A Pitfall in Survey QA/QC

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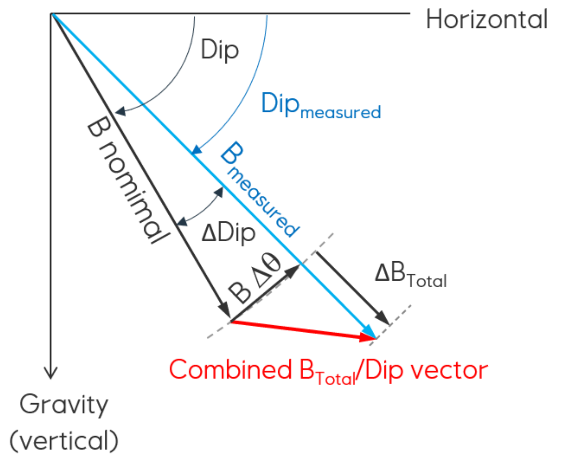
Outline

- Background
- MSA data requirements
- Data example
    - FAC «Combined-Btotal-Dip»
    - MSA estimates
- Discussion/Conclusion

Background

- **MWD survey measurements have to satisfy Field Acceptance Criteria (FAC)**
    - Accelerometer: ΔGTOT
    - Magnetometer: ΔBTOT, ΔBDIP, and/or Combined-Btotal-Dip (CBDip)
- **Failing the FACs indicates that there is something wrong**
- **Passing the FACs does <u>not</u> guarantee that there are no errors in the data.** For example:
    - CBDip is insensitive to axial interference when drilling horizontal east west
    - CBDip is insensitive for magnetic mud at certain drilling directions, especially for «short collar» azimuth computation
- **Multi-station analysis (MSA) can help to detect and correct systematic errors in survey data**
    - Wellbore geometry and data quality impact reliability of estimates



FAC	Acceptance limit EQN
ΔGTOT	± 0.018 m/s²
CBDip (IFR, long collar)	525 nT
CBDip (IFR, short collar)	300 nT

MSA data requirements

- **Data requirements to ensure correct application of MSA** (Nyrnes et al., 2009, SPE-125677)
  - Acceptable noise level in data
  - Which parameters can be estimated, and whether they can be estimated simultaneously
- **Tangent sections can cause extra difficulty** (Nyrnes and Torkildsen, 2005, SPE-96211)
  - Effect of scale factor can be modelled by an axial bias and vise versa because of linear relation between axial bias and cross-axial scale factor
  - Curvatures of perfect singularity
  - Can result in unreliable estimates

	ENHANCED REF.
Parameter	**Requirement**
general	$max(\Delta\alpha_i) < 100°$ $-80° < \Theta < 80°$ $n \geq 3e$ $n \geq 4$
bias bx, bias by	Only general requirement necessary
bias bz	$\frac{1}{n}\sum_{i=1}^{n}\lvert \sin I_i \sin A_i \rvert < 0.91$
scale bx, scale by	$\frac{1}{n}\sum_{i=1}^{n}\lvert bz_i \rvert < 0.7B$
scale bx, scale by, bias bz	$\frac{1}{n}\sum_{i=1}^{n}\lvert \sin I_i \sin A_i \rvert < 0.87\ (0.91)^*$ $\frac{1}{n}\sum_{i=1}^{n}\lvert bz_i \rvert < 0.5B\ (0.7B)^*$
scale bz	$\{max(bz_i) - min(bz_i)\} > 0.6B$ $\frac{1}{n}\sum_{i=1}^{n}\lvert \sin I_i \sin A_i \rvert < 0.91$
max. noise	$\sqrt{\frac{1}{(2n-e)}\sum_{i=1}^{n}\left(\Delta B_i^2 + (B_i\Delta\theta_i)^2\right)} \leq \frac{60nT}{\left(0.4+\frac{e}{8}\right)}\left(1+\frac{2}{\sqrt{2n-e}}\right)$
max. single survey error	$\sqrt{\Delta B_i^2 + (B_i\Delta\theta_i)^2} \leq \frac{180nT}{\left(0.4+\frac{e}{8}\right)}$
B and Θ	Can be substituted with *scale bx* or *scale by* or *scale bz*

Table 2: *Requirements for the estimation of magnetometer error terms, the Earth's magnetic field intensity and dip angle.*

*Acceptance values in parenthesis are to be used if $\{max(bz_i) - min(bz_i)\} > 0.15B$ or if $\{max(gz_i) - min(gz_i)\} > 0.7\ ms^{-2}$.

