Recommendations for management of Inclination-Only survey data (Rev. D)

1. Introduction

Inclination-Only, undefined azimuth, survey data are common in both legacy and modern data sets. This document describes good practice for uncertainty calculations, clearance scanning, target sizing and data management purposes. The recommendations are the consensus of the ISCWSA error modeling and collision avoidance sub-committees.

2. Method

If the tie-on is nominally vertical (e.g. a vertical wellhead or another Inclination-Only survey log):

- The well path is considered vertical, independent of the measured inclination.
- The actual deviation of the well path from vertical is treated as an inclination dependent uncertainty and is combined with the actual measurement uncertainties.
- For planned well paths, special treatment of uncertainty is required to model the anticipated inclination (described in section 3).
- TVD is calculated using minimum curvature calculations from the recorded MD and Inclination, assuming a constant azimuth.

If it is possible to assign an estimated azimuth to the Inclination-Only data:

- An estimated azimuth (e.g. derived from the previous survey log) is assigned to the Inclination-Only survey stations. (The error model's estimate of azimuth uncertainty must reflect the accuracy of the tie-on azimuth and likelihood of subsequent azimuth wander.)
- The well path is calculated in the normal way from the resulting MD, Inclination, Azimuth survey.
- No special treatment of planned well paths is required.
- Uncertainty based calculations such as clearance scanning and target sizing require no special treatment.

3. Error models

If the tie-on is nominally vertical:

- Lateral and high side uncertainty calculations only use the ISCWSA xy misalignment terms.
- The model for actual surveys uses misalignment terms 1 and 2 to quantify deviation of the well path from vertical, and terms 3 and 4 to model instrument measurement uncertainty.
- The model for nominally vertical plans uses misalignment terms 3 and 4 to quantify total uncertainty. (Terms 1 and 2 are not useful in this case since they return zero uncertainty at zero inclination.)
- Along-hole uncertainty calculations use the ISCWSA depth terms DREF, DSF and DST.

Error model – **Actual** survey log (vertical tie on, fixed installation, measured inclinations)

Term	Propagation	Value
XYM1[1,2]	Systematic	20 deg
XYM2[1,2]	Systematic	20 deg
XYM3[1,2]	Systematic	0.5 deg
XYM4[1,2]	Systematic	0.5 deg
DREF	Random	0.35m
DREF	Systematic	0.0m
DSF	Systematic	5.6×10^{-4}
DST	Global	2.5×10^{-7} m^{-1}

Error model – **Planned** interval (vertical tie on, fixed installation, expected max inclination)

Term	Propagation	Value
XYM1[1,3]	Systematic	0.0 deg
XYM2[1,3]	Systematic	0.0 deg
XYM3[1,4]	Systematic	0.5 x (expected max Inc) deg
XYM4[1,4]	Systematic	0.5 x (expected max Inc) deg
DREF	Random	0.35m
DREF	Systematic	0.0m
DSF	Systematic	5.6×10^{-4}
DST	Global	2.5×10^{-7} m^{-1}

Notes:

1. Alternative 3, w12 = sinI, w34 = cosI, where I is the measured inclination. In all other parts of these weighting functions and in the transformation calculations, the wellpath is assumed to be vertical, i.e. I = 0, A = 0.
2. Term value is set to describe the maximum possible deviation from vertical when the output is scaled to 3 standard deviations. This holds good up to 30°of inclination, when the output begins to lag the worst-case deviation.
3. As a simplification, Misalignment terms 1 and 2 are set to zero or not used because they are only effective at higher inclinations.
4. *Expected max inclination* is a user-selected input. Via the 0.5 weighting, it is treated as describing a 2 standard deviation confidence interval. This is intentionally more conservative than the *Actual* model recognizing that the inclination value is a prediction, not a measurement. It also accommodates measurement uncertainty in addition to the inclination dependent displacement uncertainty. Unlike the Actual model, TVD is not adjusted based on the predicted inclination, therefore TVD will equal MD.

If software does not support the special treatment of inclination that is required for the *Actual* error model, a similar result is achieved by entering the survey stations as zero inclination and assigning a Planning model with a maximum inclination determined from the actual inclinations. However, the use of a single inclination over the entire drilled interval for position uncertainty calculations loses the sensitivity provided by the *Actual* model. This approach also loses the wellpath information contained in the actual survey log unless actual inclinations are recorded as comments.

