Automatic MWD Survey Processing

Konstantin Bulychenkov

Bio

Konstantin Bulychenkov

- MWD STD platform core services development
- Previously, SLB R&D experience:
  - Definitive Dynamic Survey-While-Drilling development
  - GyroSphere measurement processing
  - Drillstring interference compensation hardware
- In-field experience in MWD, LWD, Drilling Optimization, and Advanced Survey Support

Vision of Automation

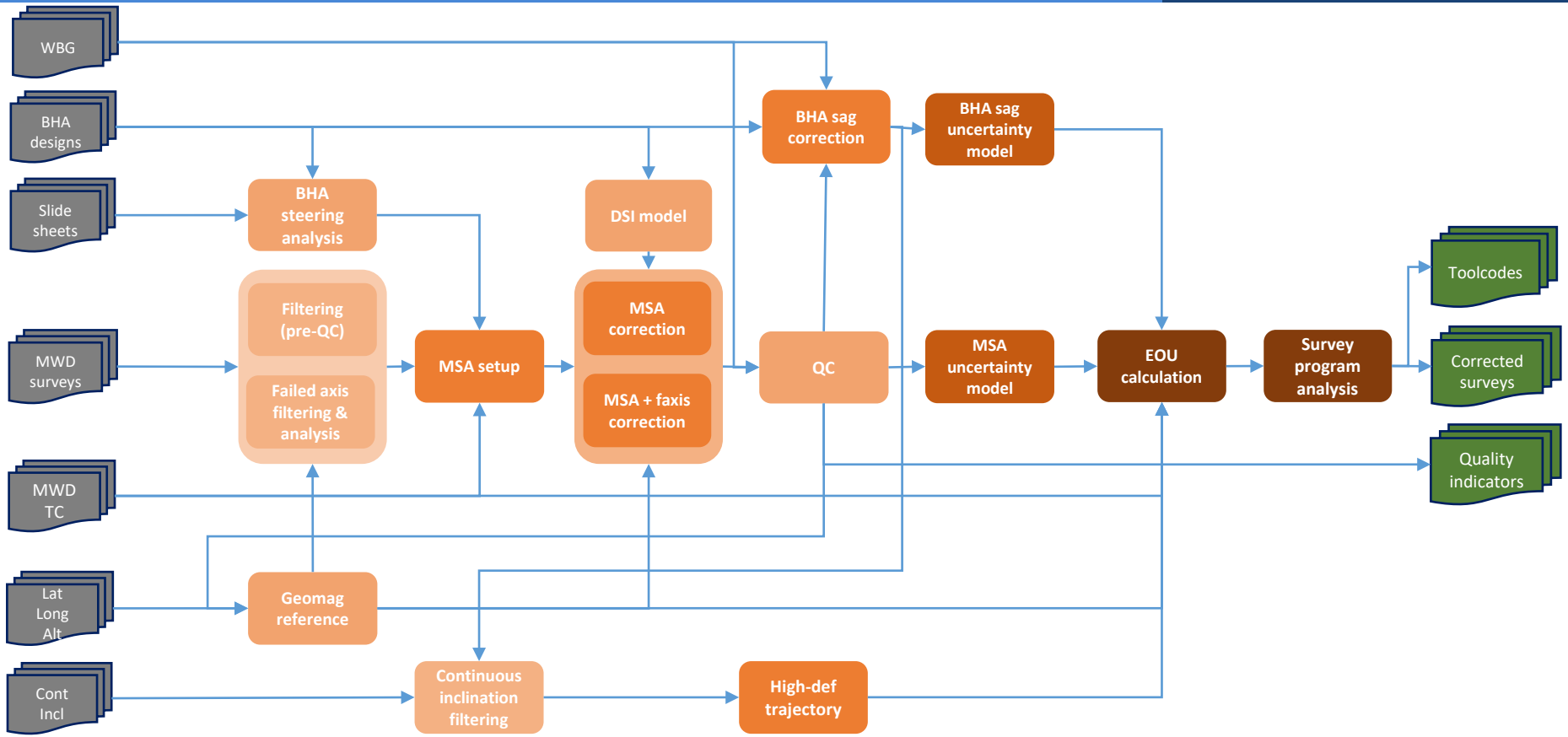
Human involving in case of issue only

Automation goals:

- To provide MSA correction, BHA sag correction, high-def trajectory
- To work autonomously under normal conditions (serviceable D&I module, no strong unexpected external interference, correct D&I calibration, reference error within geomag error model)
- To tolerate “bad” surveys, noised continuous inclination, arbitrary data density, strong axial and cross-axial drillstring interference
- To alert in case of non-compliance situation or issue (no expert analysis required)

Automation Cornerstones

- Data Validation
- Data Filtering
- Algorithm Robustness
- Quality Analysis


WBG
BHA designs
Slide sheets
MWD surveys
MWD TC
Lat Long Alt
Cont Incl
BHA steering analysis
Filtering (pre-QC)
Failed axis filtering & analysis
Geomag reference
MSA setup
DSI model
MSA correction
MSA + faxis correction
Continuous inclination filtering
BHA sag correction
QC
High-def trajectory
BHA sag uncertainty model
MSA uncertainty model
EOU calculation
Survey program analysis
Toolcodes
Corrected surveys
Quality indicators

