Uncertainty Estimation of Historical Bathymetric Data from Bayesian Networks

Paul A. Elmore

Naval Research Laboratory, Mapping Charting and Geodesy Branch,

Stennis Space Center, MS 39529

David H. Fabre, Raymond T. Sawyer, and R. Wade Ladner

Naval Oceanographic Office, Bathymetry Databases Division,

Stennis Space Center, MS 39522

Objective and Approach

Objective

Produce a computationally efficient method for estimating bathymetric uncertainty of Naval Oceanographic Office DBDB-V* data

Approach

- Adapt Monte Carlo (MC) technique to Bayesian network (BN)
  - *Lower computation costs and inputs*
- Design and train network
  - *Implement MC on sample sets*
- Examine differences between MC & BN
  - *Does this approach appear valid?*

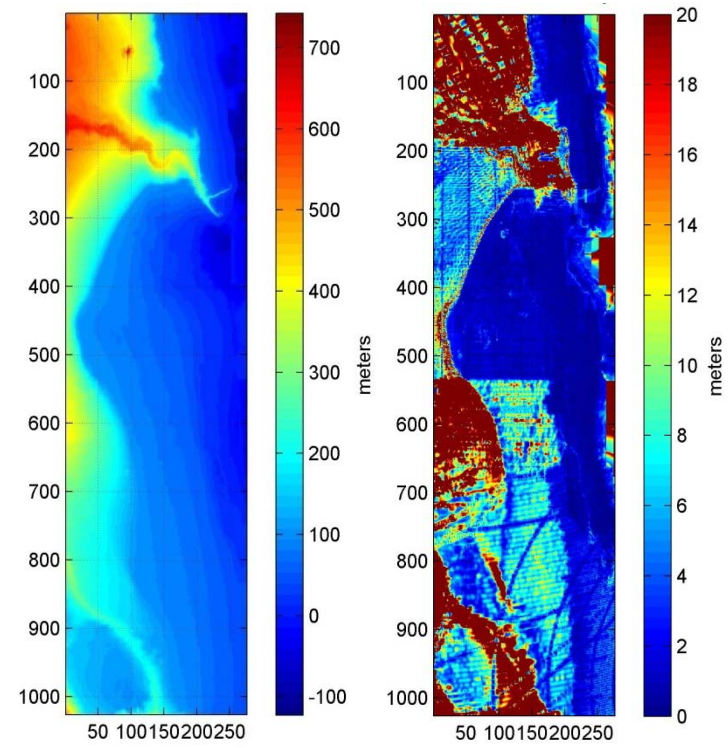


Figure : Fused bathymetry and uncertainty surfaces for the North Canyon Experiment (NCEX) data set. Units along the axis are pixels with each pixel being a 50 meter grid.

*Digital Bathymetry Database – Variable Resolution

Background and Motivation

State-of-the-art for uncertainty estimation of historic bathymetry data is based on Monte Carlo (MC) procedures by Jakobbson, et. al. (2002)*

- Navigation error, bottom slope, & sensor accuracy -> depth uncertainty.
- Requires original soundings data - very computationally intensive
- Not pragmatic to use on all soundings data held by NAVOCEANO.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. B12, 2358, doi:10.1029/2001JB000616, 2002

On the effect of random errors in gridded bathymetric compilations

Martin Jakobsson, Brian Calder, and Larry Mayer

Center for Coastal and Ocean Mapping and Joint Hydrographic Center, University of New Hampshire, Durham, New Hampshire, USA

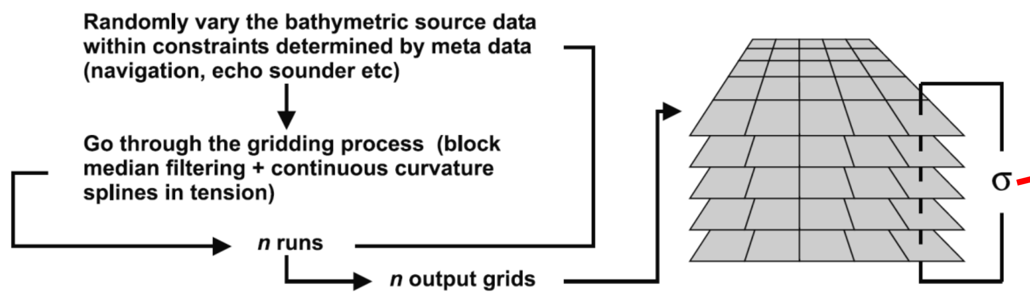
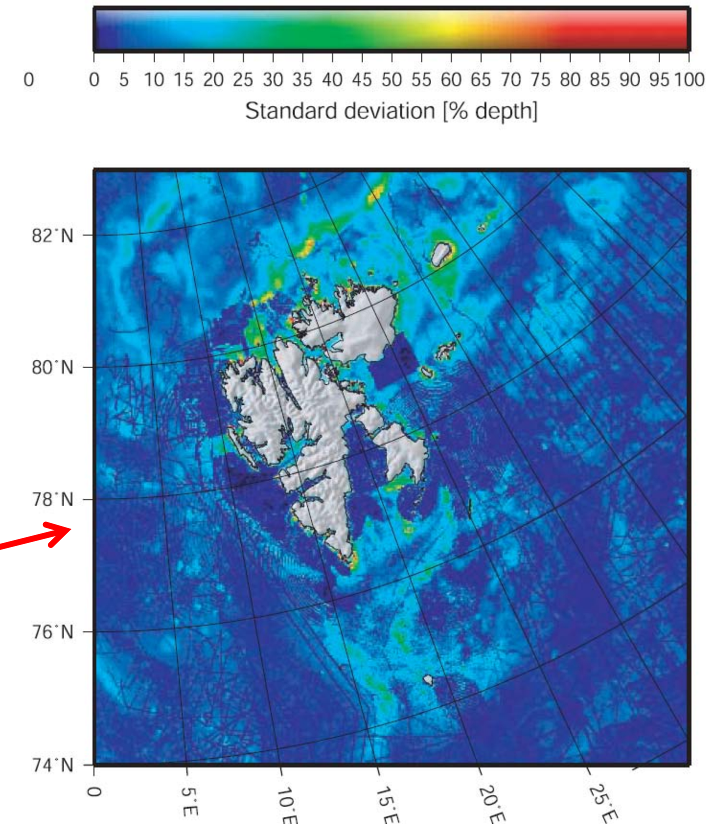


Fig. 3 from Jakobbson et al. (2002)

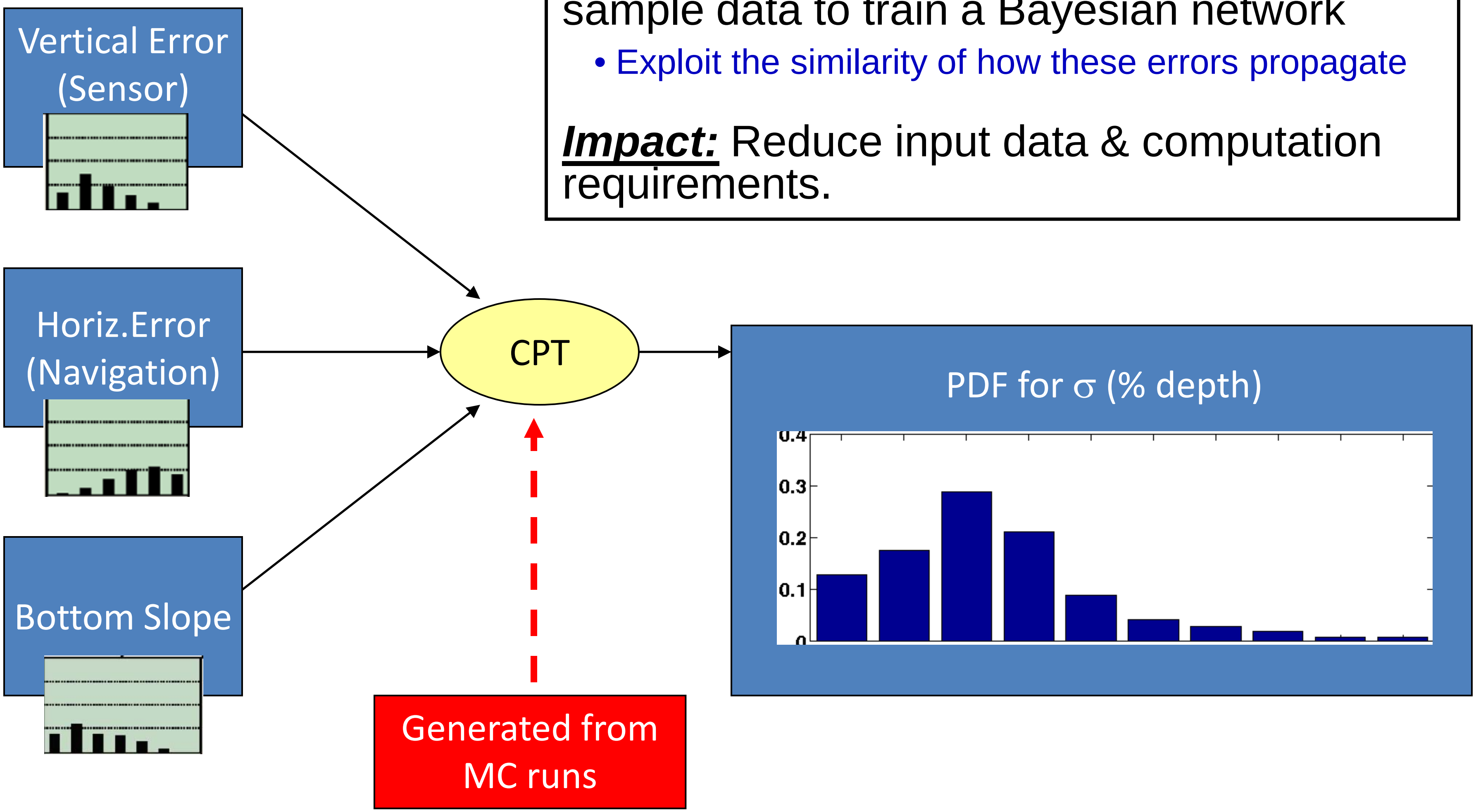


Solution Strategy - Bayes Net Adaptation

Strategy: Use Monte Carlo technique on sample data to train a Bayesian network

- Exploit the similarity of how these errors propagate

Impact: Reduce input data & computation requirements.



