

## Hydro 2007

### An Analysis of Vertical Position Error Estimation in TPE and CUBE for Hydrographic Surveying

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## Introduction

Total Propagated Error (TPE) and Combined Uncertainty Bathymetric Estimator (CUBE) are tools and concepts designed for use with Hydrographic survey data to minimize subjective user intervention and to help automate data cleaning and filtering. With the trend in Hydrographic Surveying towards objective estimation of data quality, these methods rely heavily on the error estimates generated by the georeferencing and motion compensation systems installed on Hydrographic survey vessels.

Previous studies have demonstrated the usefulness of including an instantaneous estimate of horizontal position error in TPE and CUBE<sup>1</sup>. These studies proved that the use of *a priori* error estimates is not robust and methods are now in place to read and make use of computed RMS position error estimates.

At the same time a new trend in bathymetric survey data processing has emerged; the use of Altitude on the ellipsoid in place of vertical displacement (Heave).

Applanix POS MV (Position and Orientation System for Marine Vessels) is a GPS aided Inertial Navigation System that has been specifically designed to produce an accurate estimate of the echo-sounder position and orientation on the ellipsoid in all vessel dynamics. Applanix POS MV computes all motion variables including latitude, longitude, Altitude, heading, pitch, roll, and Heave. It is the Altitude which has become an area of focus. It is now possible to consistently compute high

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<sup>1</sup> Canter, Lockhart & Collins Caris 2005 , Error Estimation in Positioning and Orientation Systems

bandwidth Altitude with sub 5cm results using inertially aided RTK, and to produce an even more robust solution by making use of post processing techniques.

This paper will serve to identify the effect of using Altitude in place of Heave. In addition, this paper will serve to identify the effect of using error estimates in TPE and CUBE for both of those variables and the effects on final hydrographic data quality.

## Discussion

The basic components which make up the measurement of the vertical in hydrographic survey are illustrated below. The illustration shows the relation of the GPS antenna to the water line, the geoid, the chart datum and the sea bottom. It is after all, the depth which we are interested in. The important thing to stress here is that, if we know the relation of the echosounder to the ellipsoid, and the ellipsoid to the chart datum, then we eliminate the need for dynamic draft.

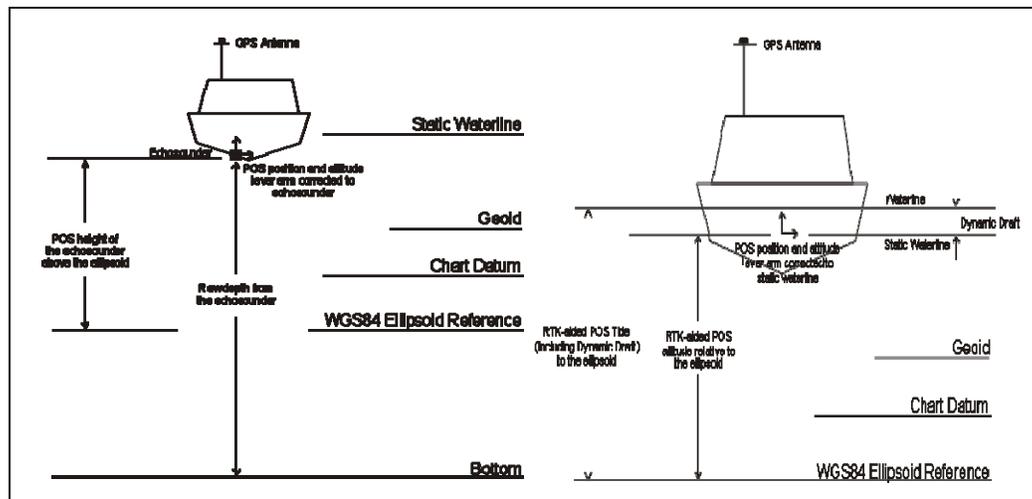


Figure 1 – The Vertical – The Basics <sup>2</sup>

The aim of TPE is to automate the processing of hydrographic data, and therefore it is extremely important to pay attention to how error estimates are weighted in TPE. A focus of this paper is error estimates for the vertical.