Data Validation

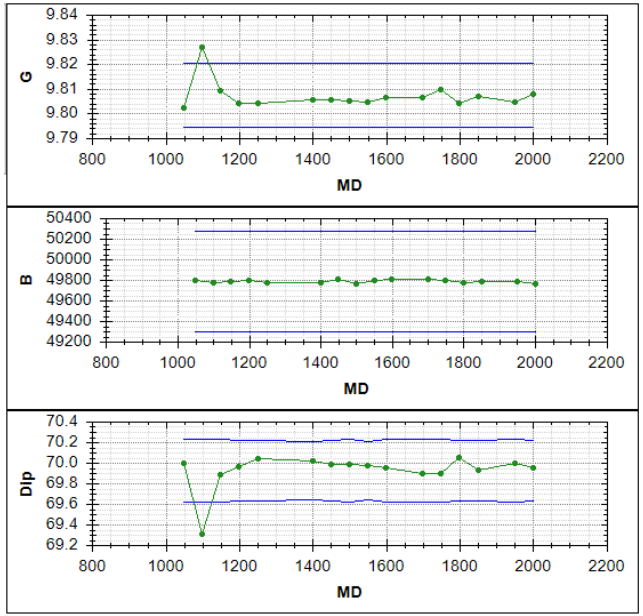
- Validation of internal data consistency:
  - BHA
  - WBG
  - Slide sheet
  - Continuous inclination
  - etc.
- Some cross-validation between different data classes (BHA vs WBG, etc.)

Data Filtering

- Raw 6-axis survey filtering:
  - Automatic MSA Filtering
  - Failed Axis Filtering & Analysis
- Corrected 6-axis survey steering filter:
  - DLS restriction
  - Steering QC
- Continuous DLS capacity filter

Data Filtering: Automatic MSA Filtering

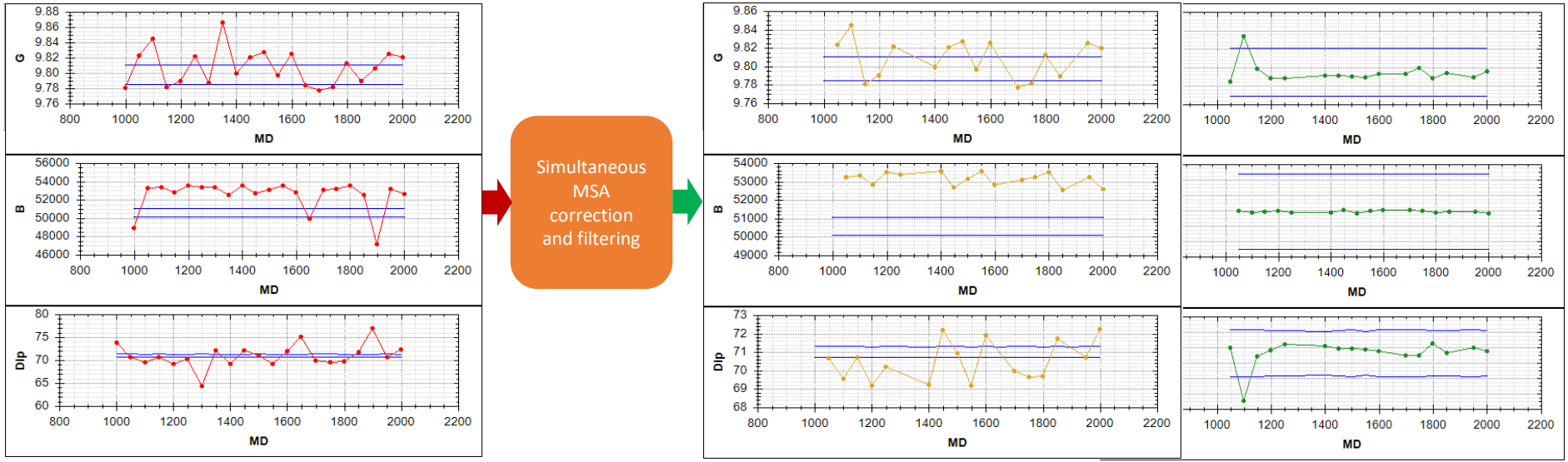
- MSA correction with extremely steadiness to bad surveys (up to 80% in data set)
- Keeping the surveys complying with standard MWD error model based on Gravity, Total B, and Dip
- Steady to severe standard D&I errors: scale factor error, bias, DSI, misalignment
- Performing multidimensional analysis, that is impossible for human