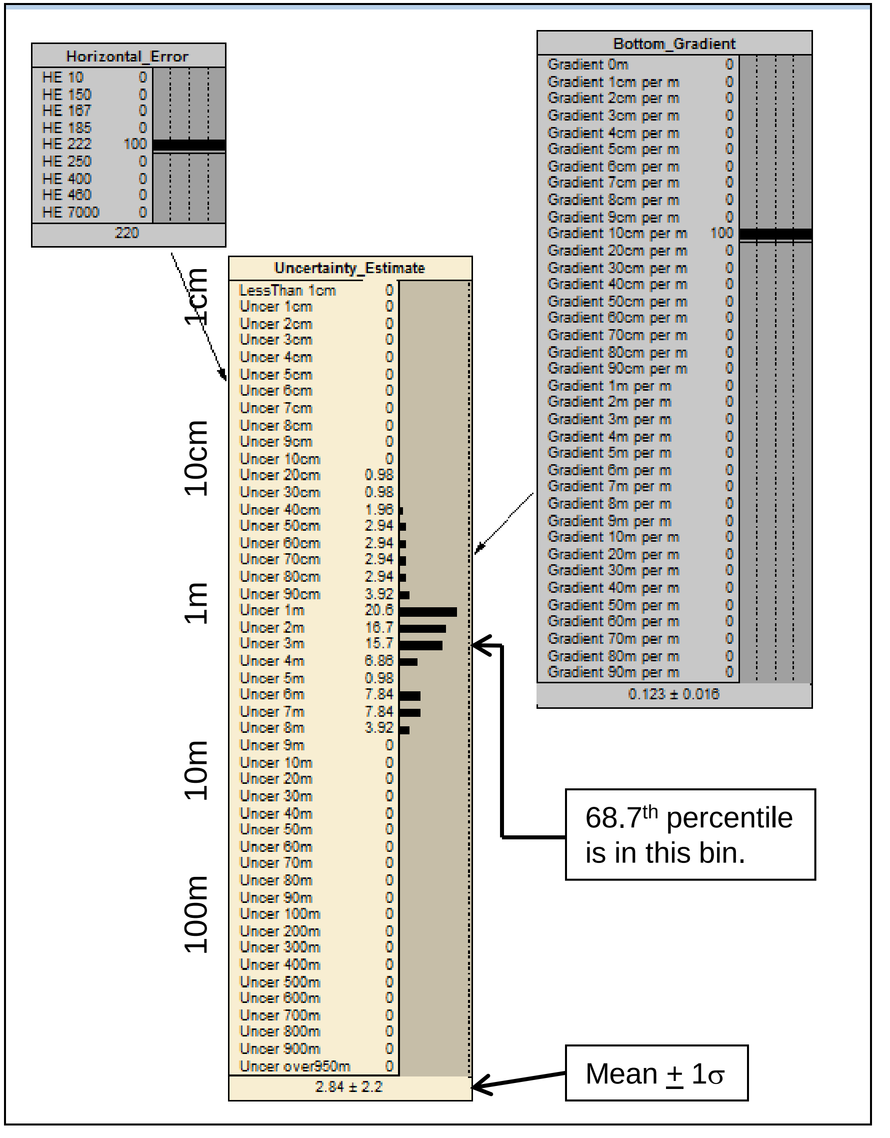
Bayesian Network Training and Use

- Train BN w/ Monte Carlo technique
  1. Tabulate applicable horizontal errors
  2. Monte Carlo procedure on error categories
  3. 2D histogram of possible uncertainties for CPT
  4. Repeat for each training area (Atlantic, Mariana Trench and Hawaii areas discussed here)

- Example BN to right
  1. Logarithmic scaling; one significant digit.
  2. Uncertainty estimate: pick 68.7th quantile

Table I: Horizontal Error Categories

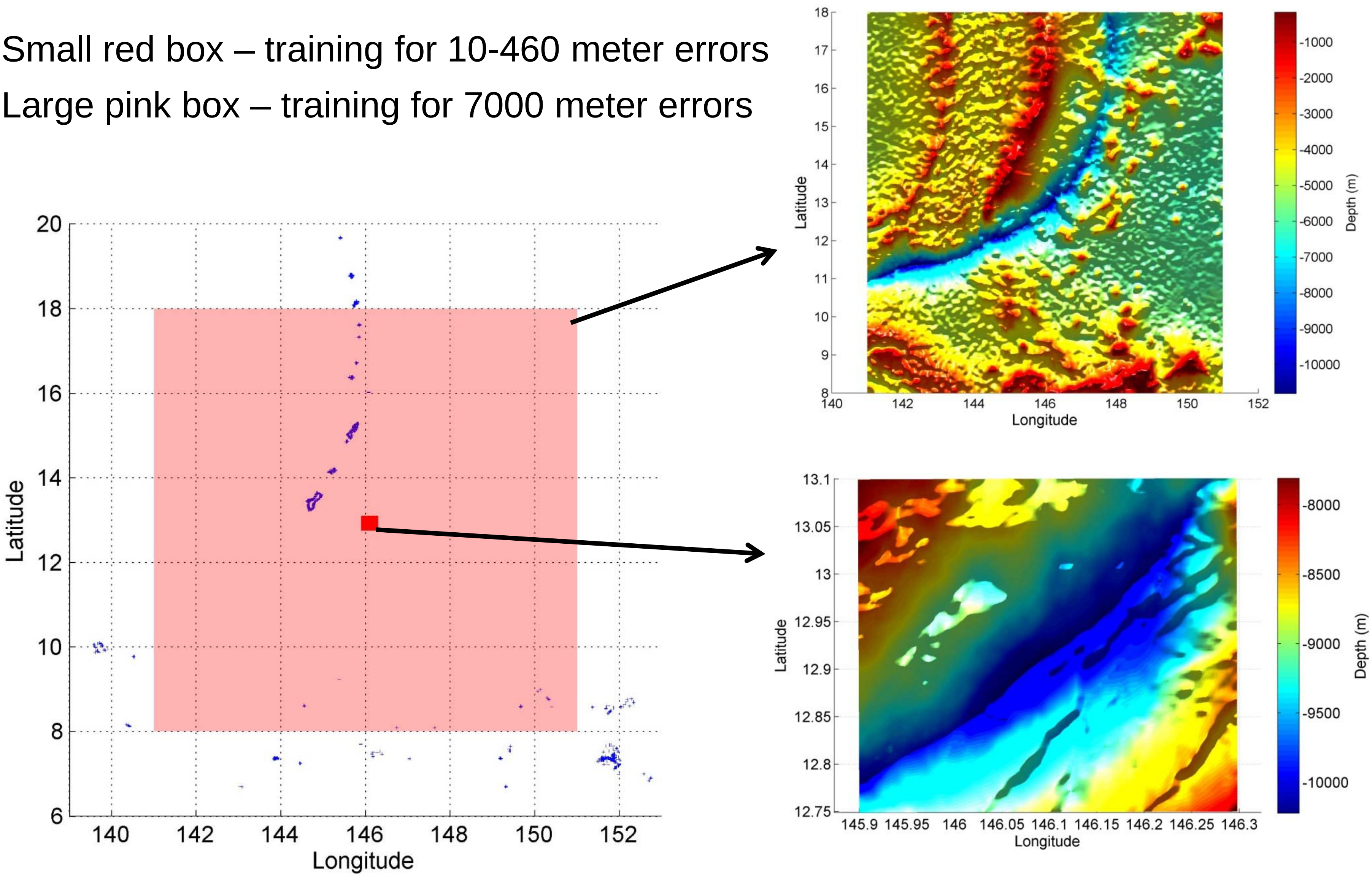
Navigation Mode	Accuracy	Navigation Mode	Accuracy
GPS/SINS (3 or more Satellites)	10-15 m	NAVSAT/Single Range LORAN/ SINS	250 m
GPS/DR (3 or more Satellites)	10-15 m	NAVSAT/ SINS	250 m
NAVSAT/Range Range LORAN/SINS	150 m	NAVSAT/ Single Range LORAN /DR	250 m
NAVSAT/Range Range LORAN/DR	167 m	NAVSAT/DR	400 m
NAVSAT/Hyperbolic LORAN/SINS	185 m	LORAN/ SINS LORAN/ DR	463 m
NAVSAT/Hyperbolic LORAN/DR	222 m	Satellite Altimetry	7000 m



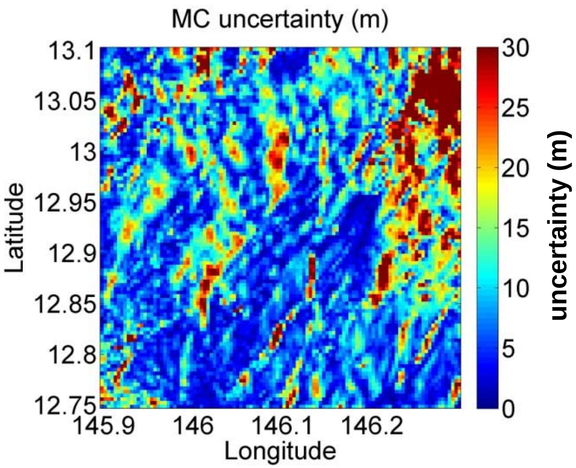
Training Area 1 – Mariana Trench

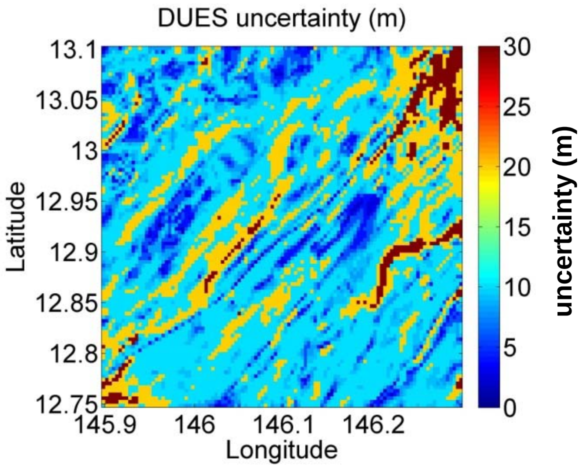
Small red box – training for 10-460 meter errors

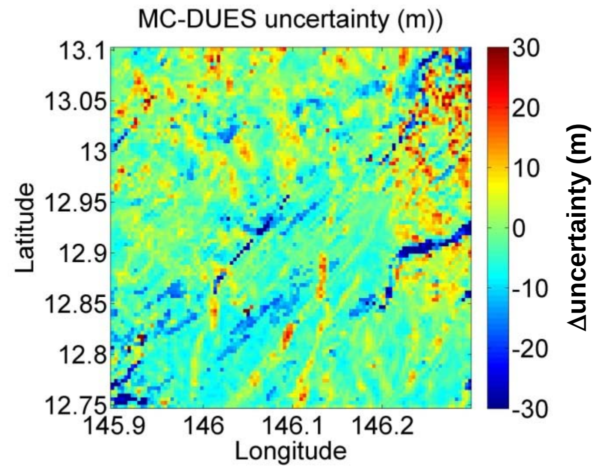
Large pink box – training for 7000 meter errors