“In order to obtain the total variance for the final depth ( $D_{final}$ ) of an individual sounding, one must sum all of the variances that are associated with depth uncertainties. These variances are a combination of the total measured depth variance and the reduced swath depth variance.”

$$\sigma_{DFinal}^2 = \sigma_d^2 + \sigma_D^2 \quad 3$$

The variance with subscript (d) is the total variance of the measured depth, and the variance with subscript (D), is the total variance of the reduced depth. The measured

<sup>2</sup> Pat Sanders, HyPack

<sup>3</sup> *The Study of Total Propagated Error in Hydrographic Surveying*, Corey Collins, Department of Geodesy and Geomatics Engineering, University of New Brunswick, March 2004.

depth is corrected for Heave. Heave is equal to the vertical displacement of the vessel, to a zero mean level, at a given instant in time. The reduced depth is corrected for Tide.

Heave RMS is currently a function of wave height and not necessarily an objective error estimate of the measurements which make up the Heave function. In order to use Heave in bathymetric processing, knowledge of dynamic draft is required. There is no standard method for measuring or estimating dynamic draft error.

Long swell periods can not be measured by conventional inertial instruments which measure Heave. Therefore, a component of unmeasured motion and error estimation exists in the total variance of the measured depth when Heave is applied.

Errors associated with tide measurement are related to the measurement at the gauge itself, and spatial de-correlation related to the distance of the gauge to the survey area. The tidal measurement variance is described in the equation below.

$$\sigma^2_T = \sigma^2_{Tm} + \sigma^2_{Tpred} \quad 4$$

The  $\sigma^2_{Tpred}$  does not include measurement of changes in water level due to seiche, wind driven tide, or other phenomena which can cause slowly varying changes in water level.

This paper will show visible benefits in plots of depth surfaces, when Heave is replaced with post processed ellipsoidal Altitude. The uncertainty for Altitude is computed by the Inertial Navigator and can be input into TPE. The uncertainty for Tide and dynamic draft fall out of the equation. The remaining uncertainty will be in the transformation of ellipsoidal Altitude to the chart datum.

Heave should only be replaced with Altitude when the accuracy in the positioning system is capable of providing sub 5 centimetre accuracy (or as otherwise required by the user). As mentioned above this means that Post Processed Kinematic (PPK) positioning data should be used (see illustration below). There are several benefits to be gained by GPS/Inertial post processing. Real time kinematic (RTK) often suffers from radio link issues and rarely do we find that 100% of the acquired position data to be in fixed integer narrow lane mode.

In post processing the data gathered at the reference is made directly available to the GPS recomputation and fixed integer will be achieved all the time if the rover is within 20 to 30 kilometers of the reference. In post processing a smoother can be applied to the inertial position data. The effect of the smoother will be to significantly reduce error in any periods where GPS data is lost. A smoothed best estimate (SBET) of position is produced. SBET data provides sub 5 centimetre Altitude with a high degree of confidence.