Sufficient observations, spread in toolface and magnetic dip < ± 80 °

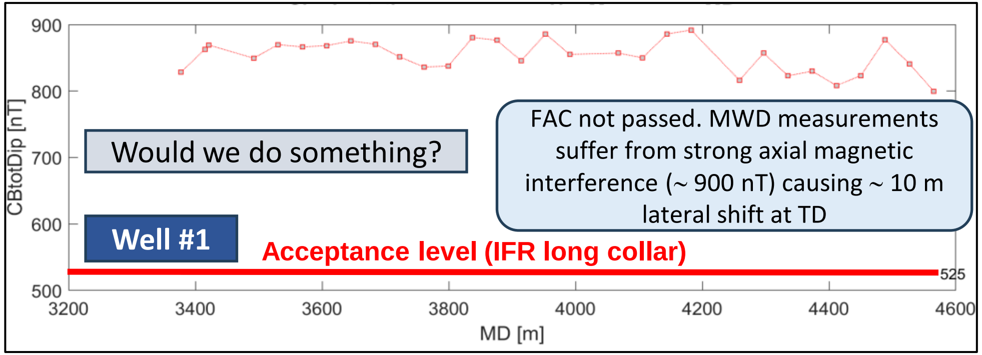
Axial bias cannot be estimated reliably close to horizontal east-west

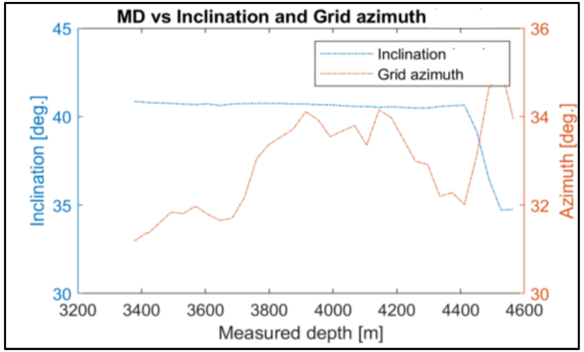
Cross-axial scale factor can be estimated when cross-axial field strength sufficiently large

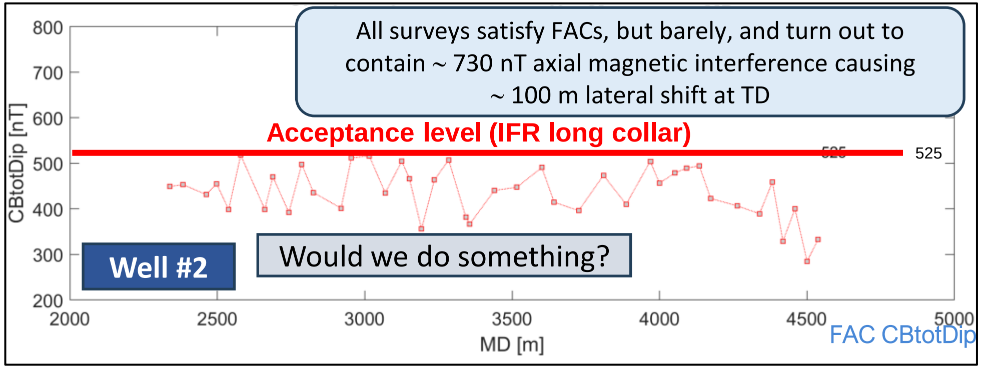
Axial bias and cross-axial scalefactor can be estimated simultaneously when sufficient spread in direction, or with stricter requirements on both of them

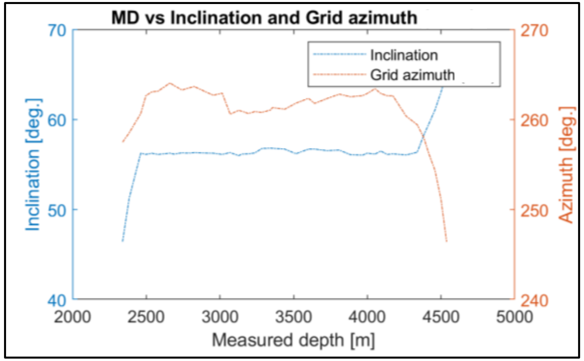
MSA requirements (Nyrnes et al (2009), SPE-125677)

FAC CBtotDip – When do we make a call to correct surveys?