Corrected

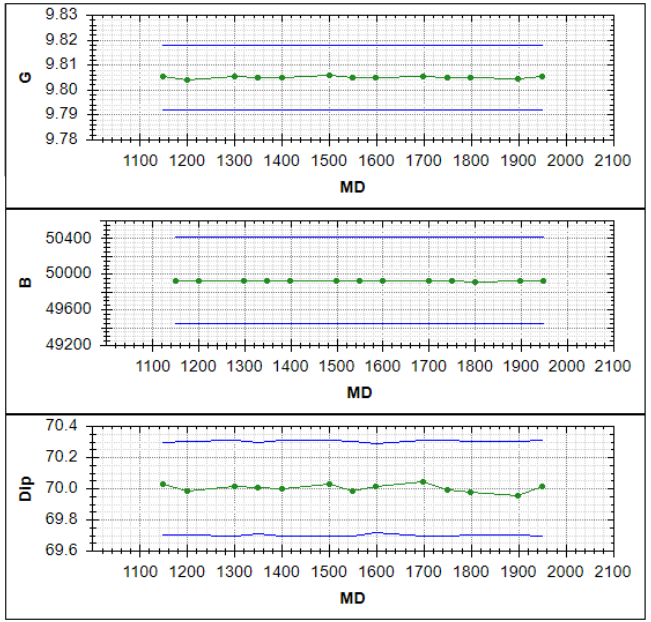
Data Filtering: Automatic MSA Filtering

Severe MBX, MBY, MBZ, ABX, and ABY + bad surveys



Data Filtering: Failed Axis Filtering & Analysis

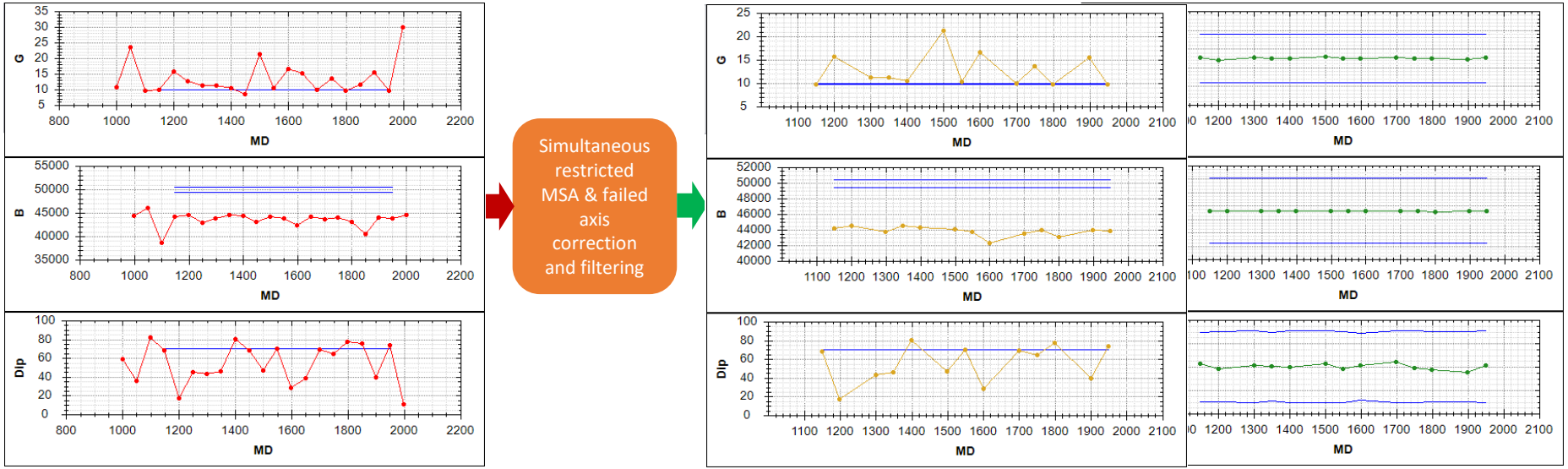
- Similar with the previous algorithm
- Recognizing of D&I axis failed, normal surveys, failed axis surveys, and bad surveys
- Steady to severe standard DSI errors
- Requiring of much more computational resources



Corrected

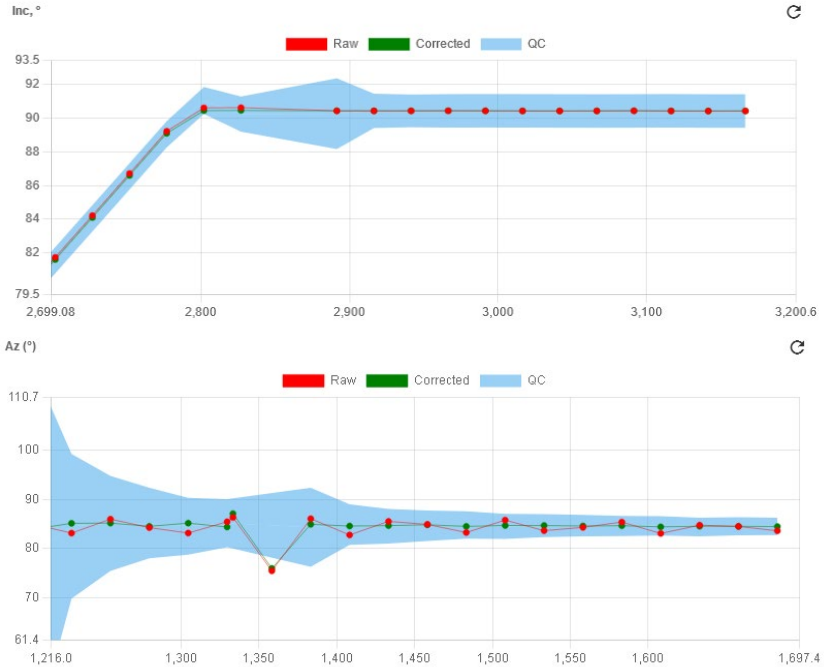
Data Filtering: Failed Axis Filtering & Analysis