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<sup>4</sup> Ditto 1

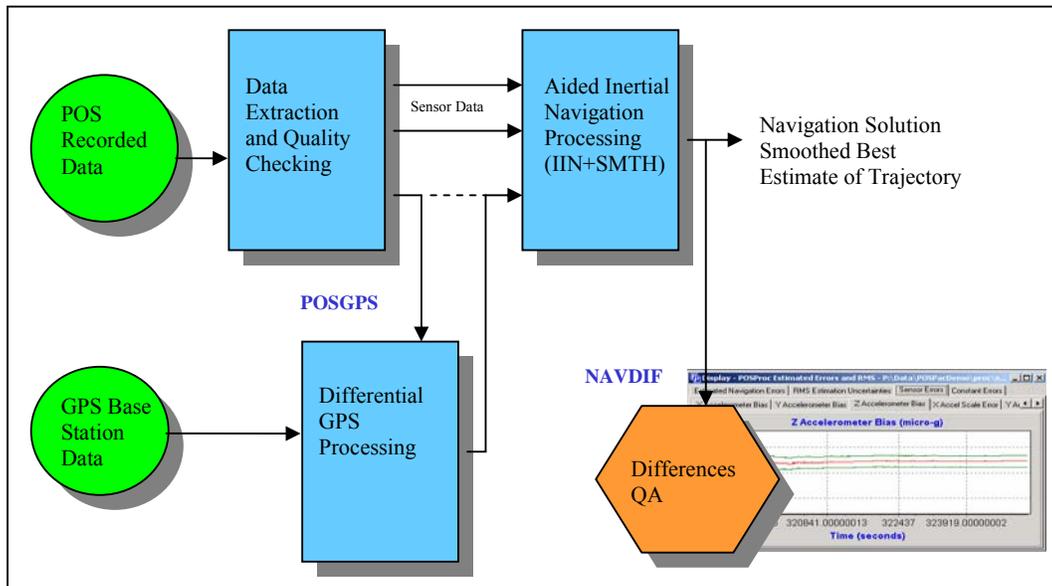


Figure 2 –GPS/Inertial Post Processing with Applanix POSPac

## Data Analysis

CARIS HIPS 6.1 has been used in this analysis. This version of CARIS has been engineered to accept SBET data. SBET data not only contains latitude, longitude and Altitude, it also contains an RMS value for each position attribute. CARIS HIPS 6.1 also has options to load the RMS data. The use of these values in the TPE computation provides a more rigorous determination of the overall error budget. Furthermore, it will aid in the process of automated data cleaning by identifying areas of varying uncertainties instead of the processor having to identify these areas through investigation. It will also highlight areas of concern which are currently concealed in the TPE computation.

A data set acquired offshore California in 2005 was used in this analysis. The survey vessel was the MV Quicksilver with a 32 foot length and 3 foot draft. The vessel was equipped with a Reson Seabat 7125 and an Applanix MV 320. Real time navigation was based on OmniStar HP. All positioning raw data was saved in Applanix POS MV and reprocessed in Applanix POSPac. The survey area was near shore in an area which was heavily influenced by tides.

The data was processed in four different ways.

Case 1: Traditional Heave with a prior estimates of positional and attitude error

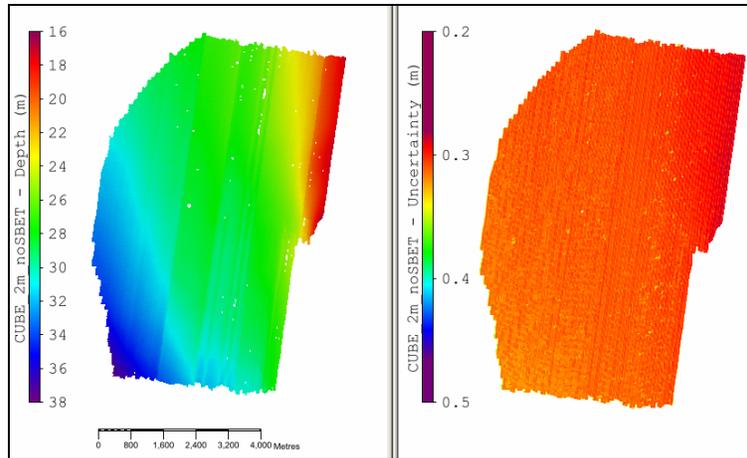
Case 2: Traditional Heave with real estimate of positional and attitude error

Case 3: Altitude substituted for Heave with a priori estimates of positional and attitude error

Case 4: Altitude substituted for Heave with real estimates of positional and attitude error

## Case 1: Standard CUBE Processing with Heave and Apriori Estimates of Error

The left hand part of Figure 3 below is a plot of depth from standard CUBE processing. Note that there are data issues which are especially visible in the lower portion of the plot. These inconsistencies have magnitudes of up to two meters and are the result of busts in the application of tide and dynamic draft. On the right hand side of figure 3 is the CUBE uncertainty surface. This surface is mostly flat due to the fact that static, a priori estimates of error have been used. The a priori estimates of error are taken from the manufacturer's specifications.

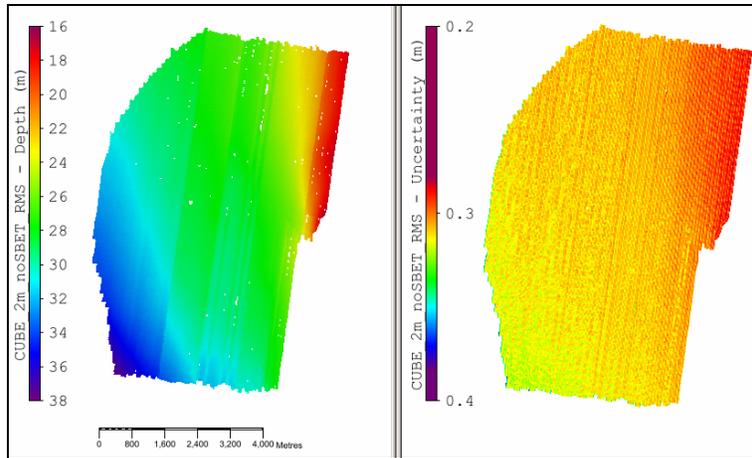


**Figure 3 – Standard CUBE Processing with Heave  
Depth (on the left) & Uncertainty (on the right)  
A priori estimate of error**