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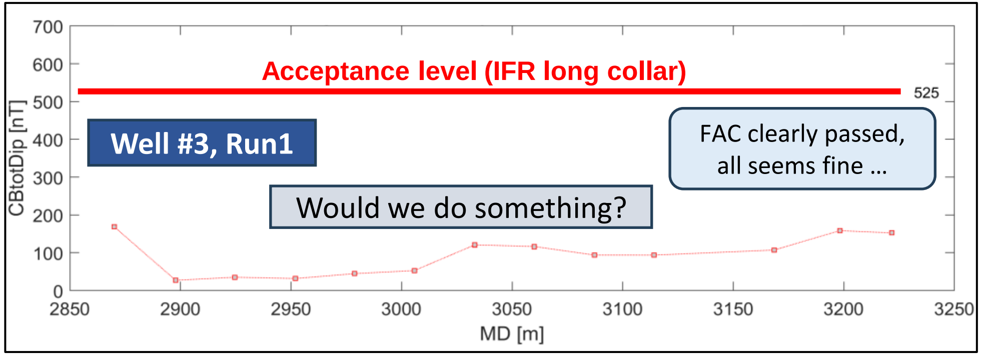
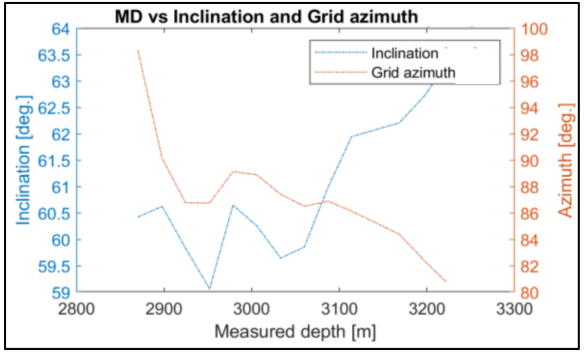
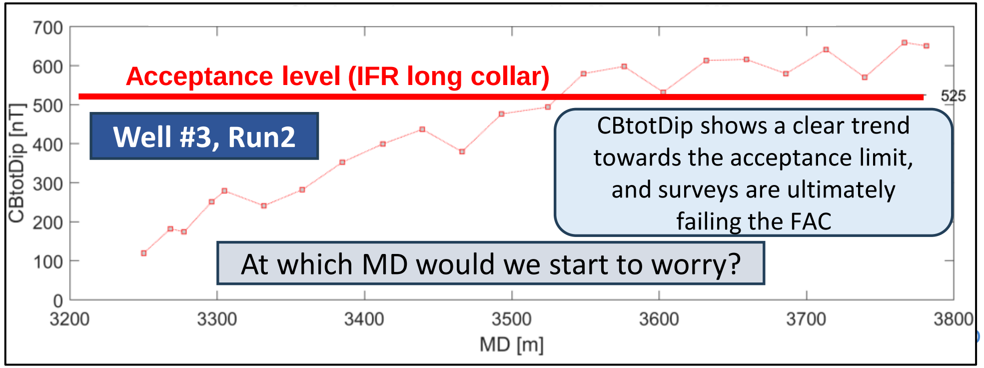
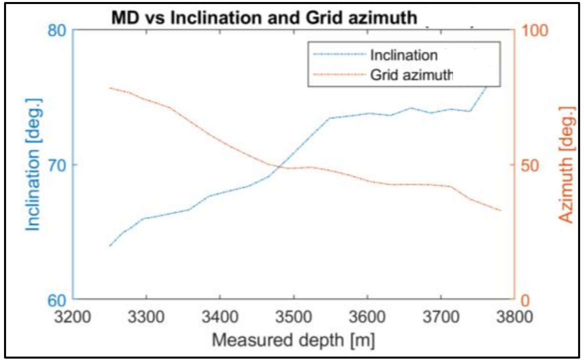








MSA estimates – Well#3 Run2

MSA stability check

Parameter	Gz (m/s²)	|Bz|/B	|sin(I) sin(A_m)|
Minimum	2.12	0.42	0.46
Maximum	4.31	0.51	0.86
Average	-	0.48	0.69
Difference	2.19	-	-
Requirement for MSA*)	**> 0.7**	**< 0.7**	**< 0.91**

*) To estimate axial bias and cross-axial scalefactor simultaneously

Dip = 76.361°, and requirements to simultanously estimate axial bias and cross-axial scalefactor are satisfied

«Weak» requirements can be used

MSA parameter estimates

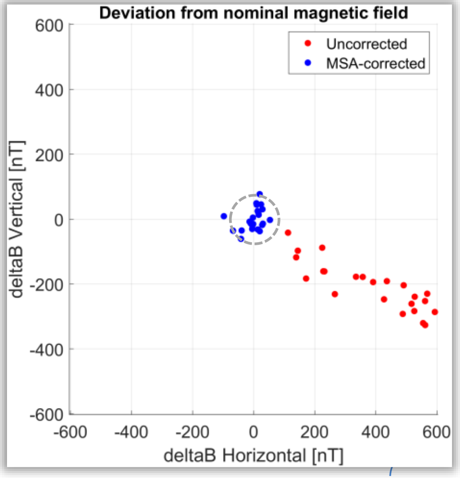
Parameter	Estimate	Standard dev
Bias Bz (nT)	602	27
Scalefactor Bx (%)	-1.01	0.06
Scalefactor By (%)	-0.90	0.06

The MSA results indicate drillstring interference and magnetic mud

What about Run1??