Severe MBX, MBY, MBZ, failed accel X, and bad surveys



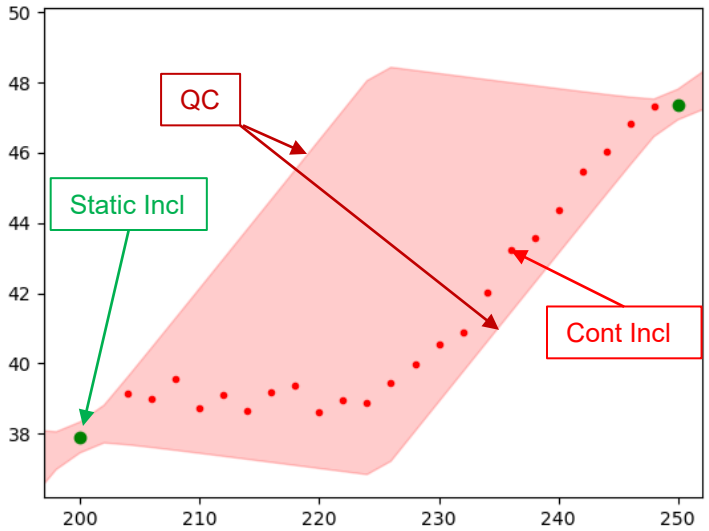
Data Filtering: DLS Filter

- Marks out-of-the-tolerance DLS surveys as potentially bad
- Tolerance calculation based on maximum DLS capability for current BHA and relative measurement error between two neighbor surveys
- Allows to detect bad surveys invisible for GBD-filters



Data Filtering: Continuous Inclination Filter

- Based on DLS capacity
- Removed significantly noised and incorrect data
- QC boundaries calculated based on continuous inclination uncertainty and uncertainty of projected inclination
- Projection uncertainty is DLS capacity multiplied by delta between continuous inclination depth and static inclination depth



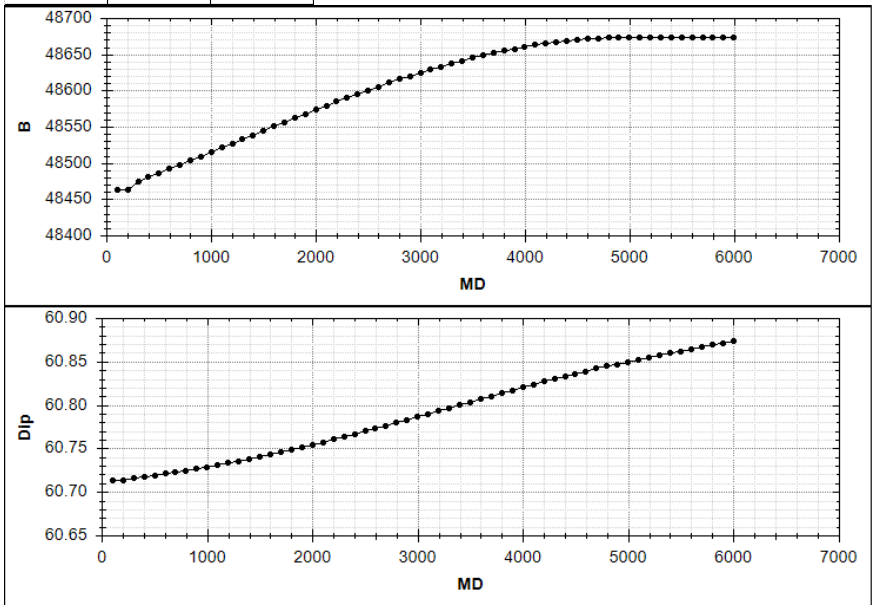
Algorithm Robustness

- MSA correction:
  - Geomagnetic data
  - Novel MSA algorithm
    - Failed axis correction
    - MSA setup
    - EDI model
    - Steering analysis
- High-def trajectory and BHA sag correction:
  - Input DLS smoothing
  - Static-continuous inclination fusion algorithm

