Error Model Maintenance Sub-committee for the 59th ISCWSA meeting

April 17th Glasgow, Scotland

Attendees

In-Person (43):

Adrian Ledroz	Bianca LaCombe	Ian Walker	Marc Willerth	Tom Southren
Alan Gosse	Brett Van Steenwyk	Ildiko Langaker	Marianne Houbiers	Will Lanigan
Anas SIKAL	Chad Hanak	Jay LaCombe	Mike Nowlin	Yvonne Nwamaka Oguh
Andreas Hueper	Charles Duck	Jerry Codling	Morten Gjertsen	
Andrew McKinnon	Craig Sim	Jon Bang	Nicholas Robertson	
Andy McGregor	Darren Aklestad	Ken Miller	Patrick Knight	
Arnaud Chulliat	Denis Reynaud	Kevin Sutherland	Phil Scott	
Austin Pile	Erik Blake	Kyle Rickey	Robert Wylie	
Ben Hawkinson	Hans Dreisig	Makito Katayama	Stewart Vant	
Benny Poedjono	Harald Bolt	Manoj Nair	Steve Grindrod	

Online (9):

Cecile Knaben
Ciarran Beggan
Dalis Deliu
Inge Edvardsen
Knut Ness
Michael Caulkins
Mike Attrell
Mohammadreza Kamyab
Stephen Winchester

Agenda

- Non Static Surveys Check in and Discussion
- XCL and RMIS Investigations (Marianne and Jerry)
- Depth Bias revisited (Andy and Harald)
- Geomagnetic Storms and Survey error (Manoj)

Discussion

Non-static Surveys

- Currently SLB has published a proposal for a magnetic survey error model for a tool that is acquiring data during rotation.
- There is demand from operators to use this service as well as similar type offerings from other vendors, however they would like for a consistent error model framework to exist across these tools.
- The committee is seeking feedback from other vendors to better understand who is working on this type of offering and if those who are on similar tools would be able to align
    - Baker is working on non-static surveys, questions about one of the SLB terms
    - Halliburton is also working on a tool and is reasonably happy with the SLB proposal, agrees there is value in alignment and thinks it shouldn't be too hard to align.
    - Icefield is working on a hybrid survey tool, not the same as magnetic MWD but similar concerns about mixing static and continuous surveys in a way that is not readily supported by the current error model implementations.
    - Currently, trying to manually enforce mode switches, or split up survey legs with differing tool codes is both an operational headache as well as likely to cause inaccuracies due to survey leg tie-on effects

- The group agrees there are two separate issues here, one that is hopefully tractable in the near term, and one that will require deeper research
    - Near term: Vendors producing high frequency surveys that are acquired during rotation should align on a common error model framework that each company can populate with their own coefficients.
        - Survey legs produced using this methodology can either treat traditional static surveys as if they had been acquired in a rotating fashion or exclude them from the survey listing…but survey legs would remain using a single tool code for the survey leg and uncertainties could be readily modelled using existing software workflows.
        - For several vendors, the goal has been to use the current static survey accuracy as a specification for how accurate the rotary surveys must be, implying minimal impact on EoUs between a "mode switching" vs. "assume one mode" survey type.
        - There may also be the possibility to propose a conservative "generic" model for use in the absence of a vendor specific model, similar to how gyros were done