MSA estimates

Difference between nominal and measured magnetic field



MSA estimates – Well#3 Run1

MSA stability check

Parameter	Gz (m/s²)	|Bz|/B	|sin(I) sin(A_m)|
Minimum	4.41	0.48	0.85
Maximum	5.05	0.54	0.87
Average	-	0.51	0.86
Difference	0.64	-	-
Requirement for MSA*)		**< 0.5**	**< 0.87**

*) To estimate axial bias and cross-axial scalefactor simultaneously

Dip = 76.361°, and requirements to simultanously estimate axial bias and cross-axial scalefactor on the border of being satisfied

«Strong» requirements must be used

MSA parameter estimates

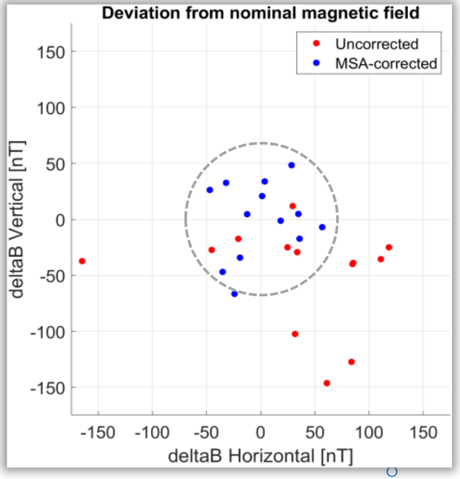
Parameter	Estimate	Standard dev
Bias Bz (nT)	758	97
Scalefactor Bx (%)	-1.20	0.14
Scalefactor By (%)	-1.06	0.13

The MSA results indicate that Run1 also suffers from severe drillstring interference and magnetic mud!

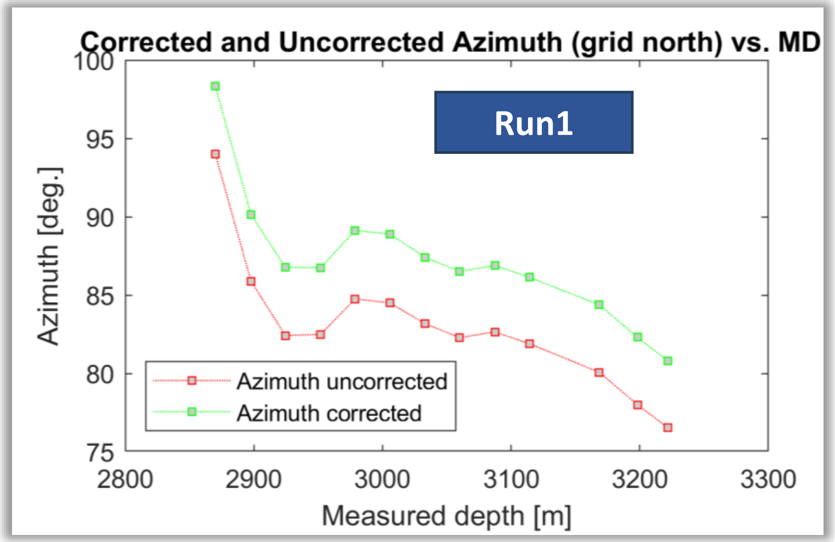
Both errors are cancelling each other in the FAC