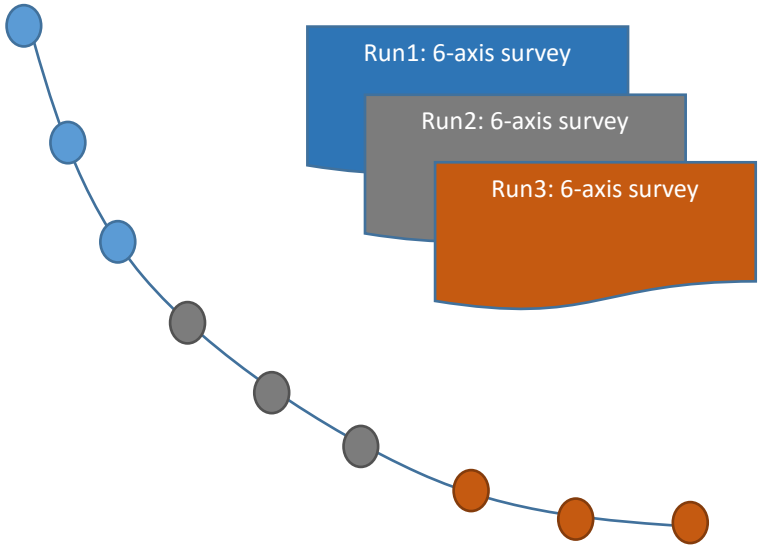
MSA Correction: Geomag

- Reference drift causes 5-10% of total MSA issues:
  - Midland case: 32.63/-101.74 deg
  - Without High-Res GeoMag the algorithm detected severe MSX, MSY, MSZ, and MXY: 6300 ppm, 5800 ppm, 2800 ppm, and 0.12 deg
  - Reasonable misconclusion – D&I calibration issue
- Can be compensated by reference calculation along trajectory with high-def reference model

Traj		
MD, m	Inc, deg	Az, deg
0	0	0
500	0	0
5000	90	45
6000	90	45



MSA Correction: Novel Algorithm [1]



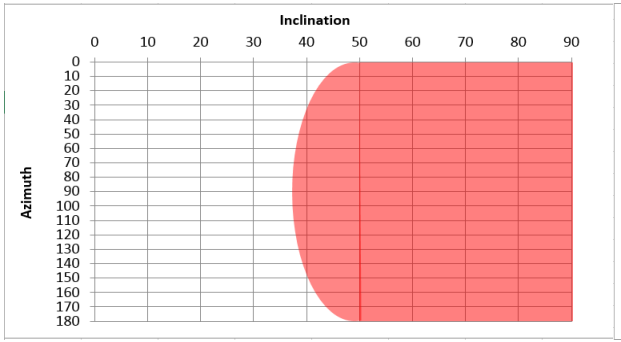
- Robustness from multiple data processing:
  - All 6-axis surveys from the entire well
  - Drillstring interference model
  - Survey-to-survey binding with slide sheets
- No no-Go zone
- Validation of MSA vs EDI vs Steering
- Extended correction range and convergence:
  - ABX, ABY, ABZ: +/-0.2 m/s2
  - ASX, ASY, ASZ: +/-25000 ppm
  - MBX, MBY, MBZ: +/-12000 nT
  - MSX, MSY, MSZ: +/-80000 ppm
  - MXY, MXZ, MYZ: +/-2.87 deg

1. Novel MSA Correction, K. Bulychenkov, 54th General ISCWSA Meeting, October 7rd, 2021

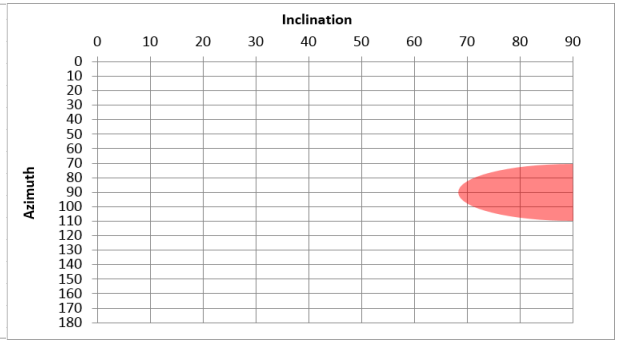
MSA Correction: Failed Axis Correction

- Experimental function
- Novel multi-run MSA algorithm for failed axis correction
- Higher accuracy, better robustness
- Uncertainty prediction by full covariance analysis

