Application of Partial Correlations Between Geomagnetic Terms- Technical Supplement

MWD Error Model Rev5

Introduction

Historically, there were two methods of combining uncertainty between reference and offset wells in collision avoidance calculations, these were by arithmetic summation or by root-sum-squared combination of the uncertainties on the centre-to-centre line between the wells (refer to table 1 of SPE-187073, Well Collision-Avoidance Separation Rule, Sawaryn et al).

When root-sum-square (combined covariance) methods are used in collision avoidance calculations, covariance matrices from reference and offset wells are added to together. In statistical terms, this is justified and correct if the errors in the two wells are uncorrelated (correlation coefficient, ρ= 0).

However, strictly this is not correct if the some of the errors between the wells are correlated as discussed in Appendix A of SPE-187073. In particular, it was recognised that this is not the case for the geomagnetic reference errors for wells in proximity. i.e. for the declination, total field and dip error sources generally modelled with global propagation. These are commonly referred to as DECG, DBHG, MFI and MDI.

Analysis by geo-physicists has suggested that in fact there will be partial correlations (ρ has a fractional value). These correlations will depend on whether the magnetic references in the two wells are from the same or different sources.

When SPE-187073 was written there was not an agreed means to conveniently handle this complication. This document describes a means of incorporating this functionality into the error model framework, via an elegant solution where the partial correlations between the existing sources are replaced with a number of new sources, which are either fully correlated or uncorrelated with each other.

Note, values in this document are generic for the various categories of geo-magnetic reference model and apply globally. These values are not mandated by ISCWSA but are given as a reasonable generic estimate. Individual providers of geo-magnetic data may be able to supply more accurate localised uncertainty estimates for their specific model.

This document describes the means to incorporate this functionality into an error model implementation.

Note: Correlation of depth errors is NOT considered herein.

Conceptual Case

If two wells originate from the same pad and running parallel to each other, and if the declination error for both wells was fully correlated then it would rotate both wells in the same direction through an equal angle. The relative separation of the two wells would be independent of the declination error, i.e. the declination error source could be completely removed from the analysis.

However, if the wells came from different pads and ran parallel, but in opposite directions then a given declination error would rotate one well to the left and the other to the right. Depending on the sign of the declination the wells would either move closer or further apart, but declination would have a significant impact.

Therefore, for combined covariance CA calculations, correlation of geomagnetic terms must be considered.

Correlation Between Magnetic Reference Error Terms

Stefan Maus from H&P Technology considered the possible omission and commission errors of the usual magnetic reference models. He then considered how the errors from these different models would be correlated with each other. This analysis is based on several assumptions and best estimates of the division and correlations of errors. The enclosed spreadsheet below sets out this analysis.

Wellpath-correlatio
n-between-geomag

Converting Partial Correlations to Multiple Error Sources

Equation (A.24) of SPE-67616 allows for the correct handling of fully correlated error sources.

$$C_{A,B}^{Relative} = C_A + C_B - \sum_{\substack{i \in Global \\ Geomag}} \left(\boldsymbol{E_{i,A} E_{i,B}^T} + \boldsymbol{E_{i,B} E_{i,A}^T} \right)$$

And:

$$\boldsymbol{E_{i,A}} = \sum_{l} \sum_{k=1}^{K-1} \boldsymbol{e_{i,l,k}} + \boldsymbol{e_{i,K}^{*}}$$

Where

$E_{i,A}$ is the sum of the error vectors for that source over all previous survey legs l, all preceding survey stations k in this leg and the half interval error vector e* for the final survey station, K.

CA and C_B are the usual covariances of wells A and B.

In a standard combined covariance calculation, $C_{A,B}^{Relative}$ would equal $= C_A + C_B$

Correlated terms are handled by the correction term, $\sum_{i \in Global} \left(\boldsymbol{E_{i,A} E_{i,B}^T} + \boldsymbol{E_{i,B} E_{i,A}^T} \right)$summed over all globally propagating terms.

Coping with partial correlated sources would be a more complicated case. However, Jon Bang of Gyrodata, suggested extending the current error sources to a broader set, which are then fully correlated with themselves and uncorrelated with any other source. By doing this, the partial correlations can be naturally accommodated.

