | 1 | 0 | 0 |
| 2 | 28 XYM1 | Misalignment: XY Misalignment 1 | XYM1 | SPE 90408 Table 9 - Alt | Align | 0.1 | deg | s | 1 | 0 | 0 |



Benefits of Expanding the Error Model

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Removes any ambiguity around "Error-Model-Based QC"

• It's in the error model!

Sets clear data requirements for Error-Model End Users

• To use an error model, you must have the associated QC parameters with the survey

Establishes clear limits on all QC parameters, clearly defines error covariance

• Derived from weighting functions, scaled to the operator's risk management policy

Expedites troubleshooting of survey issues, calls attention to good surveying practices

• Errors with no QC attached cannot be internally verified, require additional procedures



Not Just MWD

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Math doesn't care about magnetics – Anything with QC and an error model can do this

Example: Wireline gyro

- Earth-rate measurements, Zero-velocity updates, Pre- & Post- run calibration checks
- If these are in the error model, operators will know to ask for them!

Encourage QC of Depth Measurements

• Example: EDR Depth – Pipe Tally depth, now pipe tally must be stored with surveys

Enable earlier acceptance of new survey tools

• If a vendor provides a model and QC with a mathematical relationship, they are easier to audit



Survey QC becomes routine calculation, like a collision avoidance scan

Lapses in QC procedures are evident at the time they are critical to operations

The users most impacted by a QC failure are empowered to identify issues



Marginal Sigma and Total Survey Confidence enable a non-expert user to quickly validate a survey set against its error models

Adding QC criteria directly into all error models can simplify the survey verification process and promote good surveying practices



Thank You for Your Time! Any Questions?