## Case 2: Standard CUBE Processing with Heave and Dynamic Estimates of Error

Case 2, illustrated in Figure 4 below, is very similar to the Case 1 plot above except that dynamic estimates of error have been used in TPE for position. Dynamic estimates of position error are calculated as an RMS which are derived in the Applanix POS MV Integrated Inertial GPS Navigator. The depth surface remains flawed due to tide and datum busts, however the uncertainty surface reflects the fact there are changing uncertainties for horizontal position. The uncertainties increase with water depth. The effect of dynamic uncertainties, on the depth surface, is minimal because the positions were derived in Post Processed Kinematic (PPK) mode, very accurate positioning is the result. The dynamic error estimates (from the PPK) were close to the a priori ones. Previous studies have demonstrated the effect of GPS satellite outage and the difference in depth surfaces when dynamic error is not used.<sup>5</sup>

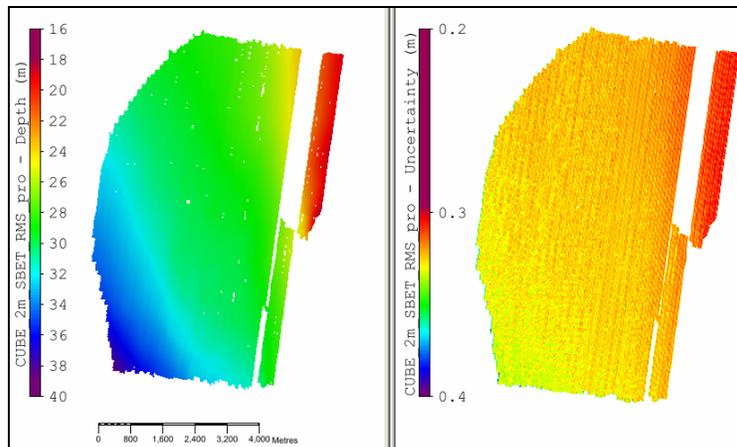
<sup>5</sup> Canter, Lockhart & Collins Caris 2005 , Error Estimation in Positioning and Orientation Systems



**Figure 4 – Standard CUBE Processing with heave  
Depth (on the left) & Uncertainty (on the right)**

### **Case 3: Altitude substituted for Heave with a priori estimates of position error**

Case 3, illustrated in Figure 5 below, shows the effect on the depth surface of using Altitude instead of Heave. A dramatic improvement in data coherency is seen. It is important to note that amount of human processor intervention in Case 1 through 3 was approximately the same. The result however is clearly better with the use of PPK Altitude. On the right hand side of figure 5 is the CUBE uncertainty surface. This surface is mostly flat and not showing any centralized problematic areas due to the fact that the static, a priori estimates of error have been used. The a priori estimates of error are taken from the manufacturer's specifications as was done in CASE 1 except for Altitude instead of Heave.



**Figure 5 – Altitude substituted for Heave:  
Depth Surface on left, Uncertainty Surface on right;  
A priori estimate of position error is applied**

#### Case 4: Altitude substituted for Heave with real estimates of position error

Case 4, illustrated in Figure 6 below, again shows the effect on the depth surface of using Altitude instead of Heave. A dramatic improvement in data coherency is seen. Again, it is important to note that amount of human processor intervention in Case 1 through 4 was approximately the same. The result however is clearly better with the use of PPK Altitude. As in Case 1 vs. Case 2, we do not see a big difference in the uncertainty surface when dynamic error is used instead of the manufacturer's a priori estimates. This is, as discussed above, because the data quality from PPK was excellent. However there are two small localized areas where there is an increase in the uncertainty layer. As stated before, the use of dynamic error will clearly highlight localized areas of sensor problems as opposed to a priori estimations coming from the vessel file.

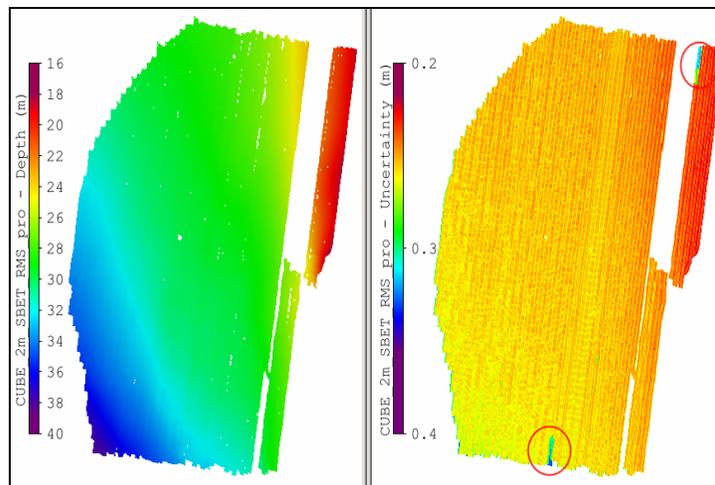


Figure 6 – Figure 5 – Altitude substituted for Heave: Depth Surface on left, Uncertainty Surface on right; Dynamic Estimates for Position error are applied