No-Go Zone: 5-axis correction



No-Go Zone: Novel MSA correction



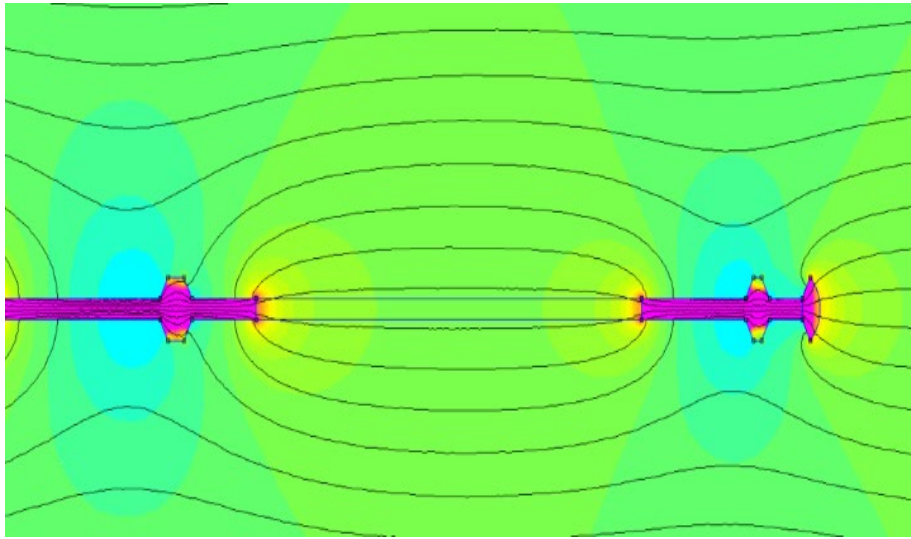
MSA Correction: MSA Setup

$$\mathbf{C} = \begin{bmatrix} \cdots & \cdots & \cdots & & \cdots & \cdots & \cdots \\ \cdots & \delta_G^2 & 0 & & 0 & \cdots & \mathbf{0} \\ \cdots & 0 & \delta_B^2 & & 0 & \cdots & \mathbf{0} \\ \cdots & 0 & 0 & \delta_D^2 & \cdots & & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots & \cdots & & \cdots \\ \cdots & \mathbf{0} & \mathbf{0} & \mathbf{0} & \cdots & & \mathbf{C}_{\mathbf{apriori}}^{\mathbf{terms}} \end{bmatrix}$$

- Apriori error terms' covariance matrix (based on standard MWD error model) improves MSA stability
- But it affects MSA output shifting the solution to apriori values
- MSA setup relaxes apriori covariance matrix based on full covariance analysis to correct only error terms that can be corrected exactly
- That provides the balance between MSA performance and stability

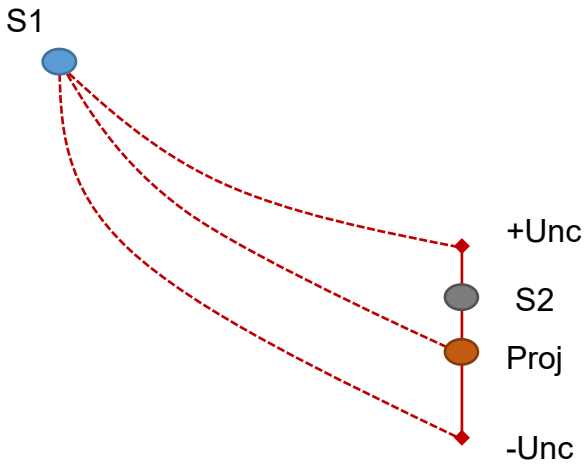
MSA Correction: EDI Model [1]

- Robust modeling of both effects of remanent and induced magnetization
- Remanent magnetization modeled by hysteresis loop and remagnetization stochastic simulation
- Induced interference modeled by demagnetization factor
- The model demonstrated a good performance vs reality
- Verification of EDI vs pre-MSA output and steering based correction



1. Novel method to predict drillstring interference, K. Bulychenkov, 52th General ISCWSA Meeting, October 21rd, 2020

MSA Correction: Steering Analysis



- Calculates DLS performance based on BHA design, actual surveys, and slide sheet
- Calculates projection and projection uncertainty for each station
- Provides information for linking all surveys to each other in the MSA system of equations
- Verifies all survey links vs MSA output based on uncertainty modeling and excludes bad data

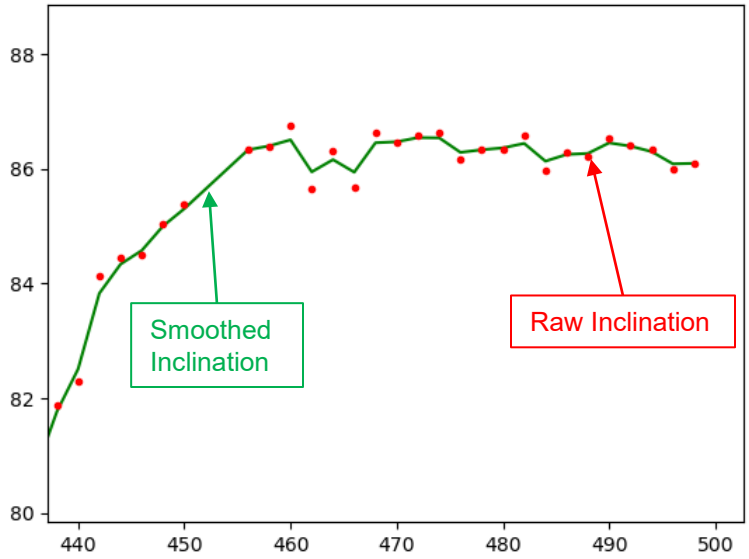
$$\mathbf{J}_{\Delta az}^{wf} = \begin{bmatrix} 0 & \cdots & wf_{j,i,asx}^{Az} - wf_{j,i+1,asx}^{Az} & \cdots & wf_{j,i,mbz}^{Az} - wf_{j,i+1,mbz}^{Az} & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \cdots & wf_{j,i+1,asx}^{Az} & \cdots & wf_{j,i+1,mbz}^{Az} & -wf_{j+1,1,asx}^{Az} & \cdots & -wf_{j+1,1,mbz}^{Az} & \cdots & 0 \end{bmatrix}$$