        - In the case of gyros, the generic was so conservative it was hard to ever use it, but that may be what is desired in a generic model.
        - Alternatively, the MWD error model was aiming for accuracy, but also to serve as a specification for new vendors entering the space with new technologies…For instance bias/scale terms may have been defined by expected performance of fluxgates, however they were then used for acceptance criteria on when MEMS sensors were accurate enough to use. A similar concept could apply for the rotating survey.
    - Longer term, it would be preferable to have a way of mixing surveys of different type, explicitly describing how each station was acquired and enabling uncertainty to be correctly propagated along mixed survey legs.
        - This would enable the combination static/rotating magnetic surveys as well as remove ambiguity in existing gyro workflows, where inclination is used to infer survey mode, and precisely when mode switching occurs and how to handle it may differ across various software implementations.
        - As an added bonus this could enable more rigorous MWD workflows, where surveys that are known to have corrupted azimuth due to external interference or magnetic storms could be flagged as having an interpolated azimuth and not require special handling or concerns about tie-on effects.
        - These types of correlations are theoretically possible with the matrix methods of error correlations proposed in previous meetings, however more discussion is needed before a formal switch.
- A separate issue that may require more investigation is the depth errors expected to be present for surveying while drilling with at least some pipe in compression. Whether these errors are the same magnitude or should be equally correlated with off-bottom static surveys is unclear.
        - There is likely a strong dependence on other factors such as well trajectory and drilling parameters
- Yet another concern is that there is a potential explosion in the number of required error models for continuous surveys
        - Do we need to support various flavors of correction (+IFR, +MS, +Sag, etc)?
        - Are the same corrections even applicable or valid under the new surveying conditions?
        - Similar question for QA/QC…are the criteria the same or are there new things we need to add?
- Conversation then drifted into a broader discussion on the impacts of the new course lengths and other measurements:

- Is there a tighter EoU that should be applied because of high frequency measurements, or at a certain point are you just measuring noise and putting false tortuosity in your trajectory?
    - Some of the modifications with a rev5 tool code will produce a smaller EoU with a tighter course length, is there a point where this reduction hits a limit?
    - Are there concerns about meaningfully using DLS / Tortuosity measurements on extremely short intervals? Should there be an alternate way to look at "angle change over the effect longer interval" that can keep DLS numbers in the same range as users are accustomed to, while still letting us take advantage of the additional data acquisition?
    - Is there the same meaning between calculating a dogleg angle measured between a static measurement and a rotating measurement if we consider changes in the drillstring?

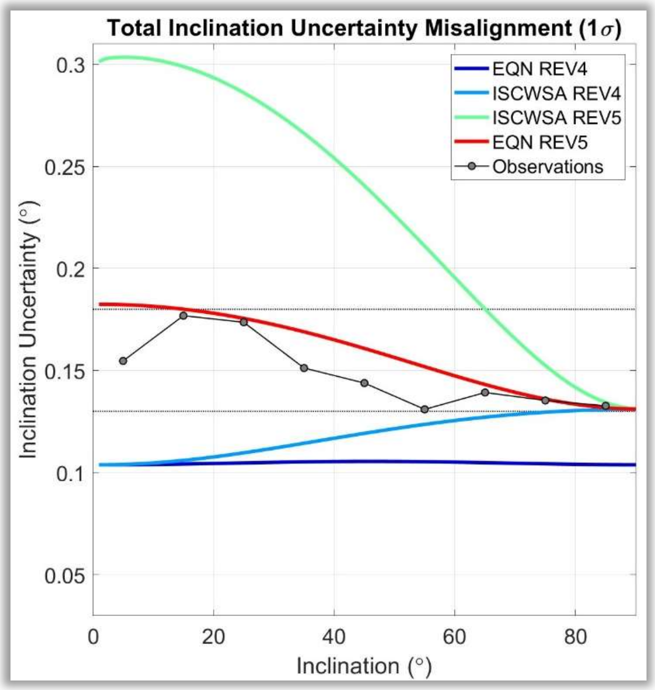
- A workgroup is to be formed to align on a rotating magnetic survey error model
- Any vendors working on a rotating survey who wish to be part of the error model alignment workgroup should reach out to the sub-committee chair (marc.willerth@hpinc.com)
- Another workgroup will be formed to cover the broader idea of combining survey types within a survey leg.
- Further investigation is needed on the limiting accuracy provided by decreasing course lengths. Vendors with access to extremely high-frequency measurements (e.g. 1-ft wireline gyro surveys) to produce an analysis of positional change caused by downsampling high frequency data to see if there is a limit.