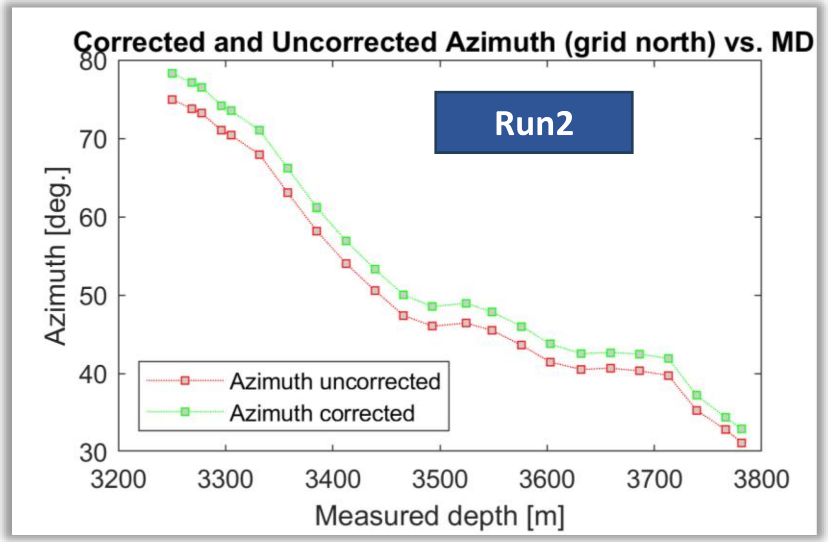
MSA estimates

Difference between nominal and measured magnetic field



MSA estimates Well#3 – Impact on Azimuth





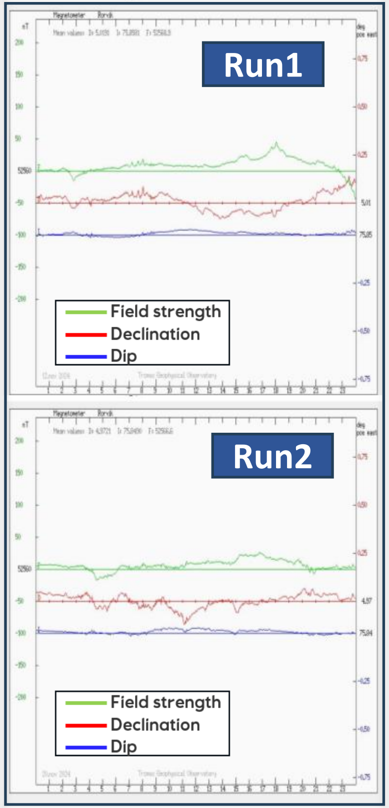
The MSA correction in Run1 and Run2 result in a lateral shift of ~ 40 m at TD of Run2

Can we rely on the MSA results and if so, could this have been discovered earlier?

Can we rely on the MSA estimates?

- No overlapping gyro survey
- No solar activity recorded in nearby magnetometer station Rørvik on drilling dates
- Investigation of mud and BHA
    - No magnetic hotspots found sufficiently near sensors (BHA has «long collar» design)
    - Some magnetic content found in mud samples (~ 125 nT or 0.25% in the lab)
- Results can be reproduced with simulations
- MSA estimate of geo-reference values only, results in unlikely estimates
- Estimating axial bias or cross-axial scalefactor alone, results in less good MSA estimates

	A priori	Run1	Run2	Difference
Gravity (m/s^2)	9.82691	9.82679	9.82728	-0.00049
Field intensity (nT)	52729	52692	52623	69
Dip	76.36	76.32	75.91	0.41

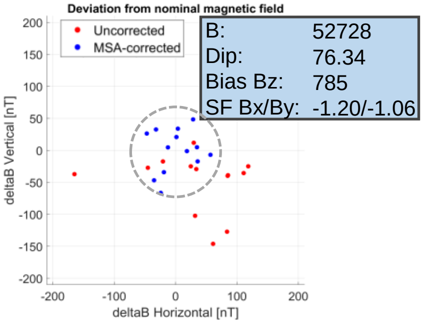


Solar activity on drilling dates

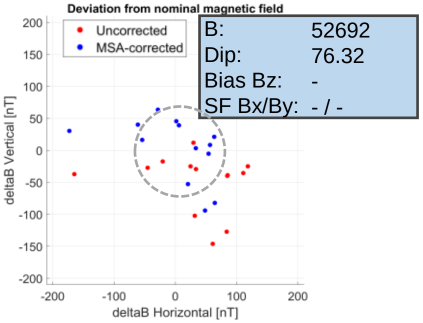
Can we rely on the MSA estimates?