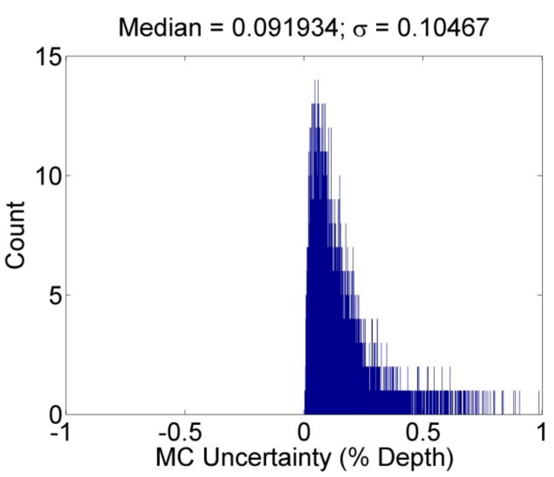


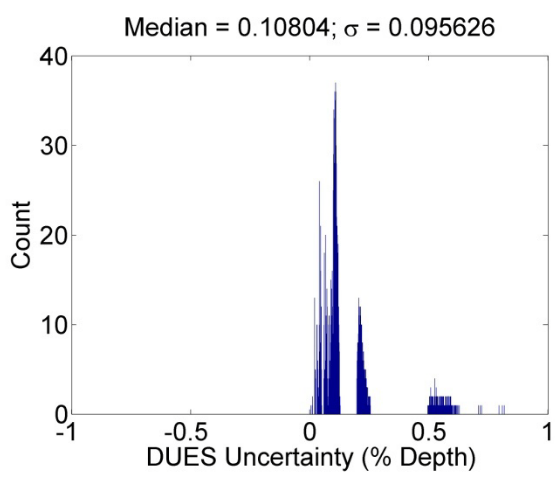
Training Area 1, 220m horizontal error

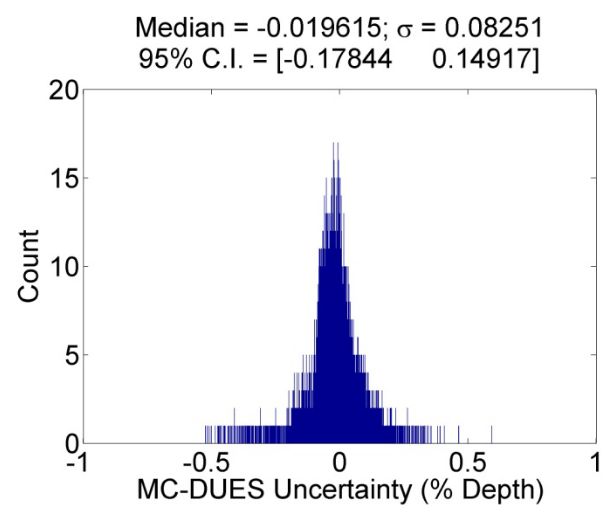




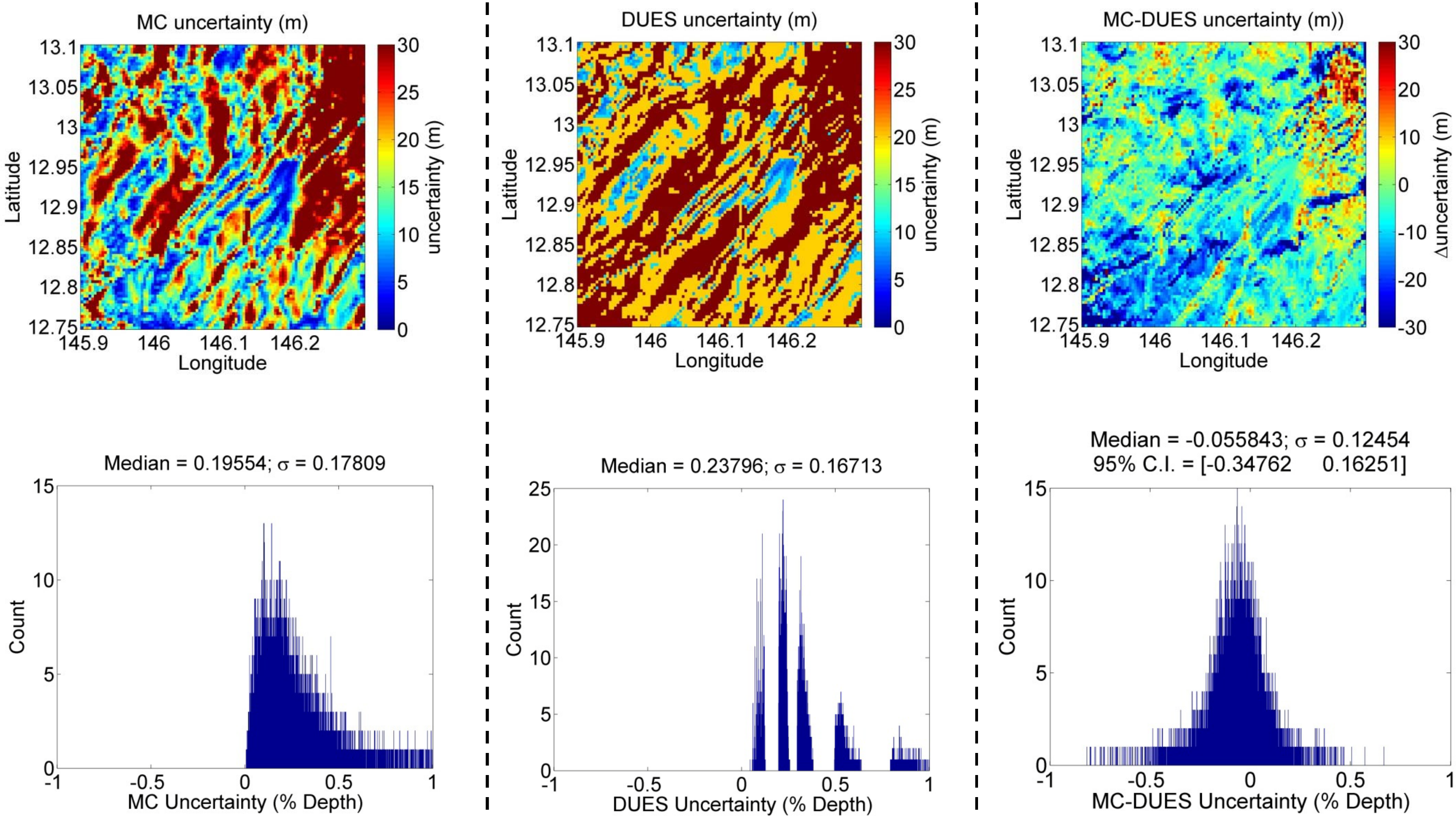




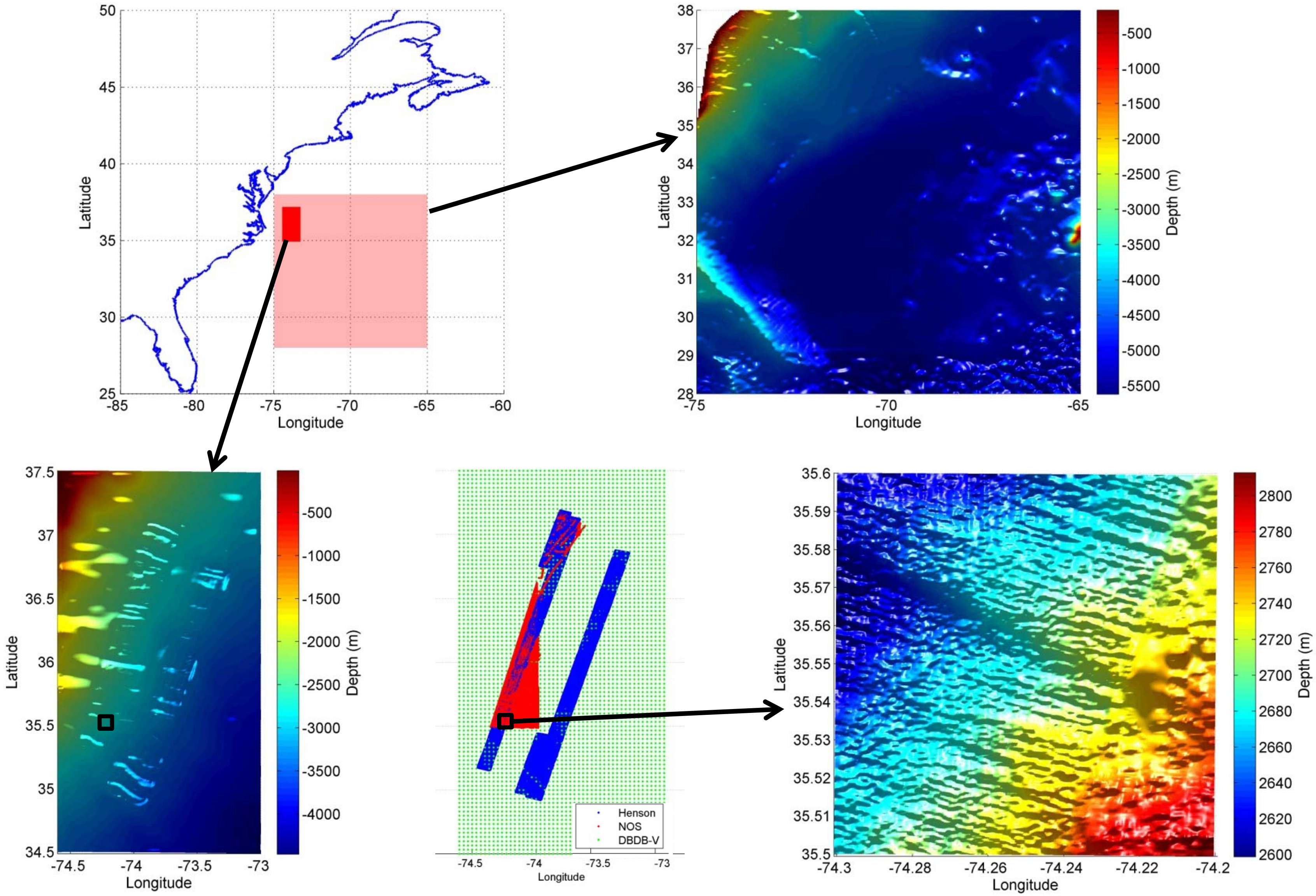




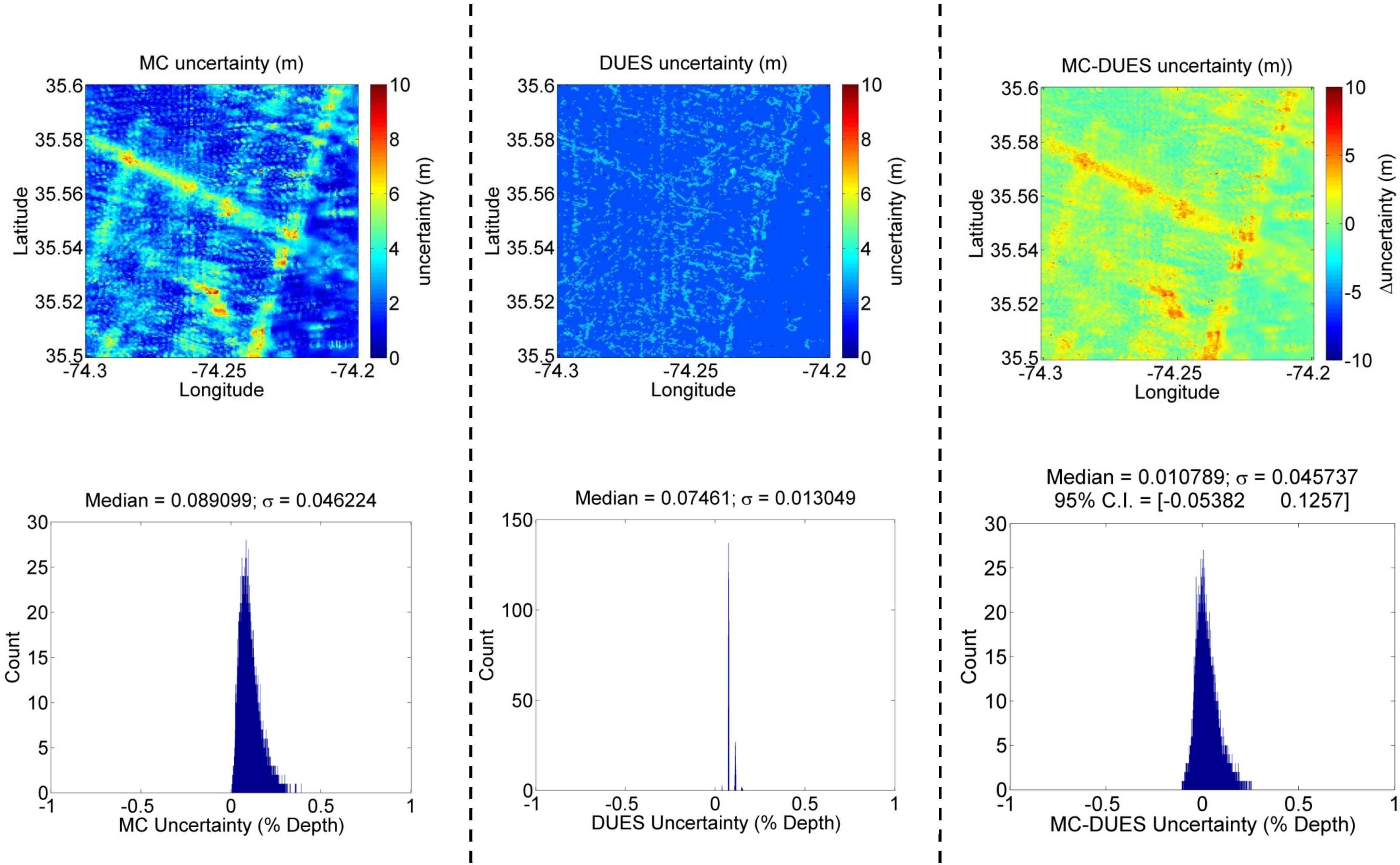
Training Area 1, 460m horizontal error



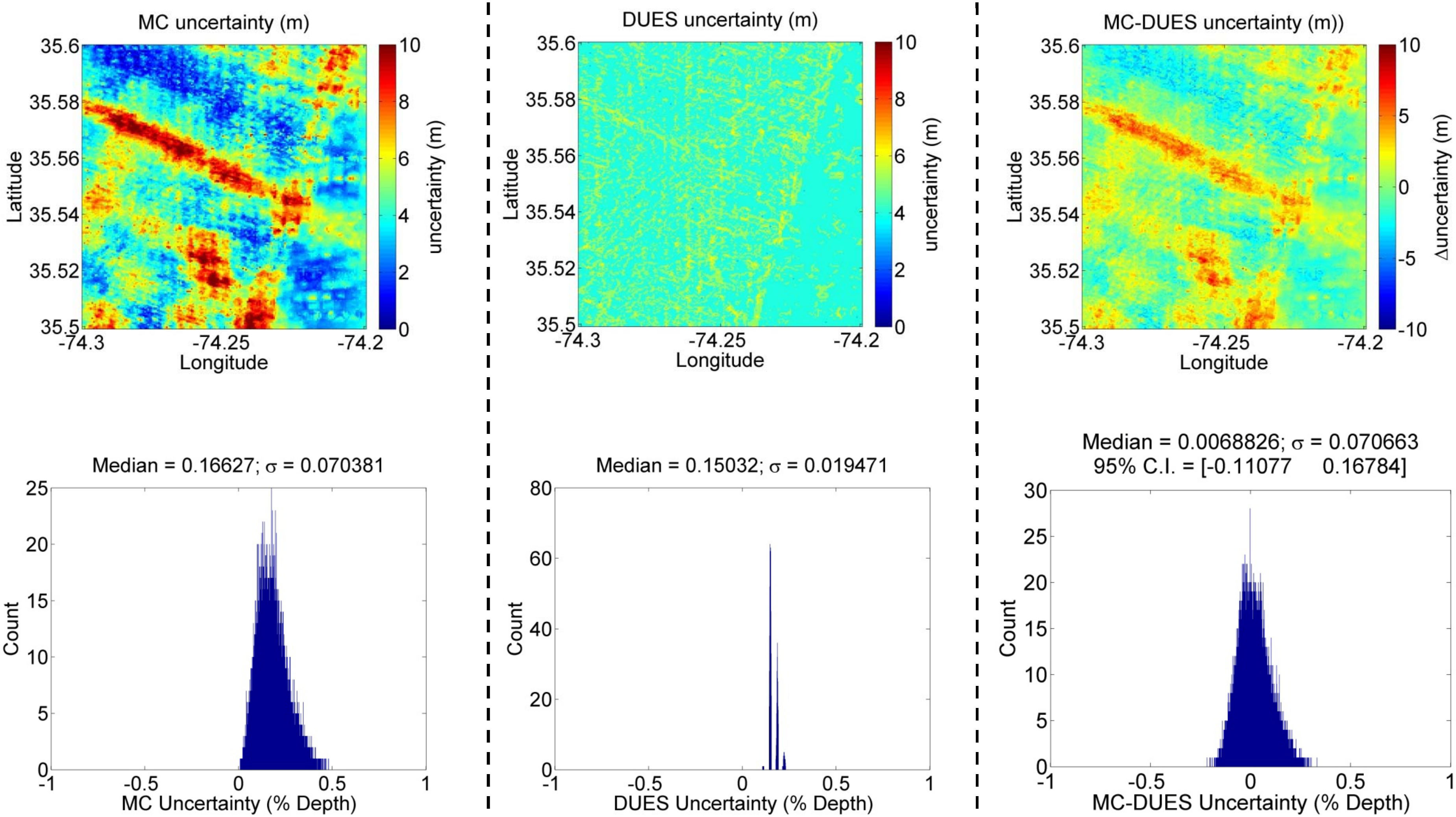
Training Area 2 – Atlantic Cont. Slope