If the tie-on is not vertical and it is possible to assign an estimated azimuth to the Inclination-Only data:

- The azimuth measurement uncertainty must reflect the fact that azimuth is estimated and uncontrolled after tie-on.
- The resulting error model (e.g. *Inclination-Only with estimated azimuth*) may become invalid when the wellbore is steered in azimuth or drops to near vertical.
- The standard Inclination-Only model may have to be assigned at that point.

4. Implementation

Software should correctly manage survey logs that have an undefined azimuth:

- Recognize Inclination-Only, undefined azimuth, surveys as a special case
- Report and plot as vertical well paths
- Retain measured inclination for use in error model weighting functions
- Calculate TVD from MD and measured inclination assuming a constant azimuth

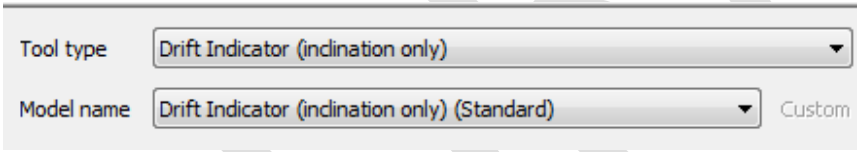
Special treatment is not required for Inclination-Only surveys with a non-vertical tie-on that can be assigned an estimated azimuth.

Example Implementation

The above recommendations may be implemented in a variety of ways. The following mock-ups show one possible implementation, and serves to highlight some of the issues that must be addressed in any implementation of the recommended method.

Data entry

Assignment of an Inclination-Only error model identifies the special status of the survey log,



and triggers special handling of the data:

Wellpath Points

	MD (m)	CL (m)	Inc (deg)	Az (GN) (deg)
Tie on	0.00	0.00	0.000	0.000
2	30.00	30.00	0.100	N/A
3	60.00	30.00	0.120	N/A
4	90.00	30.00	0.090	N/A
5	120.00	30.00	0.100	N/A
6	150.00	30.00	0.200	N/A
7	180.00	30.00	0.300	N/A
8	210.00	30.00	0.500	N/A
9	270.00	60.00	0.700	N/A
10	300.00	30.00	0.900	N/A
11	330.00	30.00	1.100	N/A
12	360.00	30.00	1.150	N/A
13	390.00	30.00	1.210	N/A
14	420.00	30.00	1.270	N/A
15	450.00	30.00	1.340	N/A
16	480.00	30.00	1.220	N/A
17	510.00	30.00	1.310	N/A

Data reporting

An Inclination-Only wellpath report should show:

- Recorded MD and Inclination
- Azimuth as a comment, such as *n/a*, *unknown*, etc.
- TVD as calculated from recorded MD and Inclination
- Zero displacement of VS, N and E from the tie-on coordinates
- DLS as zero

Example of Actual survey report format:

WELLPATH DATA (17 stations)

MD [m]	Inclination [°]	Azimuth [°]	TVD [m]	Vert Sect [m]	North [m]	East [m]	DLS [°/30m]	Comments
0.00	0.000	N/A	0.00	0.00	20.00	-8.00	0.00	
30.00	0.100	N/A	30.00	0.00	20.00	-8.00	0.00	
60.00	0.120	N/A	60.00	0.00	20.00	-8.00	0.00	
90.00	0.090	N/A	90.00	0.00	20.00	-8.00	0.00	
120.00	0.100	N/A	120.00	0.00	20.00	-8.00	0.00	
150.00	0.200	N/A	150.00	0.00	20.00	-8.00	0.00	
180.00	0.300	N/A	180.00	0.00	20.00	-8.00	0.00	
210.00	0.500	N/A	210.00	0.00	20.00	-8.00	0.00	
270.00	0.700	N/A	270.00	0.00	20.00	-8.00	0.00	
300.00	0.900	N/A	299.99	0.00	20.00	-8.00	0.00	
330.00	1.100	N/A	329.99	0.00	20.00	-8.00	0.00	
360.00	1.150	N/A	359.98	0.00	20.00	-8.00	0.00	
390.00	1.210	N/A	389.98	0.00	20.00	-8.00	0.00	
420.00	1.270	N/A	419.97	0.00	20.00	-8.00	0.00	
450.00	1.340	N/A	449.96	0.00	20.00	-8.00	0.00	
480.00	1.220	N/A	479.95	0.00	20.00	-8.00	0.00	
510.00	1.310	N/A	509.95	0.00	20.00	-8.00	0.00	

A Plan report will show all inclinations as zero and TVD matching MD.