For both runs, MSA produces the most consistent estimates when axial bias and cross-axial scalefactors are estimated simultaneously

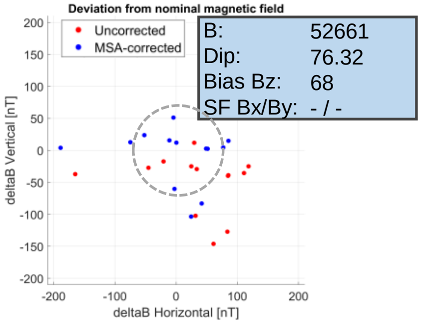
Run1



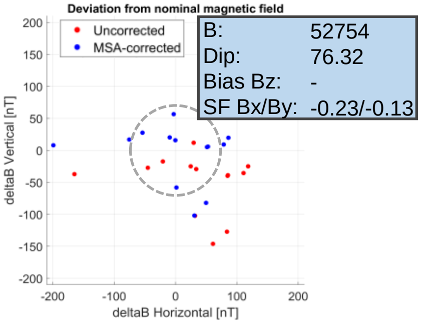
Axial bias and x-axial scale factor



Neither bias nor scale factor

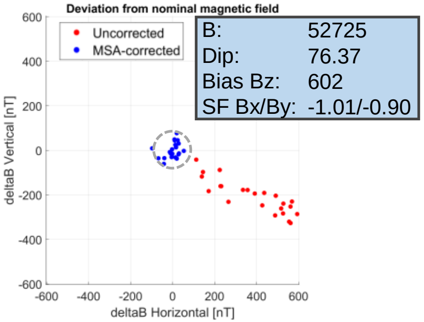


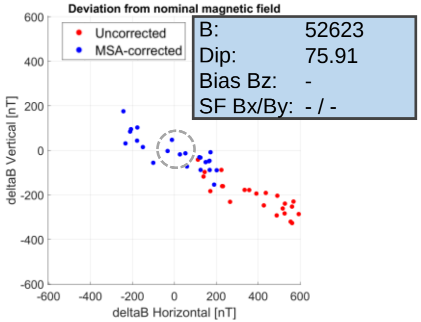
Axial bias only

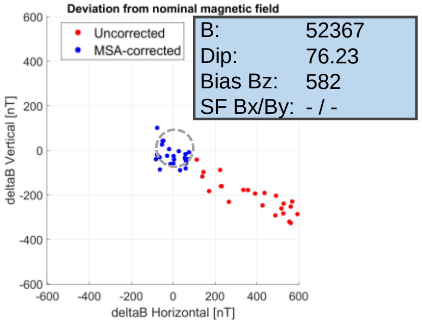


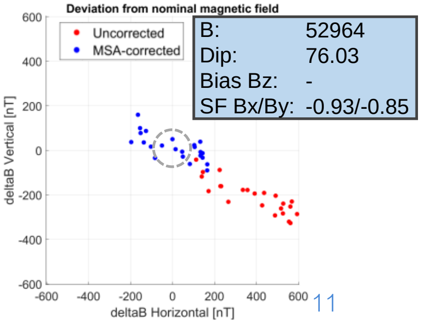
Cross-axial scale factor only

Run2





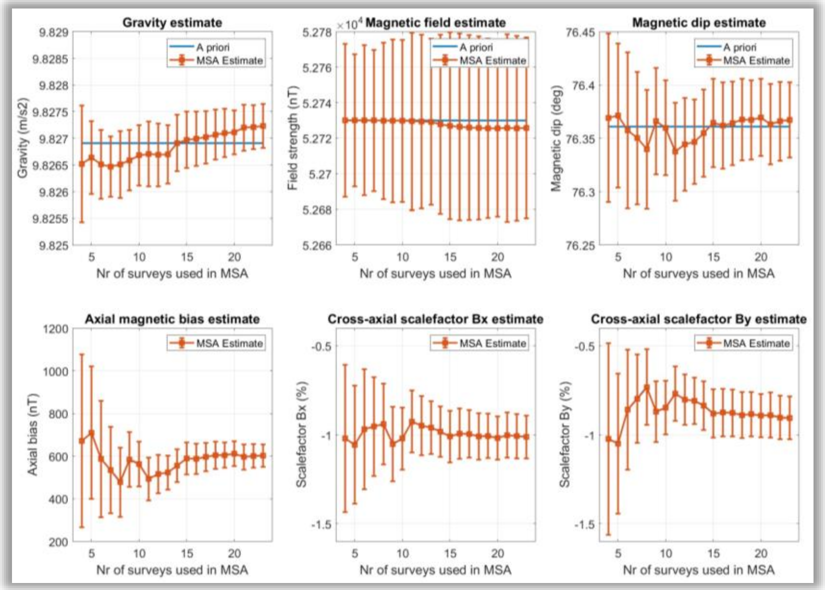




Could the survey errors have been detected earlier?