Extended Course Length and Random Misalignment analysis

<u>Presentation by Marianne Houbiers from Equinor</u>

- Research from Equinor on inclination repeatability agrees with other analysis that Revision 4 top hole misalignments are likely underestimated.
    - While revision 5 aims to have addressed this by replacing a smaller systematic error with a larger random error, adopting these changes would impact a number Equinor's operations, that have operated in this manner safely for a number of years.
- Statistics run on repeat sections seem to imply that there is both a systematic offset in survey data, along with a random component.
    - In addition to matching statistical observations, retaining the smaller systematic term from rev4 while adding a random term (additional to rev 4, but smaller than rev 5) provides an extra level of caution while avoiding the operational disruption that rev 5 would cause as published.
- The following figures were used to show a comparison of uncertainties between Rev4, Rev5, and Equinor's proposal:

Error term	Propagation mode	Rev4 ISCWSA	Rev4 EQN (current)	Rev5 ISCWSA	Rev5 EQN (proposed)
Mis1	S	0.1	0.06	0.1	0.1
Mis2	S	0.1	0.06	0.1	0.1
Mis3	S	0.1	0.1	-	**0.1**
Mis4	S	0.1	0.1	-	**0.1**
Mis3r	R	-		0.3	**0.15**
Mis4r	R	-		0.3	**0.15**
Sag	S	0.08	0.08	-	0.08
Sage	S	-	-	0.08	



Additional barriers to Rev 5 adoption have been encountered due to the XCL term

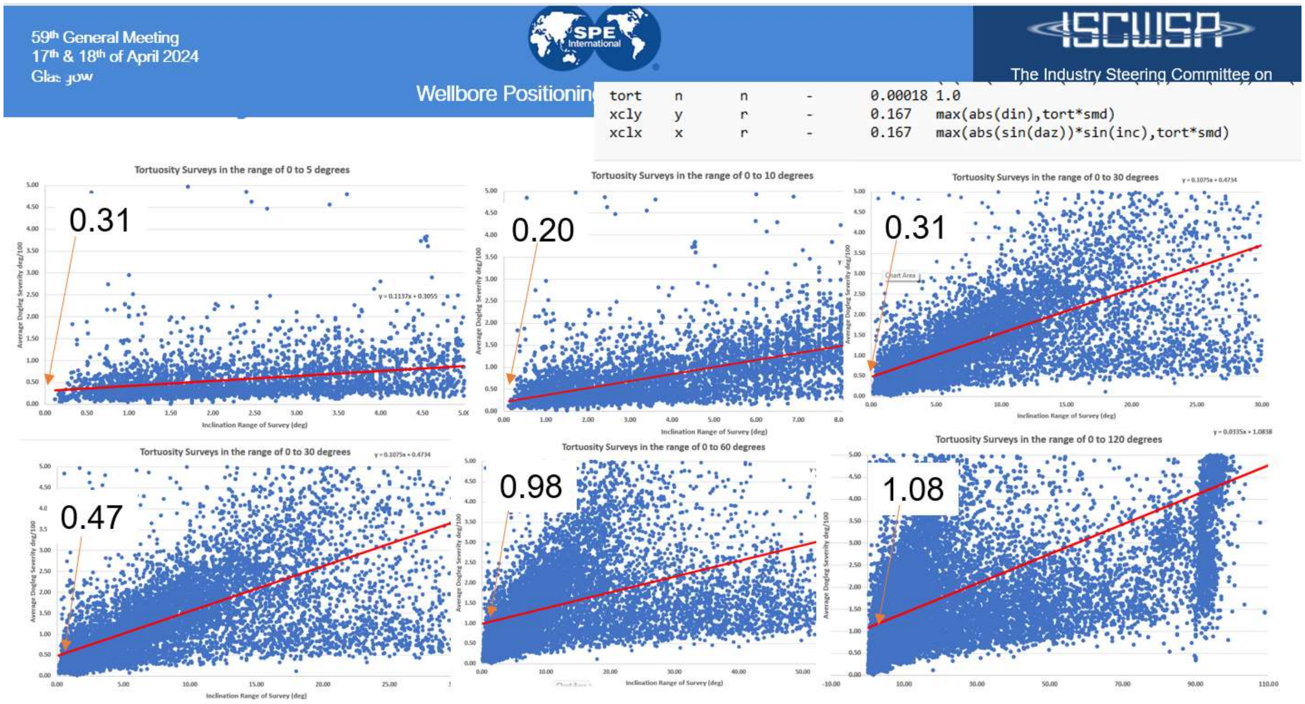
- It is a strict penalty with no minimum course length below which there is not added uncertainty
  - There is no incentive to adopt this over rev 4 and just make EoUs larger
  - There is less incentive to enforce more frequent surveying if the penalty still applies
- The minimum tortuosity may be too high, particularly at low inclinations and in large hole sizes.
- The current value may be reasonable at higher inclinations,