5. Other Considerations

Inclination-Only logs are prone to having very long survey station intervals. The proposed error models are conservative, but do not accommodate extreme course lengths. Users must manage this via operating procedures. For example, post drilling, insert a station at an acceptable distance from the station with the lower inclination, and assign it the inclination of the other station (i.e. the higher inclination of the two actual stations). In nominally vertical wells with perhaps only one inclination measurement at TD, it is particularly important to insert a station at say 100ft/30m and assign it a suitably conservative inclination. Otherwise, a Blind Drilling type model may be more appropriate.

Similarly, the validity of Inclination-Only models (with and without estimated azimuth) is questionable when applied to intervals drilled with BHAs capable of very high doglegs. It is therefore prudent to impose a BHA DLS capability limit on the use of the models (e.g. 8°/30m).

Software not aligned with these recommendations is likely to require an explicit inclination and azimuth to determine well path trajectories. This must be considered when transferring survey data between different applications.

Combining Inclination Only Surveys with 3D Surveys in a definitive survey

Special handling is required where an Inclinometer (2D) Survey is combined with a 3D Survey (Gyro or MWD) in a definitive survey. It will depend on the order and it is important to calculate the same coordinates in the definitive survey as are calculated and displayed in each individual survey.

A MWD Survey tied onto an Inclination Only survey

It is often the case that the top hole of individual wells (exploration or on land) are surveyed using Inclination only instruments and later a 3D drilling survey (MWD) is added in a deeper hole section or for sidetrack work.

Inclination Only survey

	MD (ft)	Inc (°)	Azi (°)	TVD (ft)	N/S (ft)	E/W (ft)	V.Sec (ft)	Dogleg (°/100ft)
1	0.0	0.00	0.00	0.0	21.1	-4985.3	21.1	0.00
2	1000.0	1.00	0.00	999.9	21.1	-4985.3	21.1	0.10
3	2000.0	1.25	0.00	1999.8	21.1	-4985.3	21.1	0.02
4	3000.0	0.75	0.00	2999.6	21.1	-4985.3	21.1	0.05
5	4000.0	2.50	0.00	3999.2	21.1	-4985.3	21.1	0.17
6	5000.0	4.50	0.00	4997.2	21.1	-4985.3	21.1	0.20
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MWD Survey is tied to Inc Only at 5000'MD – it is assumed that the tie-on station has zero inclination

	MD (ft)	Inc (°)	Azi (°)	TVD (ft)	N/S (ft)	E/W (ft)	V.Sec (ft)	Dogleg (°/100ft)
1	5000.0	0.00	0.00	4997.2	21.1	-4985.3	21.1	0.00
2	5350.0	6.75	225.00	5346.4	6.5	-4999.9	6.5	1.93
3	5500.0	7.75	226.00	5495.2	-6.7	-5013.4	-6.7	0.67
4	5700.0	8.50	247.00	5693.3	-21.9	-5036.7	-21.9	1.52
5	5900.0	8.50	245.00	5891.1	-33.9	-5063.7	-33.9	0.15
6	6100.0	8.50	248.00	6088.9	-45.7	-5090.8	-45.7	0.22

In the Definitive survey the station interval from 5000 to 5350 is calculated as if the Inclination at 5000' is zero (and not 4.5 deg as reported). i.e. we have a minimum curvature arc from the last inclination only survey at 0 inclination, 0 azimuth to the first directional survey at 6.75° inclination and 225° azimuth.

	MD (ft)	Inc (°)	Azi (°)	TVD (ft)	N/S (ft)	E/W (ft)	V.Sec. (ft)	Dogleg (°/100ft)	T.Face (°)	Tool
1	0.0	0.00	0.00	0.0	21.1	-4985.3	21.1	0.00	0.00	UNDEFINED
2	1000.0	1.00	0.00	999.9	21.1	-4985.3	21.1	0.10	0.00	SITOTCO:
3	2000.0	1.25	0.00	1999.8	21.1	-4985.3	21.1	0.02	0.00	SITOTCO:
4	3000.0	0.75	0.00	2999.6	21.1	-4985.3	21.1	0.05	180.00	SITOTCO:
5	4000.0	2.50	0.00	3999.2	21.1	-4985.3	21.1	0.17	0.00	SITOTCO:
6	5000.0	4.50	0.00	4997.2	21.1	-4985.3	21.1	0.20	0.00	SITOTCO:
7	5350.0	6.75	225.00	5346.4	6.5	-4999.9	6.5	2.98	-152.66	MCCONV:R
8	5500.0	7.75	226.00	5495.2	-6.7	-5013.4	-6.7	0.67	7.69	MCCONV:R
9	5700.0	8.50	247.00	5693.3	-21.9	-5036.7	-21.9	1.52	86.37	MCCONV:R
10	5900.0	8.50	245.00	5891.1	-33.9	-5063.7	-33.9	0.15	-90.99	MCCONV:R