#### Extract Analysis

The plots above have shown the highest variations between processing modes to be found in the southern part of this data set. An Extract of this portion of the survey and differencing comparisons are presented below. The size of the extract area is **2200 by 1400 meters**.

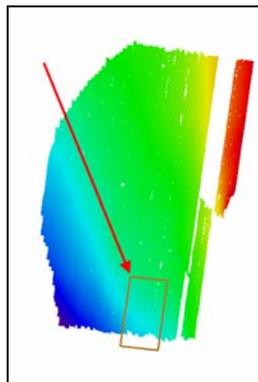


Figure 7 – Extract Area outlined in red triangle

## Case 1 vs. Case 2 Extracted Area - Processing with Heave

Although the large scale plots suggest that the depth differences between Case 1 and Case 2 are minimal, a zoom in on the extracted area does show some difference. Difference of standard processing with Static values from vessel file as compared to RMS values when Heave is applied is displayed below in Figure 8. Differences in depth are due to differences in problems in horizontal positioning. In the case where dynamic error is used the situation will be robustly handled.

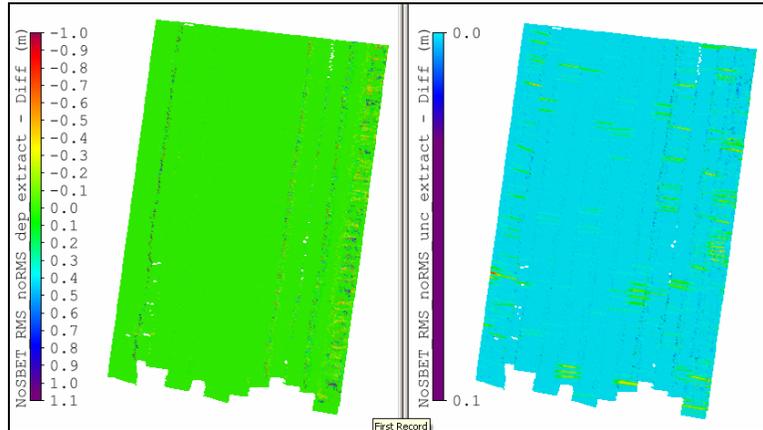


Figure 8 – Depth Surface (on left), Uncertainty Surface (on right): Standard processing with Heave; Dynamic Error vs. A priori

## Case 2 vs. Case 4 Extracted Area - Heave vs. Altitude

On the left side of Figure 9 we see differences in the depth surfaces in processed data where Altitude has been substituted for Heave. This difference is not just simply a static shift, but there are varying differences between successive passes.

We also see a significant localized difference in the use of the raw RMS as opposed to the processed RMS data. We know there are benefits in using dynamic RMS values as opposed to the a priori approach, but we also see that there are additional benefits in using the processed RMS values as well.

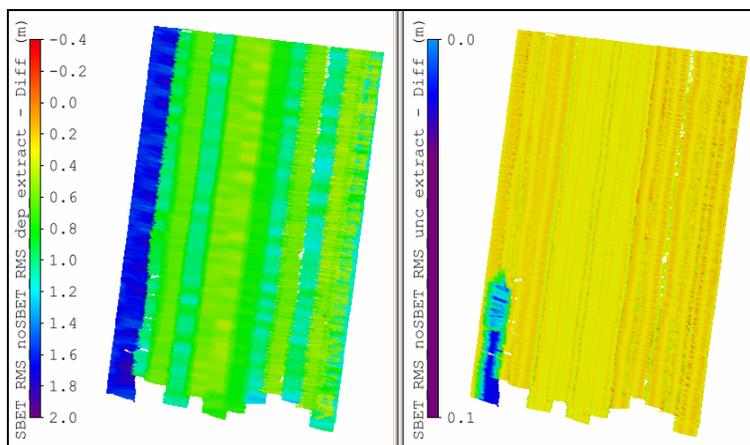


Figure 9 Heave vs. Altitude with Dynamic Error  
Depth Surface on left, Uncertainty Surface on right;