If the geo-magnetic correlations the root sum square of these new terms will give the same answer (to the resolution of the magnitudes) as the older Rev4 magnetic reference terms.

The derivation of the magnitudes of these terms, from the initial partial correlation analysis can be found in the Error Model Source tab of the attached spreadsheet.

For each existing term there are new terms:

	Terms			
Code	Code	Description	Prop	Wt Fn
DECG	DEC-U	MWD: Declination Uncorrelated Errors	W	AZ
	DEC-CH	MWD: Declination Crustal Commission HD Models	G	AZ
	DEC-CI	MWD: Declination Crustal Commission IFR Models	G	AZ
	DEC-OS	MWD: Declination Crustal Omission Standard Models	G	AZ
	DEC-OH	MWD: Declination Crustal Omission HD Models	G	AZ
	DEC-OI	MWD: Declination Crustal Omission IFR Models	G	AZ
	DEC-R	MWD: Declination Random	R	AZ
DBHG	DBH-U	MWD BH-Dependent Declination Uncorrelated Errors	W	DBH
	DBH-CH	MWD BH-Dependent Declination Crustal Commission HD Models	G	DBH
	DBH-CI	MWD BH-Dependent Declination Crustal Commission IFR Models	G	DBH
	DBH-OS	MWD: BH-Dependent Declination Crustal Omission Standard Models	G	DBH
	DBH-OH	MWD: BH-Dependent Declination Crustal Omission HD Models	G	DBH
	DBH-OI	MWD: BH-Dependent Declination Crustal Omission IFR Models	G	DBH
	DBH-R	MWD: BH-Dependent Declination Random	R	DBH
MFIG	MFI-U	MWD: Total Magnetic Field with Z-Axis Corr - Uncorrelated Errors	W	MFI
	MFI-CH	MWD: Total Magnetic Field with Z-Axis Corr - Crustal Commission HD Models	G	MFI
	MFI-CI	MWD: Total Magnetic Field with Z-Axis Corr - Crustal Commission IFR Models	G	MFI
	MFI-OS	MWD: Total Magnetic Field with Z-Axis Corr - Crustal Omission Standard Models	G	MFI
	MFI-OH	MWD: Total Magnetic Field with Z-Axis Corr - Crustal Omission HD Models	G	MFI
	MFI-OI	MWD: Total Magnetic Field with Z-Axis Corr - Crustal Omission IFR Models	G	MFI
	MFI-R	MWD: Total Magnetic Field with Z-Axis Corr Random	R	MFI
MDIG	MDI-U	MWD: Magnetic Dip with Z-Axis Corr - Uncorrelated Errors	W	MDI
	MDI-CH	MWD: Magnetic Dip with Z-Axis Corr - Crustal Commission HD Models	G	MDI
	MDI-CI	MWD: Magnetic Dip with Z-Axis Corr - Crustal Commission IFR Models	G	MDI
	MDI-OS	MWD: Magnetic Dip with Z-Axis Corr - Crustal Omission Standard Models	G	MDI
	MDI-OH	MWD: Magnetic Dip with Z-Axis Corr - Crustal Omission HD Models	G	MDI
	MDI-OI	MWD: Magnetic Dip with Z-Axis Corr - Crustal Omission IFR Models	G	MDI

	MDI-R	MWD: Magnetic Dip with Z-Axis Corr - Random	R	MDI

Note the -U terms changes from global to well by well propagation and holds the completely uncorrelated part of each well.

The existing random terms (DECR, DBHR, MFIR and MDIR) used to model changes in the magnetic reference due to the disturbance field are unchanged.

Some of the terms are included so that partial correlations between models can be modelled more simply by a using fully correlated and completely uncorrelated terms.

For example, high-def models include both -OI and -OH terms. For an anti-collision evaluation, if we are comparing +IFR models in both reference and offset wells then the -OI terms are fully correlated. Similarly, if both wells used +HRGM models then both the -OI and -OH terms are fully correlated between both wells.