Training Area 2, 220m horizontal error

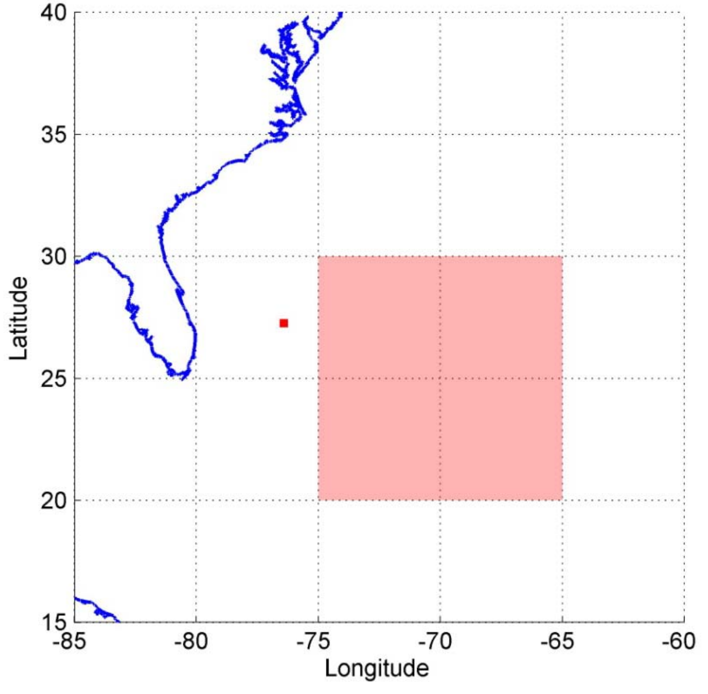


Training Area 2, 460m horizontal error

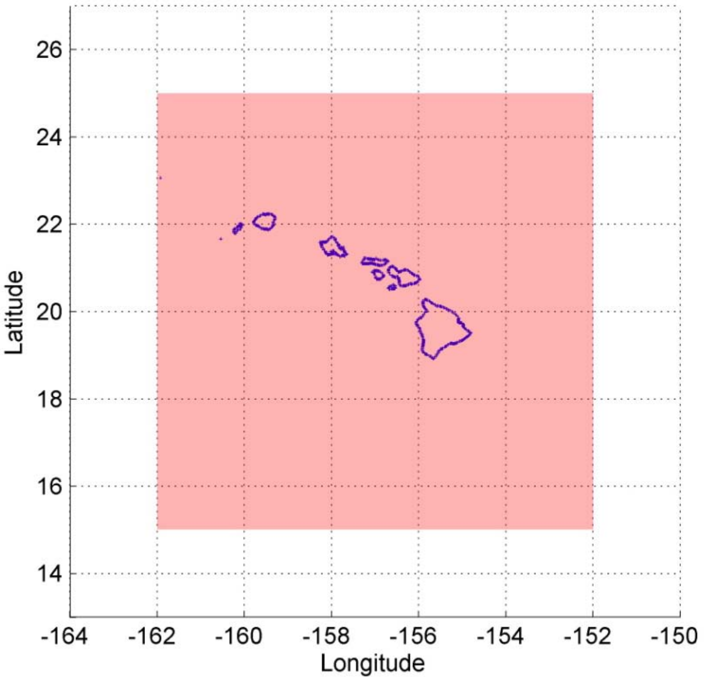


Training Areas 3 & 4

Training Area 3 - Atlantic Basin



Training Area 4 – Hawaiian Islands (altimetry only)

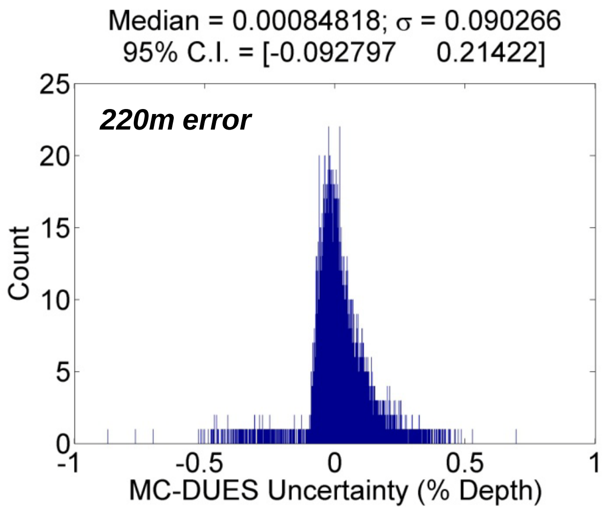


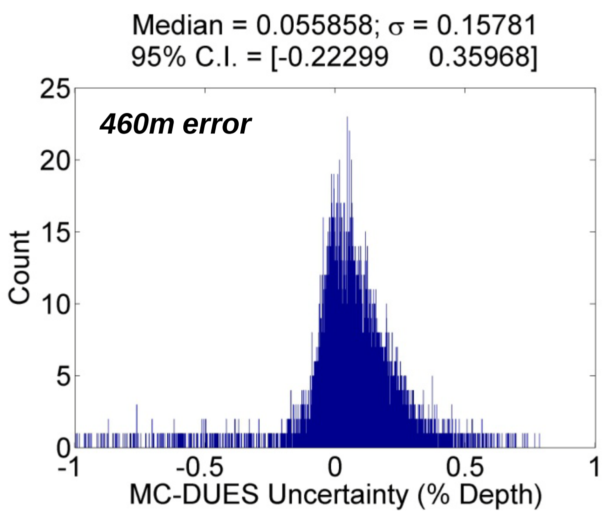
Small red box – training for 10-460 meter errors