## IHO Order

Perhaps the most striking benefit of the application of Altitude and Dynamic Error in TPE and Cube is the IHO order classification which can be derived with equal processor/operator effort. The following slides illustrate IHO order classification based on depth difference of a tie line, with the main survey swaths, across the survey area. This was calculated by constructing a surface and comparing a tie line. Comparing a check line to the constructed CUBE surface is essentially a measure of repeatability and reliability. Figure 10 is for Case 1 with Heave, a tie line against the CUBE surface and we see that only 65-72% off the data is within IHO Special Order. 73-78% of the data is within IHO Order 1 requirements.

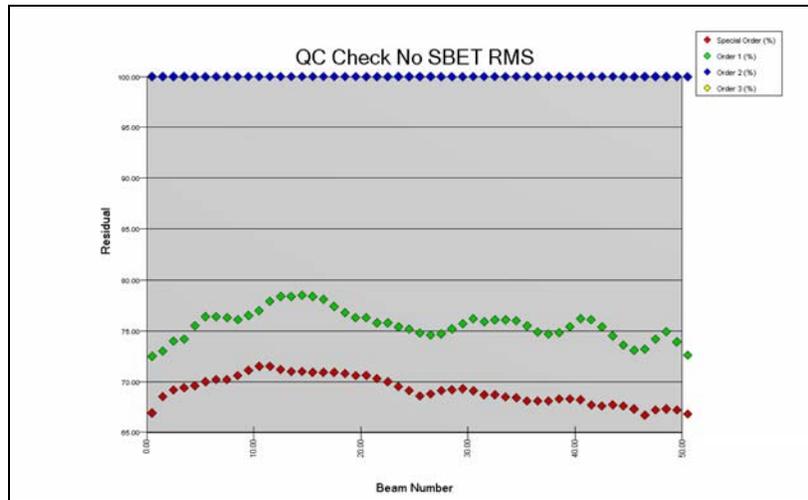


Figure 10 – CUBE surface vs. Tie Line with Heave

In Figure 11, we ran the same QC check as in CASE 1 only this time with SBET (Case 4 with Altitude) processing. We see that the repeatability and reliability increases. Now we see that the check line agrees with the CUBE surface to more than 80% in IHO Special Order terms and around 97% in IHO Order 1 terms.

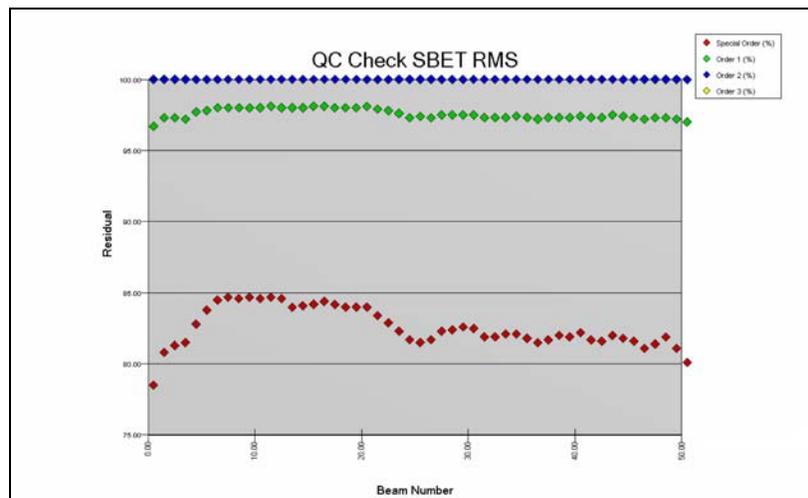


Figure 11 – CUBE surface vs. Tie Line with Altitude

## **Conclusion**

This paper clearly identifies the benefits of utilizing PPK Altitude in place of Heave and discusses the pros and cons of applying continuously updated sensor uncertainties. It was seen that the new implementation of TPE computation will allow for the modelling of changing sensor uncertainties throughout data collection. With auxiliary sensors, including the use of swath sonar, the associated uncertainties are constantly varying and it is prudent therefore to use these derived values within the TPE computation, to achieve a more robust result. More significantly in the cases presented in this paper the affect of Altitude in place of Heave on the depth surface is extreme. It was shown that with a similar effort of human processing involved a much better result could be obtained with Altitude.