Two neighbor surveys of the same run

Two neighbor surveys of the different runs

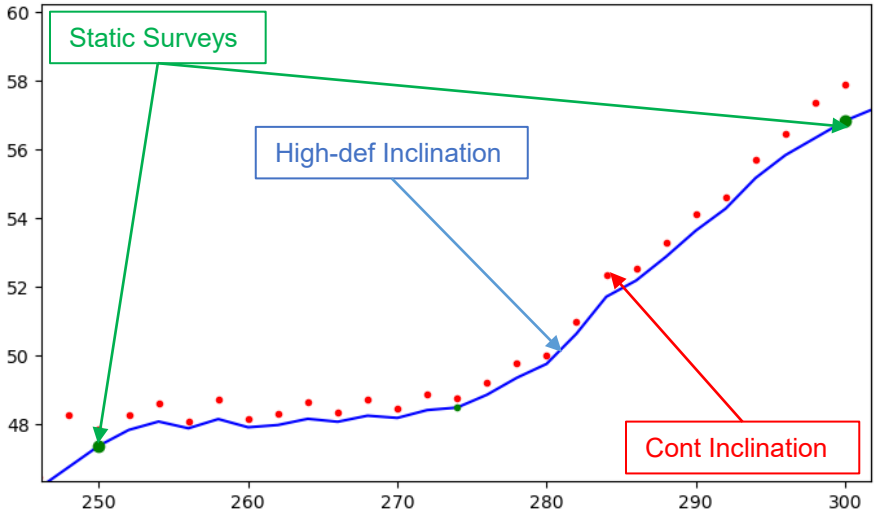
High-Def Traj & BHA Sag: DLS Smoothing

- Excludes severe DLS based on DLS capacity of the BHA
- Compensates for continuous inclination surges and DLS effect of close static surveys
- Critically important for robustness of BHA sag correction



High-Def Traj: Continuous-Static Fusion

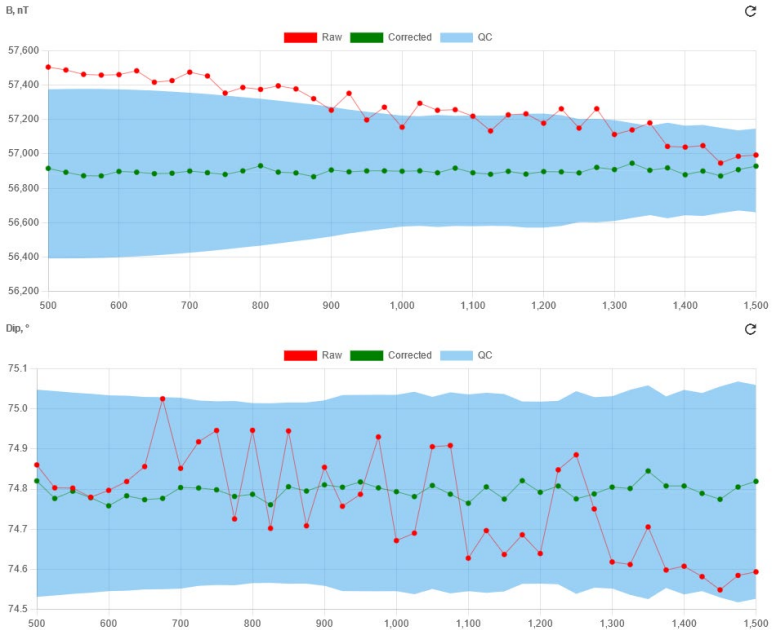
- Doesn't use absolute continuous inclination (CI) values, uses recalculated build-rate instead
- Insensitive to CI bias, scale factor error, misalignment, Total G reference error
- High robustness and stability



Quality Analysis

- Output data quality:
  - Dynamic acceptance criteria for G, B, and Dip vs MWD error model
  - Steering acceptance criteria for Inclination and Azimuth
- Internal control:
  - MSA
  - BHA sag correction
  - High-def trajectory
- External control: trajectory vs plan
- Toolcode assignment

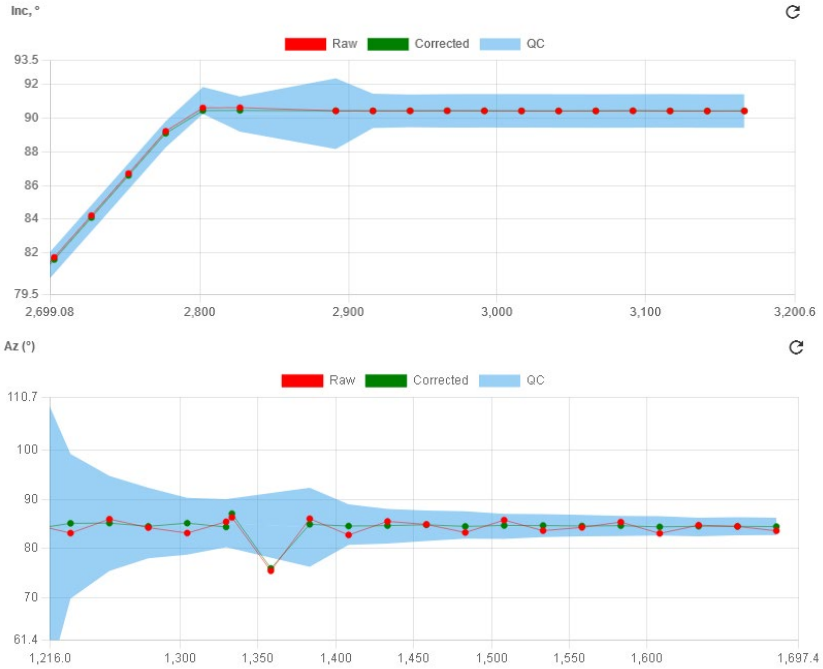
Output Data QC: Dynamic FAC



- Dynamically calculated based on MWD error model excluding reference uncertainty
- Reference error is global – the same for all surveys
- The base line is MSA corrected reference
- Separate QC for Total G, Total B, and Dip
- Provides more strict quality criteria than full MWD error model