Large pink box – training for 7000 meter errors

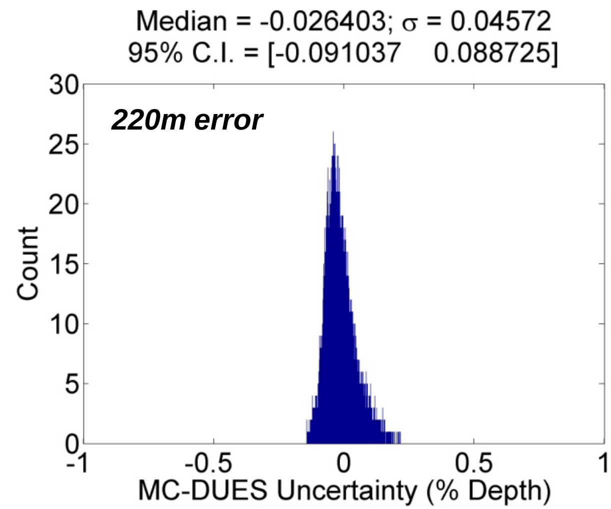
Ensemble CPT Results

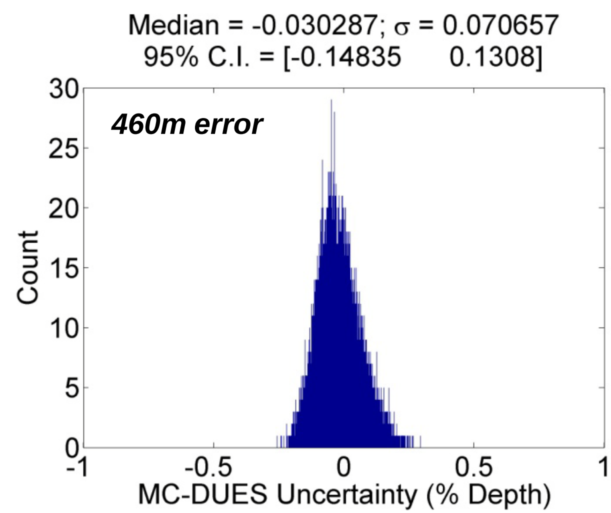
Training Area 1 – Mariana Trench





Training Area 2 – Atlantic Slope





Tabulated Differences

Differences as % depth between Monte Carlo and DUES estimators

Horizontal Error		self median	self st. dev.	self 95th C.I.	ensemble median	ensemble st. dev.	ensemble 95th C.I.
1. Mariana Trench							
10m	*0.04 ± 0.04*	-0.01	***0.03***	[-.068, .046]	0.02	***0.03***	[-.02, .09]
220m	*0.09 ± 0.1*	-0.02	***0.08***	[-.18, .15]	< 0.01	***0.09***	[-.09, .21]
460m	*0.2 ± 0.2*	-0.06	***0.12***	[-.35, .16]	0.06	***0.2***	[-.22, .36]
7 km	*2 ± 6*	0.3	***3.5***	[-7.5, 4.5]	0.2	***3.6***	[-3.6, 8.3]
2. Atlantic Slope							
10m	*0.02 ± 0.02*	-0.003	***0.016***	[-.021, .042]	-0.03	***0.02***	[-.07, .01]
220m	*0.09 ± 0.05*	-0.03	***0.05***	[-0.09, 0.09]	-0.09	***0.07***	[-.24, .03]
460m	*0.17 ± 0.07*	-0.03	***0.07***	[-0.15, 0.13]	-0.2	***0.09***	[-.30, .03]
7 km	*0.2 ± 6.7*	-0.01	***3.7***	[-1.2, 1.2]	-0.1	***3.6***	[-1.0, 1.4]
3. Atlantic Basin							
10m	*0.02 ± 0.08*	> -0.01	***0.05***	[-0.13, 0.04]	0.01	***0.05***	[-.10, .06]
220m	*0.1 ± 1.0*	-0.01	***0.4***	[-0.50, 0.77]	0.01	***0.4***	[-.2, 1.0]
460m	*0.2 ± 1.8*	-0.03	**0.8**	[-1.4, 1.2]	< 0.01	***0.7***	[-.7, 1.7]
7 km	*0.4 ± 8.0*	-0.1	***4.7***	[-8.7, 4.2]	0.1	***4.7***	[-8.6, 4.4]
4. Hawaii - Altimetry only							
7 km	*0.4 ± 3.8*	-0.1	***2.2***	[-3.3, 2.6]	-0.1	***2.5***	[-5.6, 1.5]

Worst Case σ's
10m - 0.05%
220m - 0.2%
460m - 0.8%
7 km - 4.7%

Questions?

Summary

Produced a computationally efficient method for estimating bathymetric uncertainty for DBDB-V

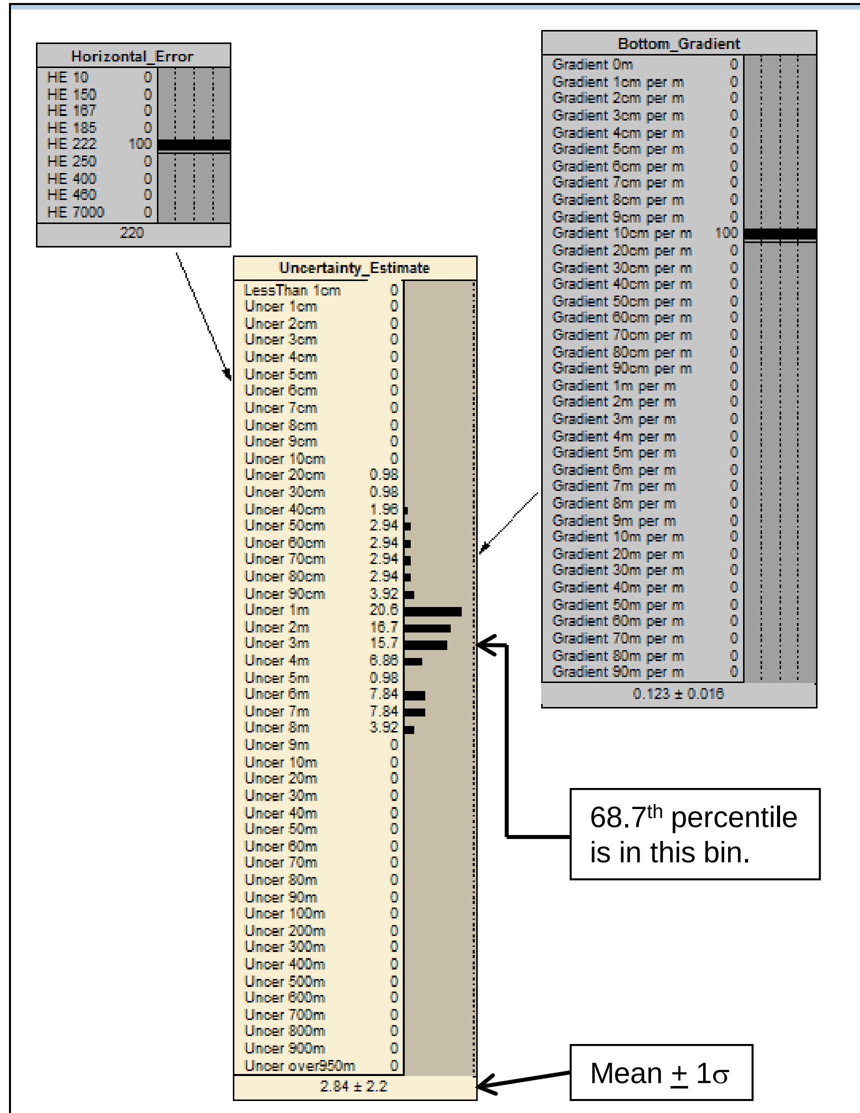
Approach

- Adapted Monte Carlo (MC) technique to Bayesian network (BN)
  - *BN implementation is an extension of the Monte Carlo technique of Jakobsson et al.*
- Designed & trained network using MC approach
  - *BN was then interfaced inside a larger automated system to estimate uncertainty*
- Examined differences between MC & BN est.
  - *Differences were at worst ~8/10th of one percent of water depth when soundings data were used*

Conclusion

BN approach appears preliminarily to be a valid approach to bathymetric uncertainty estimation.

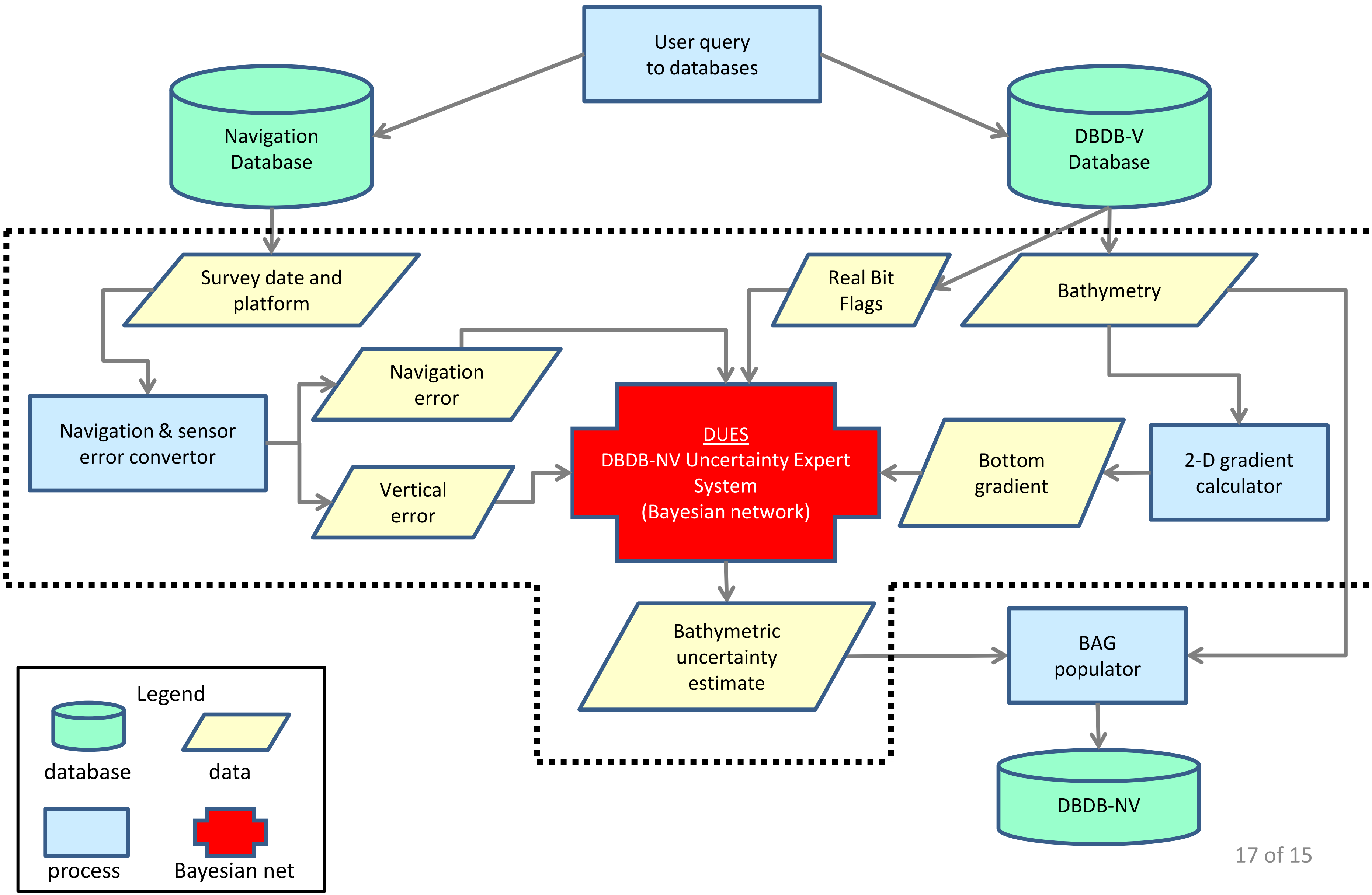
- *Further validation required for flatter areas and with more data sets.*