Minimum Tortuosity Analysis

Presentation by Jerry Codling, Landmark

- Similar to Marianne’s analysis – Minimum tortuosity is likely too high at low angles.
  - Original research was based on high angle gyro surveys.
  - New analysis looks at inclination dependence on tortuosity.

- Plot the DLS vs. inclination and look at changing Y-intercept from regression.



- New proposed minimum tortuosity: 0.2 + sin(Inclination)
  - Smoothly increases from 0.2 to 1.2

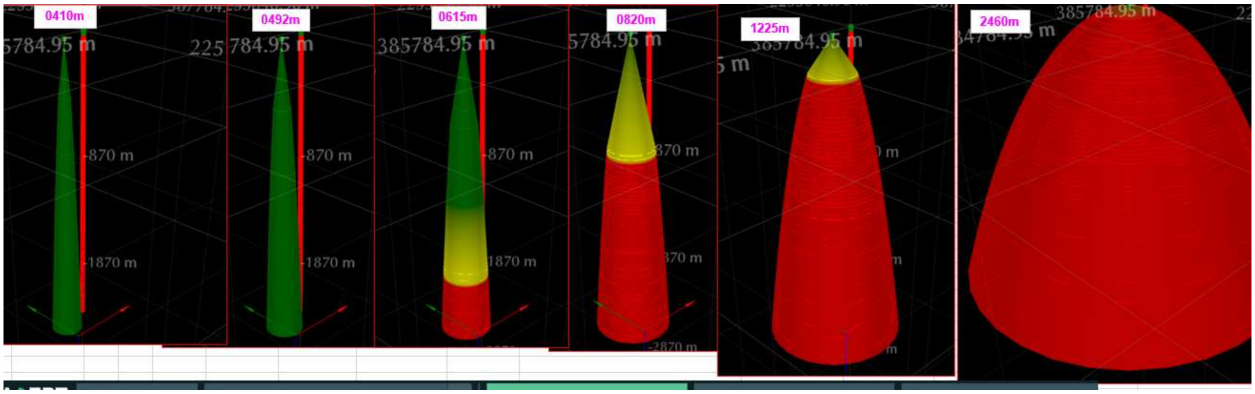
- Additional thoughts were provided around the updated misalignment terms.
  - Original data for error model misalignments studies the instrument to collar angle.
  - This would be an error that randomizes (systematic with tool face).
  - It should probably be retained along the whole wellbore as a common error source.
  - Jerry's previous work suggesting a randomized borehole-collar misalignment still holds.
    - Perhaps an improvement is to have a random and systematic component.
    - Also eliminates concerns about random misalignment and short course length.

Utility Tool Code Usage and Calculation issues

Presented by Hans Dresig, TotalEnergies

- There is an open question as to whether or not xcl errors should be present in utility tool codes, as they do not necessarily imply complete survey stations are being taken and evaluated.
  - One thought it that codes like inc-only, which imply some kind of measurement, should retain xcl, while blind or various cone models should not.
- Also in at least some implementations of the latest rev 5 tool codes, depending on how stations are interpolated or how sparse measurement data is, the error envelope can actually grow to be larger than the measured depth of the well, which seems excessively conservative.