However, if we have +IFR in one well and +HRGM in the other then the -OI terms are fully correlated but the -OH terms are uncorrelated. These were introduced as practical terms to make the existing model maths work with the partial correlations calculated by Stefan Maus. The physical significance of these are related to wavelengths of the geomagnetic field. -OI represents errors due to components at wavelengths smaller than the resolution of the IFR. -OH represents the omission of wavelengths between the order of the HRGM and IFR models.

Term Magnitudes For New Error Sources

Term magnitudes for the new error sources will depend on whether a standard definition, high definition, IGRF/WMM or IFR model is used as the source of magnetic reference data. Not all new sources will be required for each of the different reference options.

Based on the existing source magnitudes and the correlations in the attached spreadsheet, the new values are:

Code	IGRF WMM	Standard Def Models	High Def Models	IFR1	IFR2
DEC-U	0.29	0.16	0.16	0.11	0.11
DEC-CH			0.13		
DEC-CI				0.09	0.09
DEC-OS	0.24	0.24			
DEC-OH	0.21	0.21	0.21		
DEC-OI	0.05	0.05	0.05	0.05	0.05
DEC-R	0.1	0.1	0.1	0.10	0.05
DBH-U	4108	2350	2359	1271	963
DBH-CH			1789		
DBH-CI				712	712
DBH-OS	3359	3359			
DBH-OH	2840	2840	2840		
DBH-OI	356	356	356	356	356
DBH-R	3000	3000	3000	3000	750
MFI-U	107	61	61.34	40	33
MFI-CH			46.47		
MFI-CI				27	27
MFI-OS	88	88			
MFI-OH	73	73	73		
MFI-OI	13	13	13	13	13
MFI-R	60	60	60	60	15
MDI-U	0.16	0.09	0.09	0.07	0.06
MDI-CH			0.07		
MDI-CI				0.06	0.05
MDI-OS	0.14	0.14			
MDI-OH	0.11	0.11	0.11		
MDI-OI	0.03	0.03	0.03	0.03	0.02
MDI-R	0.08	0.08	0.08	0.08	0.02

Software Considerations for Handling Correlation

Steps to be taken to handle partial correlations:

In the error model calculations, for each of the new magnetic terms listed above

1) Calculate the $\boldsymbol{e}_{i,l,k}$ and $\boldsymbol{e}^{*}_{i,K}$ vectors, equation (xxx) as usual.
2) Form and store the summation of these vectors to the current survey station.
   $\sum_{l}\sum_{k=1}^{K-1}\boldsymbol{e}_{i,l,k} + \boldsymbol{e}^{*}_{i,K}$
3) Pass these vector summations out of the error model routines, along with the usual covariance matrices.
   i.e. if there are four globally correlated magnetic error sources in the tool code then there will be 4 x number of survey stations, error vector summation terms. Each of these terms is a 3x1 NEV vector.
   The summation for any globally correlated magnetic error sources which do not feature in the tool code will be zero or null.
   It is possible to be able to track which source caused each error summation, since these must be matched with similar data from the second well. Only matching error source terms will result in an correlation correction.

   When forming the combined covariance in collision avoidance calculations:
4) Add the CA and CB covariance matrices as usual.

   For each of the new globally propagating magnetic terms:
   if and only if, an error source appears in the data from **both wells**, form the correlation correction:
   $\left(\boldsymbol{E}_{i,A}\boldsymbol{E}_{i,B}^{T} + \boldsymbol{E}_{i,B}\boldsymbol{E}_{i,A}^{T}\right)$
   This is a 3x3 matrix with the same form as a covariance matrix.

   Sources which do not feature in either well and sources which only appear in one well give a zero correction.

5) Accumulate the correlation correction term from each error source into an overall summation correction at the current survey station. The results in another 3x3 matrix of a similar form to a covariance matrix.

6) Having looped through each of the new magnetic terms, subtract this correction from the covariance matrix sum at 4). This gives a new covariance matrix which is the correlation correction covariance matrix. This can be used in collision-avoidance calculations, graphics etc. in the same way the usual covariance matrices.

Note the well by well propagating terms, DEC-U, DBH-U, MFI-U and MDI-U are uncorrelated and do not appear in the sum point