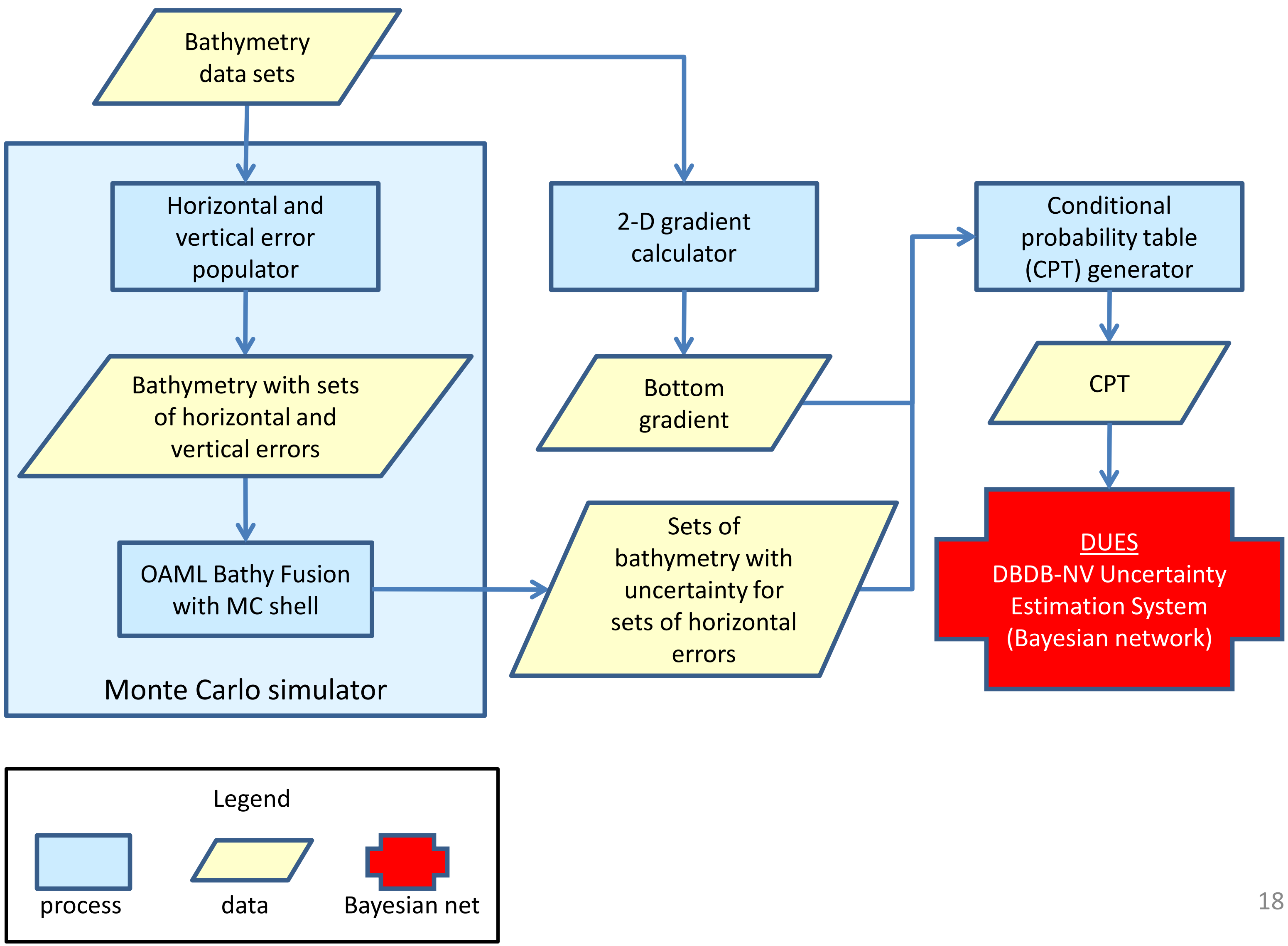
process Bayesian net

Extra Slides

Operational Concept

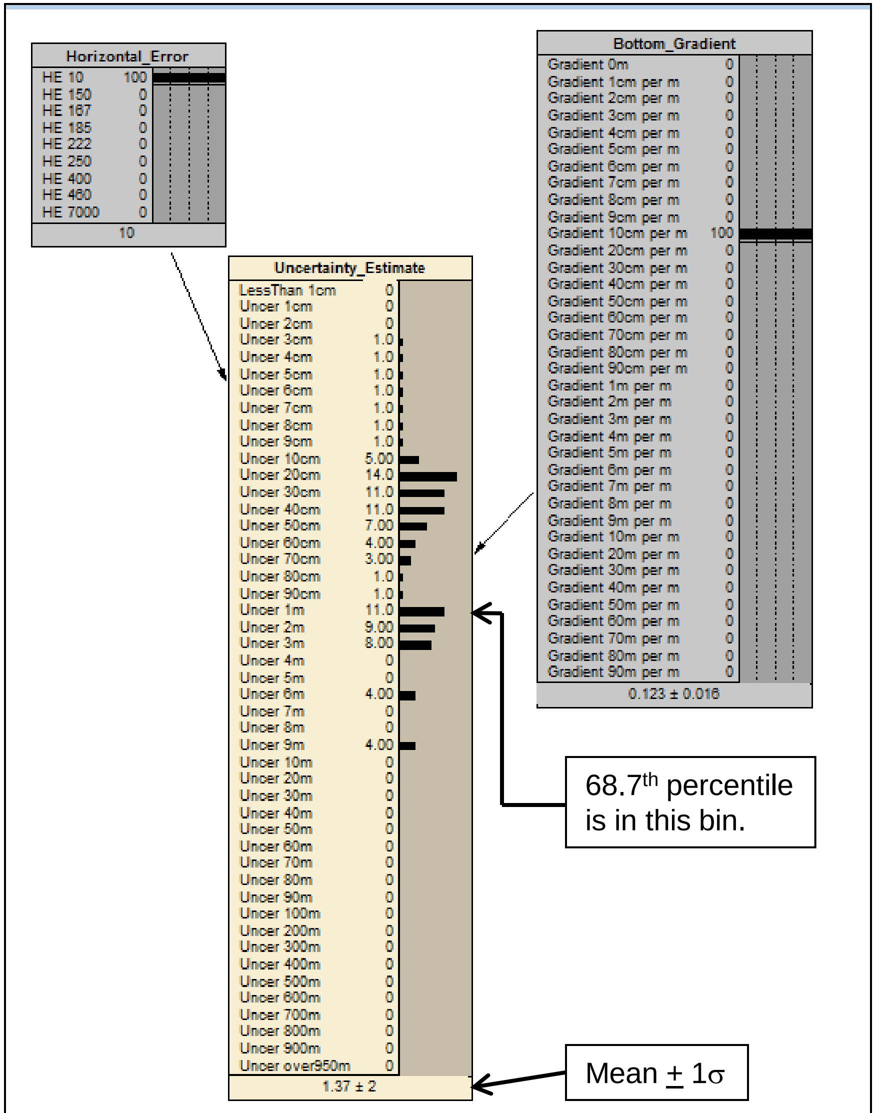


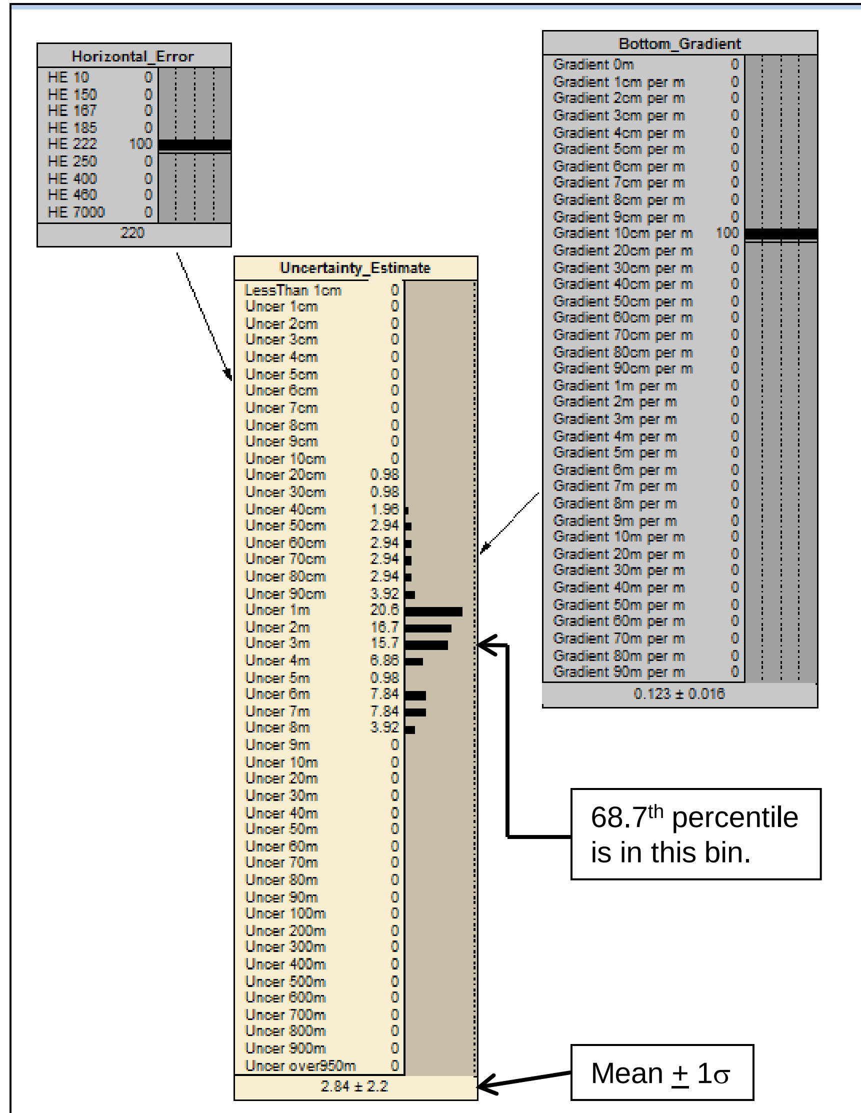
DUES Algorithm training



Gradient = 0.1 m/m

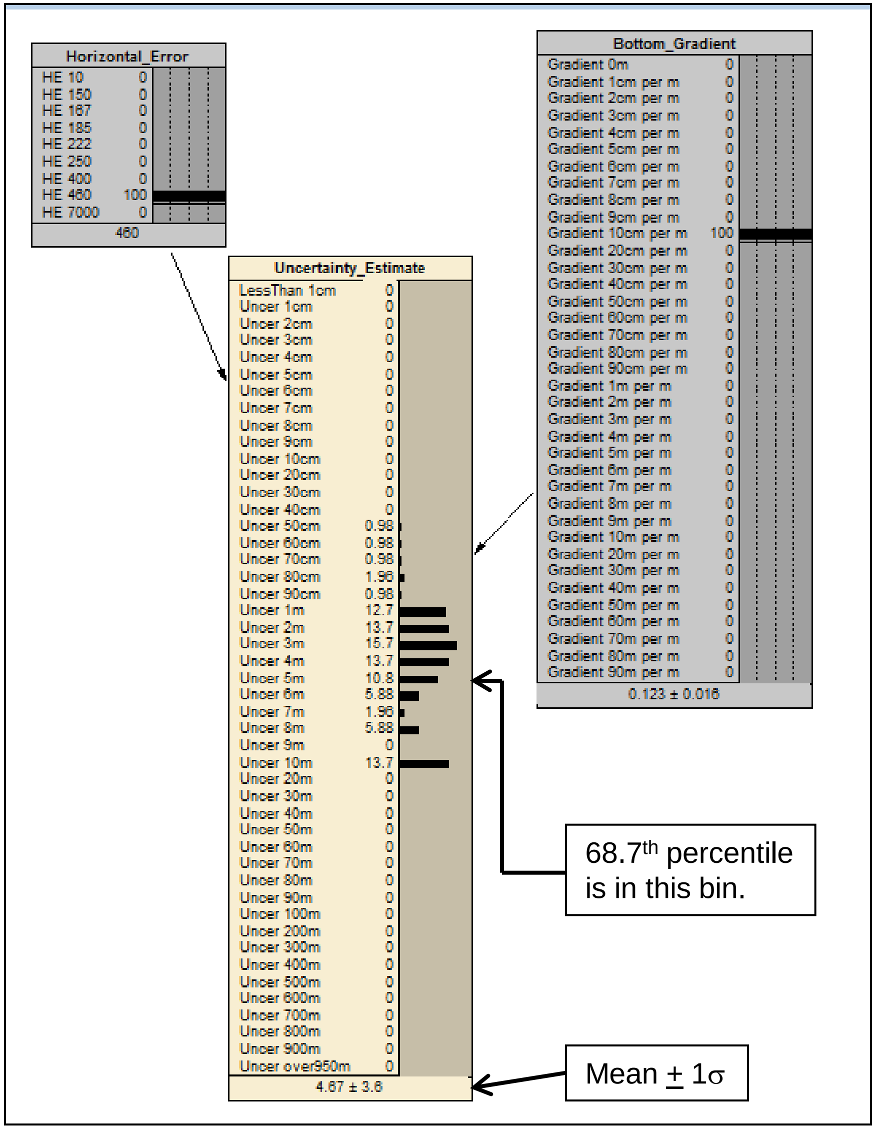
Horizontal Errors = 10 m & 220 m

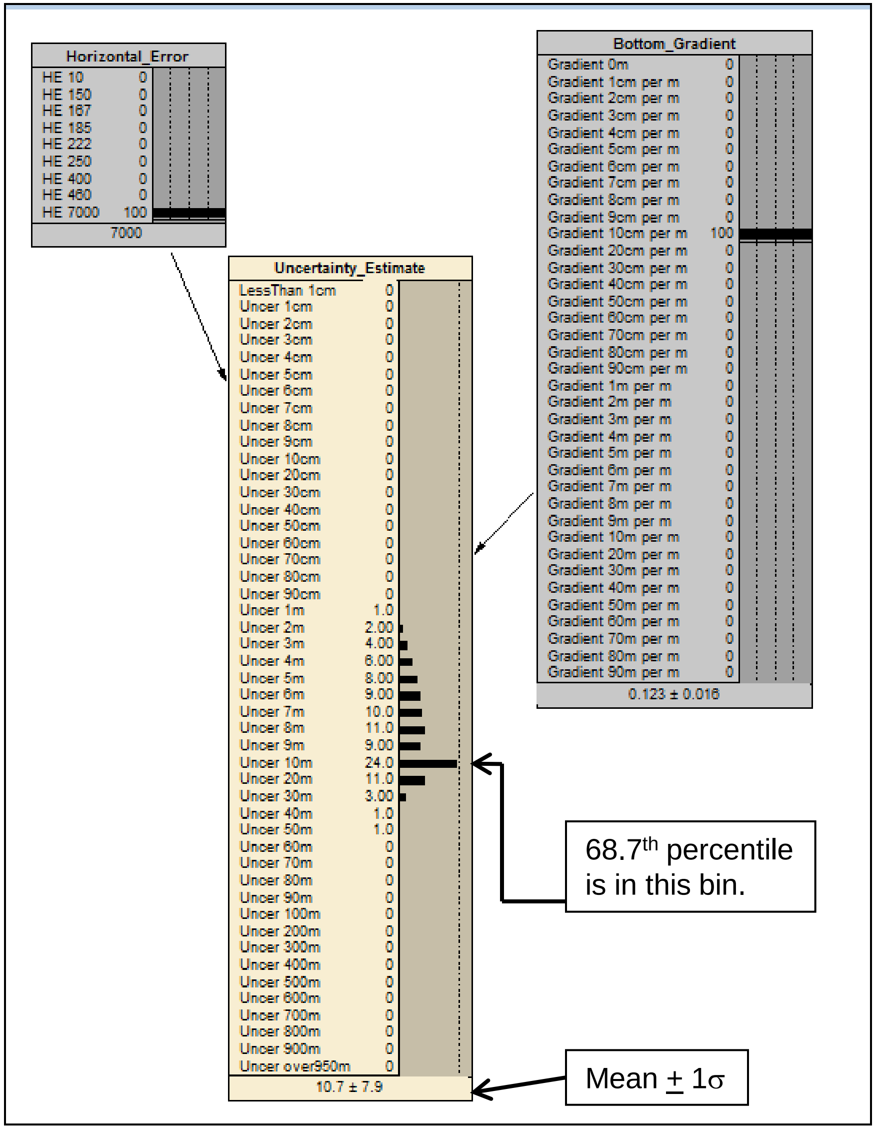




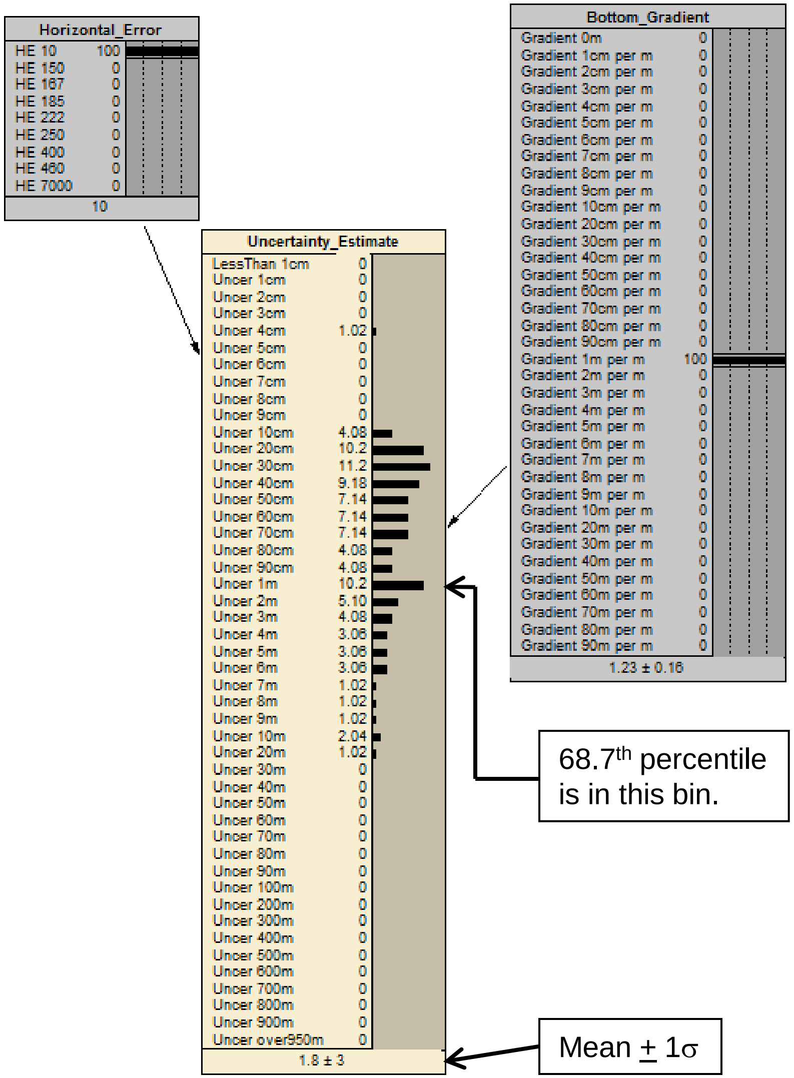
Gradient = 0.1 m/m

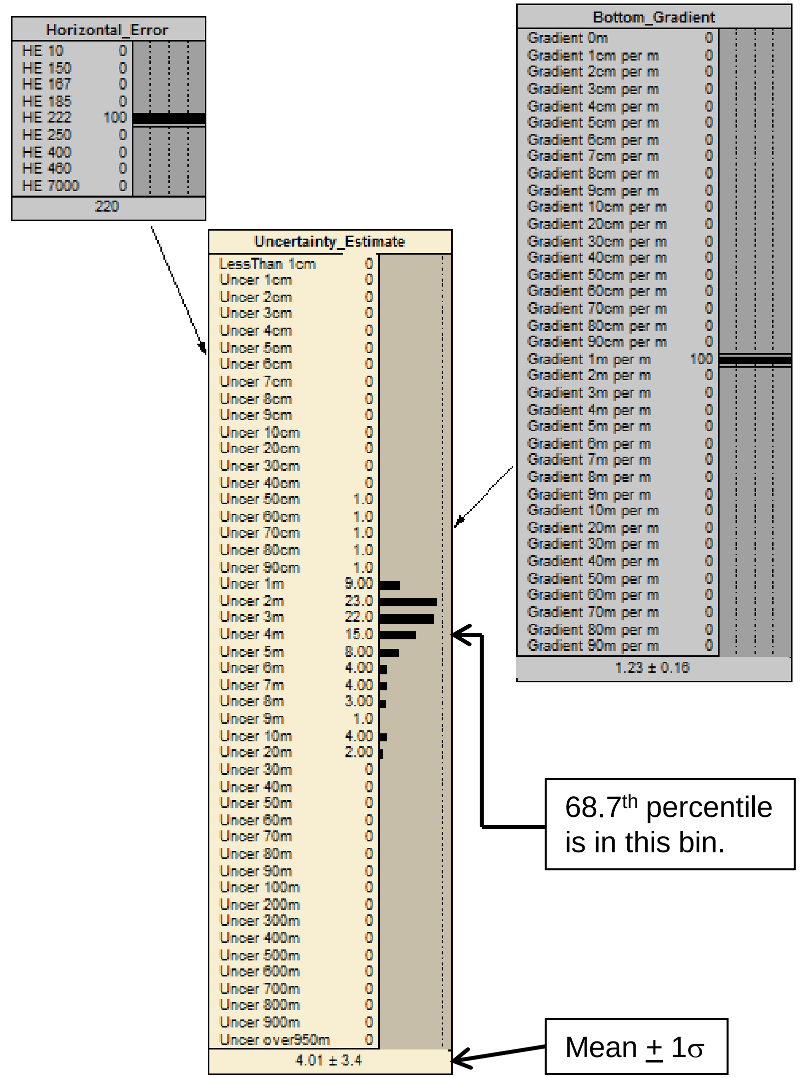
Horizontal Errors = 460 m & 7000 m