- The following graphic was shown where an Inc-only tool code is downsampled along a straight interval:



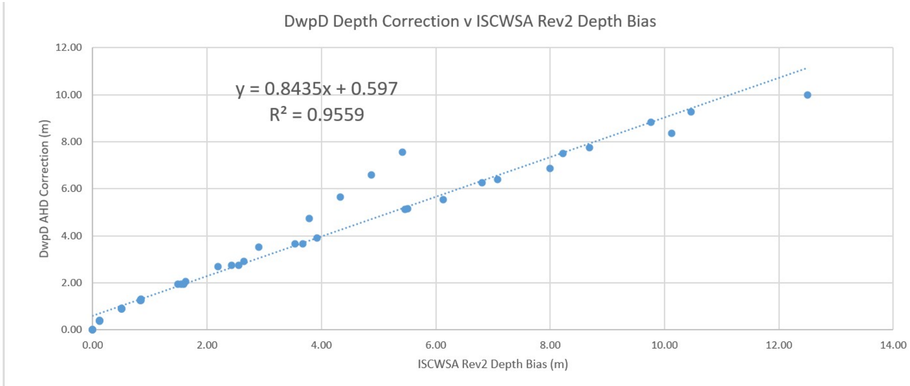
- A tangential question arose about how covariance matrices should be interpolated
    - The graphic shown appears to be linearly interpolating the variance (creating a paraboloid). It may be better to interpolate the eigenvalues / axis dimensions (creating a cone).
- One curious behavior here…because of the XCL terms, it is possible for some tool codes, if sampled sparsely enough, to accumulate error faster than a blind drilling tool code
    - This would potentially mean that in some cases a well that was going to be Inc-only should be treated as blind+trend, do we need guidance on this?
- Some operators have procedures for procedures for producing a bounding cone
    - This is often done for fields where only a surface and TD point are available
    - In theory you can tune the frequency of inc-only interpolations to produce cones of various size, but this could be a complex workflow to enforce in practice.
    - There is also a challenge in what to do for fields where you have no surveys and not enough offset well data to determine what the size of the bounding cone should be
    - Anecdotally, at least one well that was drilled "assumed vertical" was later surveyed and found to be at greater than 85 degrees inclination, so extreme cases do happen.
- A related issue here is how to handle cases where you would consider swapping tool codes
    - For instance, long lengths without a survey
    - Similarly, stretches of MWD surveys that have good inclination, but use an interpolated azimuth because there is external interference corrupting the magnetics
    - It's undesirable to switch tool codes back and forth because of tie-on effects
        - Switching, even from MWD to a blind tool code, can cause the resulting combined EoU to be smaller in some cases than using MWD the whole way.
- In general, guidance on how to make and select utility cone models would be desirable
    - More on this in the Collision Avoidance meeting later in the day
- It's also worth exploring how some of these situations could be better handled
    - Either having a way to combine surveys of multiple types without a tie on effect
    - Or possibly tuning the XCL term so that at a certain length it behaves like a blind+trend tool code without requiring a tie-on