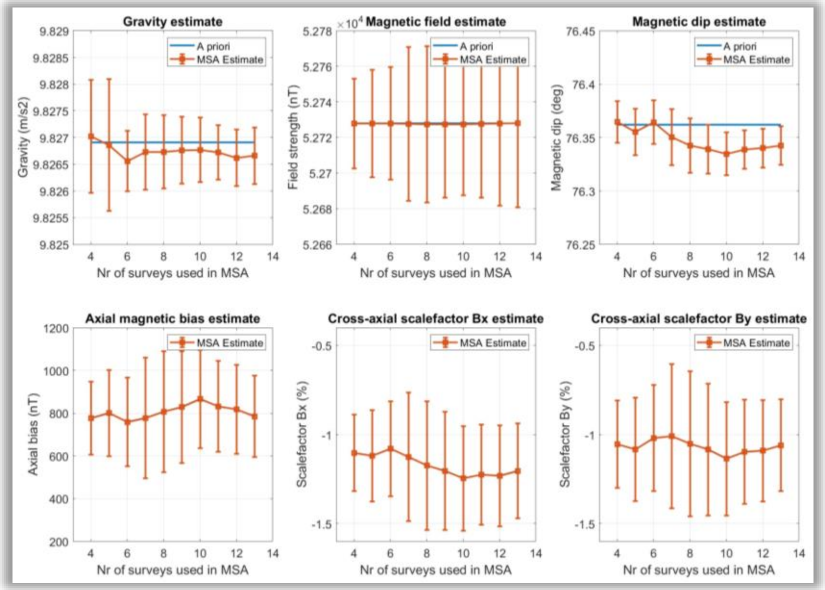
MSA estimates as function of number of survey stations used in MSA (error bars @ 1.96 σ)

Run2



MSA estimates fluctuate in the beginning, but converge the more data become available, and accuracy increases

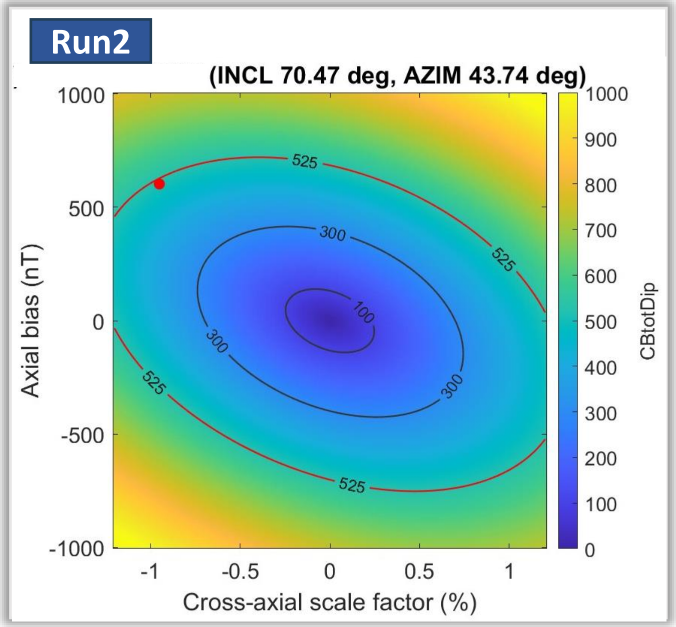
Run1

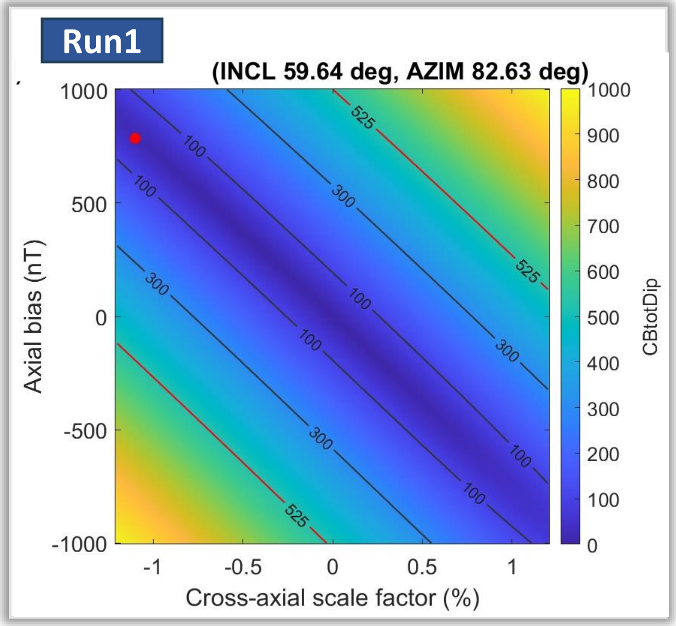


MSA estimates fluctuate slightly when more data are included and they remain relatively uncertain

MSA estimates

Could the survey errors have been detected earlier?