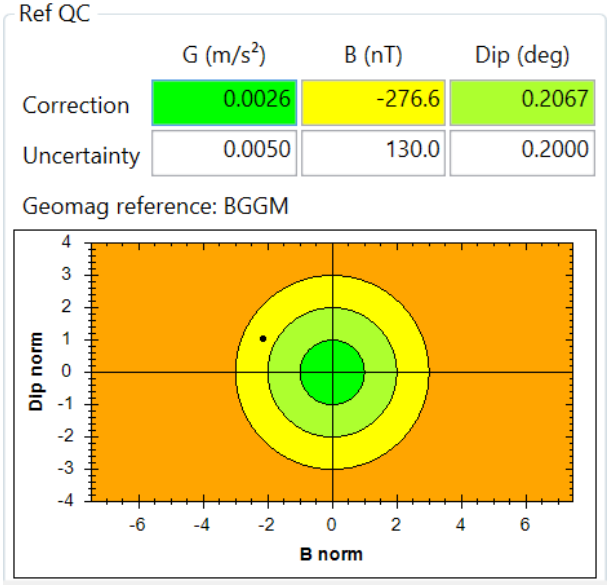
Output Data QC: Steering QC

- Calculates projected stations (inclination and azimuth) and their uncertainties based on slide sheet, actual surveys, and BHA design
- Checks if deviation of actual survey from its projection is within tolerance (2 sigma)
- Allows to detect bad surveys invisible for GBD-filters
- Also helps to recognize poor BHA performance



Internal Control

- MSA controls:
  - Actual geomag references vs geomag error model
  - Minimum MSA requirements
  - MSA result vs MWD error model and estimated DSI
  - MSA uncertainty vs MWD error model
  - Algorithm convergence
- High-def trajectory controls:
  - Continuous inclination quality: CI vs static surveys
  - Minimal data density check
- BHA sag controls:
  - Algorithm convergence
  - BHA sag result vs MWD error model



External Control

HDTRJ	MSA	SQC	SAG	POS

Plan deviation at total depth

NS, m	EW, m	dInc, °	dAz, °	dTVD, m	dH, m
71.93	1,400.59	-0.00	-0.79	3.38	7.31

HDTRJ	MSA	SQC	SAG	POS

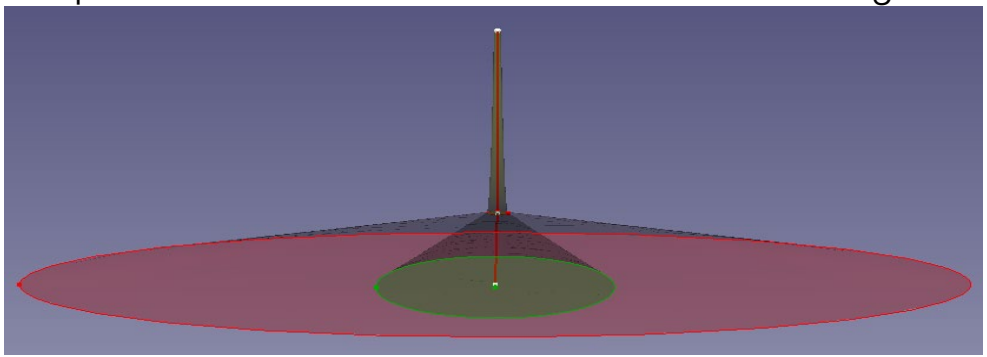
Plan deviation at total depth

NS, m	EW, m	dInc, °	dAz, °	dTVD, m	dH, m
88.27	1,405.39	-0.00	-3.75	-0.02	24.23

- Simple but essential check
- Controls trajectory deviation from plan in terms of inclination and azimuth
- Prevents unexpected issues

Accuracy Analysis

- Automatic toolcode assignment based on comparison of table error term value with actual error
- Full covariance analysis and magnetic reference quality for MSA accuracy
- Optimized Monte-Carlo simulation for BHA sag



Demo - Demo Field - Demo - High MXY East -

Last survey			
MD, m	**Inc, °**	**Az, °**	**DLS, °/30m**
2,000.00	90.02	77.36	
QC	Total G	Total B	Dip
Toolcode	MWD_Rev4_POOR_HD0		

Demo - Demo Field - Demo - High MXY North

Last survey			
MD, m	**Inc, °**	**Az, °**	**DLS, °/30m**
1,850.00	89.98	13.42	
QC	Total G	Total B	Dip
Toolcode	MWD_Rev4_MSA1_HD0		

Summary

- Full automation for the following correction routine (see diagram)
- Autonomous work under normal condition with tolerating of noised survey input, arbitrary data density, and strong DSI
- Human involving in case of non-compliance situation or issue only