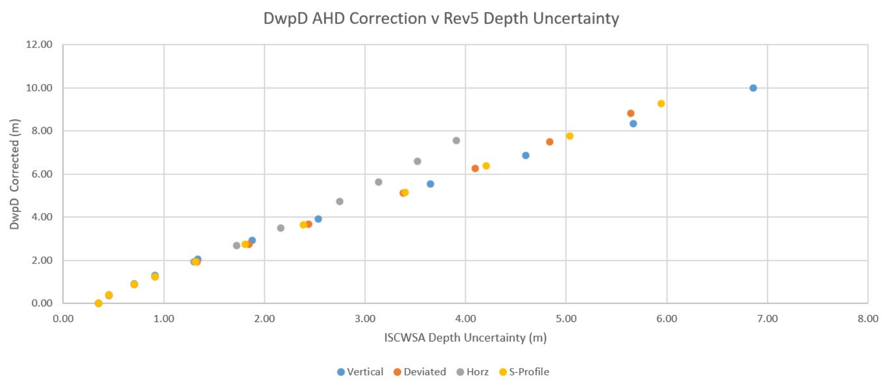
    - There are similar strange effects with long course lengths from a surface tie-on, a previous work group has a proposed behavior that it would be good to make sure is being used. If not properly implemented then a “Blind” well with one point at TS might be considered “Zero-error” well for the first half of it’s length.
        - This is similar to where the Blind tool code was originally intended to be used: when there is a need to project a long length to the bit.
- Another situation that may be worth covering is “Drilling past failure”, a common scenario in HPHT wells, the tool is continued to be used after it has begun to fail (potentially up to a blind drilling situation), and there is a desire to capture the additional uncertainty while retaining the accumulated systematic errors.
- It would also be beneficial to have diagnostics available for certain utility tool codes to make sure they are being implemented correctly by varying software suites.

Depth and Depth Bias Revisited

<u>Presentation from Andy McGregor (H&P) and Harald Bolt (Depth Solutions)</u>

- Depth model is derived from work performed by Roger Ekseth (Thesis now available on the website)
- There were a large number of error sources that he distilled into a small number of lumped terms
    - Analysis is difficult to replicate, it is hard to make new depth model in old framework
- The original ISCWSA Error models included some of the depth error as a bias
    - Stretch and thermal expansion were known to be one-sided errors
- These biases were deprecated long ago
    - It is thought that if you believe the bias exists you should correct for it and leave residual errors as zero-centered
- Some criticisms of the the current depth model
    - What is it aiming to achieve? Do we need more specific models?
    - What validation is there to support the terms in their current state?
    - How should depth corrections be handled and accounted for in an updated model?
    - Does the old “bias” relate to modern proposed “corrections”
- Study: 4 theoretical wells are construction and modern depth correction performed on them
    - Vertical horizontal, S, J profiles
    - Assumed temperature profiles, rig states, etc
    - Depth corrections were compared with the estimates from the Rev0 Bias terms
    - Depth corrections are of similar magnitude to depth biases, suggesting biases are reasonable
    - Depth corrections are well withing the uncertainty bounds of Rev5, suggesting it is reasonable.





- Conclusions – this analysis supports the original depth bias terms, it would be reasonable for operators who want to use them to do so.
    - Agreement in the horizontal well was less strong, but still within tolerances of error model
    - Ideally this could be replicated using real-world data

Geomagnetic Storms – When do they exceed error model Expectations?

<u>Presentation by Manoj Nair, NOAA</u>

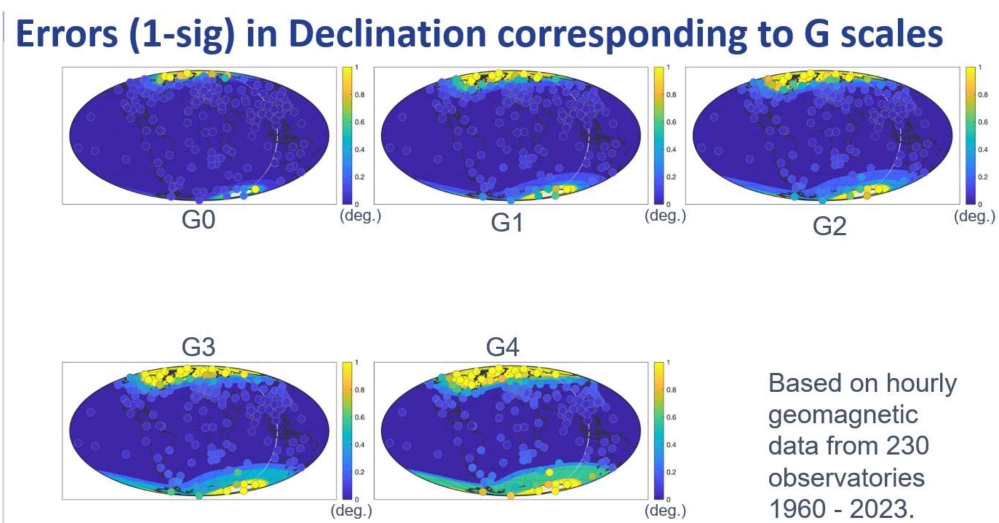
- It's well documented that space weather events can cause errors in MWD surveys
    - These are generally treated as random events
- We are approaching the peak of the Solar Cycle for Geomagnetic storms
    - Frequency of space weather events will be increasing
- Effort at NOAA to translate space weather forecasting into terms meaningful for MWD errors
    - NOAA forecasts events on either a G0-G5 or Kp0 – Kp9 scale
    - MWD surveys are more concerned about degrees of declination error