CBtotDip value as function of amount of axial bias and cross-axial scale factor for an inclination & azimuth reprentative for the run (middle station)

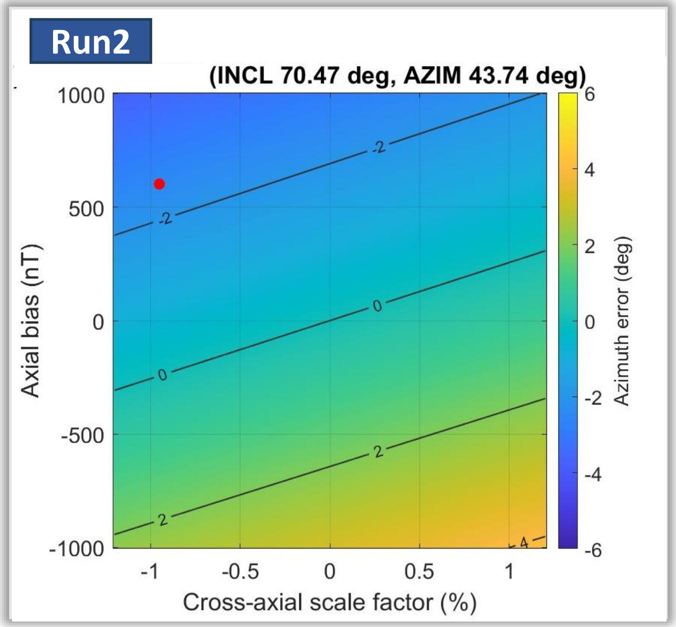
The value of CBtotDip increases with increasing axial bias (drillstring interference) and cross-axial scalefactor (magnetic mud).

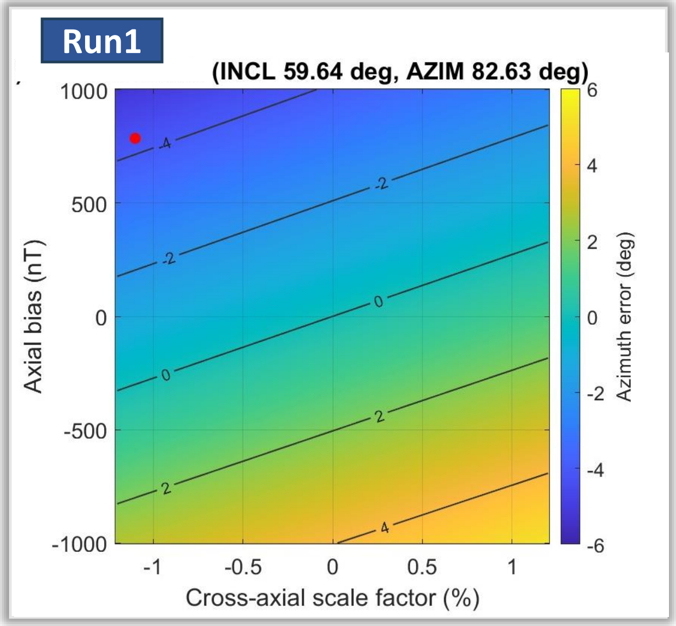
CBtotDip also depends on drilling direction. For certain drilling directions, CBtotDip has a shadow zone for magnetic interference effects.

Azimuth errors can be very large. This is exactly what happens for Run1.

This risk should be identified in the planning phase

Could the survey errors have been detected earlier?





Azimuth error as function of amount of axial bias and cross-axial scale factor for an inclination & azimuth reprentative for the run (middle station)

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Discussion / Conclusion

Field Acceptance Criteria can give a false sense of security regarding data quality	• Limited awareness that when FAC are satisfied, it doesn't exclude (big) problems with the directional survey data • Detected too late
The effect of re-using mud on directional surveying might not be fully understood	• Do we have more magnetic mud than we think? • Can the mud cause apparent axial magnetic interference (not only cross-axial shielding)? • Does it depend on location?
MSA can correct for systematic errors, but not always	• Data must be suitable for MSA • It can be difficult to identify the «correct» MSA solution for certain drilling directions • The MSA solution evolves during drilling – Inclination and azimuth estimates can change
We may need better procedures to identify potential issues earlier	• Have standard procedures for BHA and mud testing • MSA stability analysis in planning phase – Consider a gyro survey • Ensure that MSA can be started early (e.g. do a rotational shot at runstart) and have procedures on how to react when MSA solution evolves during drilling

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THANK YOU

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