Inclination Only Survey Tied onto a Gyro Survey

This is the less frequent occurrence and is handled in a similar manner. The well was drilled with Totco surveys to 7600'MD and then a multi-shot casing gyro survey is run from surface to 6516.3'MD. In the definitive survey the final 3 Totco stations are added as if they are vertical below the last gyro survey.

Gyro Survey

	MD (ft)	Inc (°)	Azi (°)	TVD (ft)	N/S (ft)	E/W (ft)	V.Sec (ft)	Dogleg (°/100ft)
62	6016.3	0.95	189.52	6014.4	1461.6	-3051.9	1461.6	0.22
63	6116.3	0.62	165.18	6114.4	1460.2	-3051.9	1460.2	0.46
64	6216.3	0.58	136.91	6214.4	1459.3	-3051.5	1459.3	0.30
65	6316.3	0.37	95.14	6314.4	1458.9	-3050.8	1458.9	0.39
66	6416.3	0.27	100.31	6414.4	1458.9	-3050.2	1458.9	0.10
67	6516.3	0.39	107.28	6514.4	1458.7	-3049.7	1458.7	0.13
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TOTCO Survey

	MD (ft)	Inc (°)	Azi (°)	TVD (ft)	N/S (ft)	E/W (ft)	V.Sec (ft)	Dogleg (°/100ft)
12	4430.0	1.00	0.00	4428.8	1516.4	-2930.5	1516.4	0.08
13	4750.0	1.75	0.00	4748.7	1516.4	-2930.5	1516.4	0.23
14	5050.0	1.25	0.00	5048.6	1516.4	-2930.5	1516.4	0.17
15	5490.0	1.50	0.00	5488.5	1516.4	-2930.5	1516.4	0.06
16	5825.0	1.75	0.00	5823.3	1516.4	-2930.5	1516.4	0.07
17	6200.0	0.75	0.00	6198.2	1516.4	-2930.5	1516.4	0.27
18	6665.0	1.50	0.00	6663.1	1516.4	-2930.5	1516.4	0.16
19	7150.0	1.00	0.00	7148.0	1516.4	-2930.5	1516.4	0.10
20	7600.0	1.50	0.00	7597.9	1516.4	-2930.5	1516.4	0.11
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Definitive Survey

	MD (ft)	Inc (°)	Azi (°)	TVD (ft)	N/S (ft)	E/W (ft)	V.Sec. (ft)	Dogleg (°/100ft)	T.Face (°)	Tool
62	6016.3	0.95	189.52	6014.4	1461.6	-3051.9	1461.6	0.22	-137.88	GCCONV:R
63	6116.3	0.62	165.18	6114.4	1460.2	-3051.9	1460.2	0.46	-146.43	GCCONV:R
64	6216.3	0.58	136.91	6214.4	1459.3	-3051.5	1459.3	0.30	-111.67	GCCONV:R
65	6316.3	0.37	95.14	6314.4	1458.9	-3050.8	1458.9	0.39	-140.97	GCCONV:R
66	6416.3	0.27	100.31	6414.4	1458.9	-3050.2	1458.9	0.10	166.47	GCCONV:R
67	6516.3	0.39	107.28	6514.4	1458.7	-3049.7	1458.7	0.13	22.00	GCCONV:R
68	6665.0	1.50	0.00	6663.1	1458.7	-3049.7	1458.7	1.11	-120.26	SITOTCO:
69	7150.0	1.00	0.00	7148.0	1458.7	-3049.7	1458.7	0.10	180.00	SITOTCO:
70	7600.0	1.50	0.00	7597.9	1458.7	-3049.7	1458.7	0.11	0.00	SITOTCO:

In this instance, the first inclination only survey in the definitive survey at 6665ft, appears directly below the last gyro survey at 6516.3ft. i.e. the well has a sharp 'corner' and we do not join the inclination survey to the gyro with a minimum curvature arc. This mirrors the way in which an inclination only well sits directly under the slot position.