Scale	Description	Physical measure	Average Frequency (1 cycle = 11 years)
G 5	Extreme	Kp = 9	4 per cycle (4 days per cycle, ~0.1%)
G 4	Severe	Kp = 8, including a 9-	100 per cycle (60 days per cycle, ~2%)
G 3	Strong	Kp = 7	200 per cycle (130 days per cycle, ~4%)
G 2	Moderate	Kp = 6	600 per cycle (360 days per cycle, ~9%)
G 1	Minor	Kp = 5	1700 per cycle (900 days per cycle, ~22%)
G 0	Normal	Kp = 0,1,2,3,4	(2560 days per cycle ~64%)

The Kp index quantifies disturbances in the horizontal component of Earth's magnetic field with an integer in the range 0-9 with 0-4 being calm and 5 or more indicating a geomagnetic storm.

Modified after NOAA Space Weather Scales, https://www.swpc.noaa.gov/noaa-scales-explanation

- NOAA has mapped the 1-sigma errors in declination related to G0-5 events



- NOAA could make a forecasting system to show disturbance errors for varying levels of solar events, would this be useful?
- Would you want to have a specific error model for these situations?

<u>Discussion</u>

- Would this would be a modification of the error model to have a k factor?
  - Yes

- Is it based on real time data?
  - No, it's an uncertainty level based on historical data, and is forecasted before the storm

- It could be useful to have something available for folks at high latitudes to say "What would my error be for the next X number of hours"

- There could be 2 use cases:
  - One having a threshold for warnings, or
  - Knowing when to take local measurements

- Having historical data could be useful but you have to wonder about the quality.
- There's the legacy problem of lookup tables,
  - Now we would have location and time based problems...
- There are also issues with this for QA/QC criteria
  - If you have a "solar storm" error model, it will expand the acceptable QC, but may not increase the EoU size because it's a random error
  - You would need to make sure that the random declination error is increased on survey measurements along with QC
  - There are also problems in that storms are not truly random as a single event...they could be effectively a bias on that period of time
    - E.g. what If the storm lasts 2 days?

Collected Action Items & Decisions

- Workgroups to be formed for the following topics:
  - Non-static survey error model alignment*
  - Dynamic Error Model Construction*
  - Agreement/harmonization on a revised misalignment proposal*
  - Combined survey type in single leg
  - Improved Utility Model Guidelines (behavior, usage, course lengths, etc)

  Note: groups with stars to have a clear near-term deliverable

- Jerry Codling to write up a document on common construction of cone-based error models
- Andy McGregor to write up and circulate a document on converting current Rev5 models to include a depth bias term
- High-frequency survey providers to perform preliminary analysis on the effect of downsampling surveys on position to identify if there is a minimum accurate course length
- The group is to consider / explore Jerry's minimum tortuosity approval for a next revision
- Marc Willerth to write up and circulate a clarifying "Why" document for the goal of various error model revisions, enabling a non-expert users to understand when they should update revisions or not