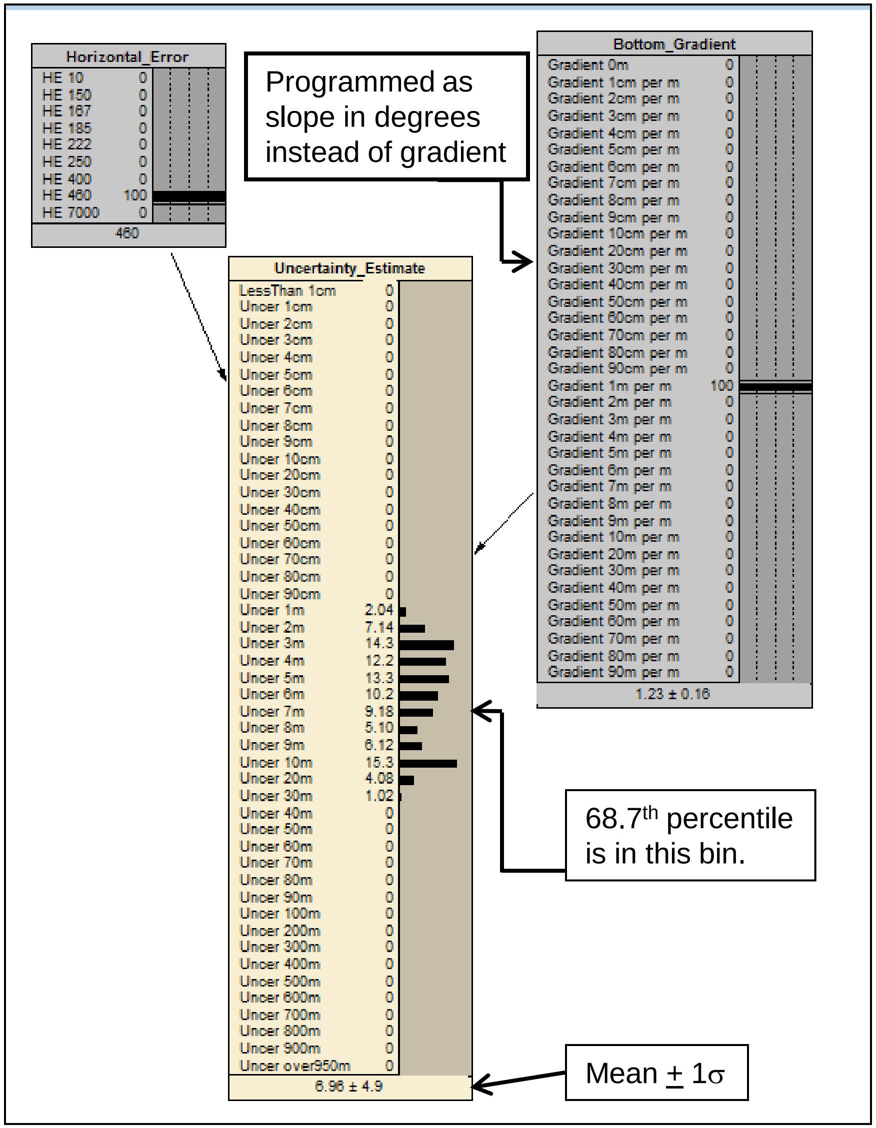


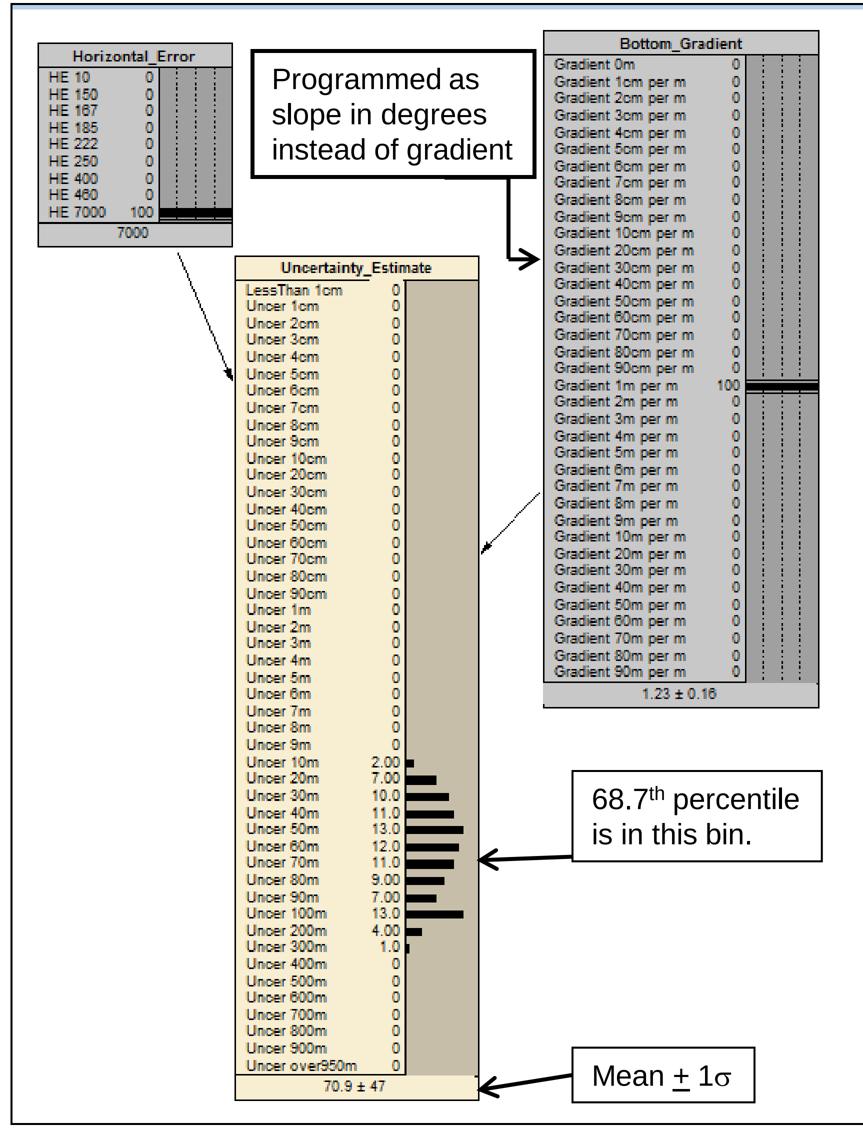
Gradient = 1.0 m/m
Horizontal Errors = 10 m & 220 m



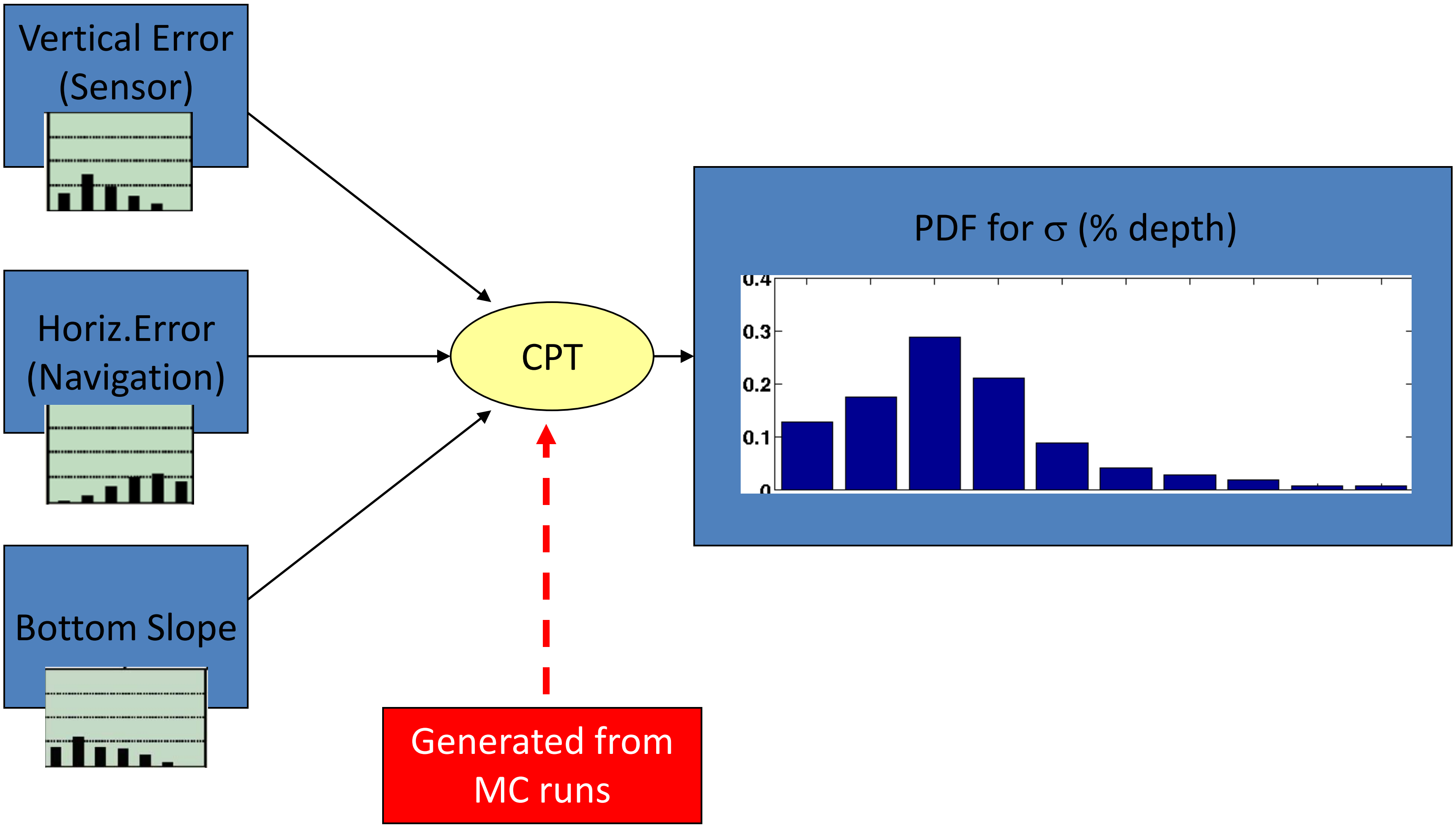


Gradient = 1.0 m/m
Horizontal Errors = 460 m & 7000 m



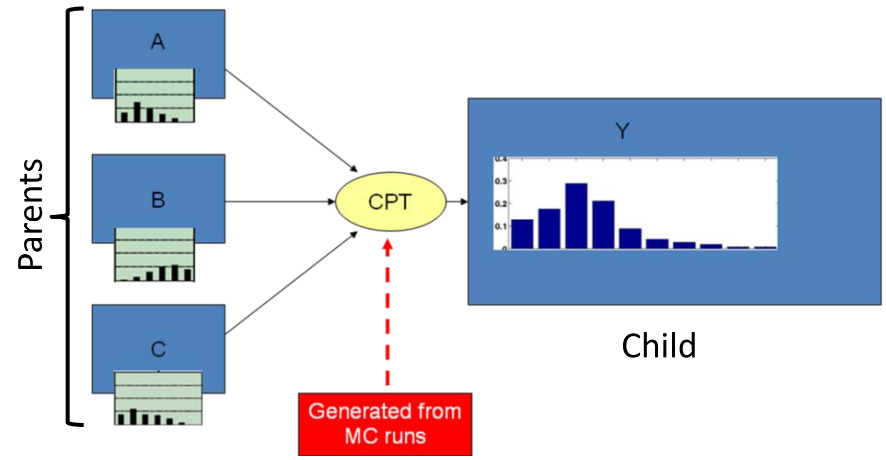


Bayesian Net Adaptation



Bayesian Network Overview

- ***BN Strategy***: Exploit the similarity of how these errors propagate
  - *Use BN to estimate errors for other data with similar systems and bottom slopes*
- BN reduces input data and computation requirements
  - *Uses probabilistic estimates and rules of statistics for computations.*
  - *Conditional probabilities link parent nodes (A, B, C, etc.) to child node Y*
  - *Conditional probability tables (CPT's) store conditional probabilities*
  - *Parent nodes are histograms of their variables*
  - *Child histogram is a weighted sum of the conditional probabilities.*



Nodes *A*, *B*, and *C* are parents of node *Y*, meaning that *A*, *B* and *C* collectively cause effect *Y*.

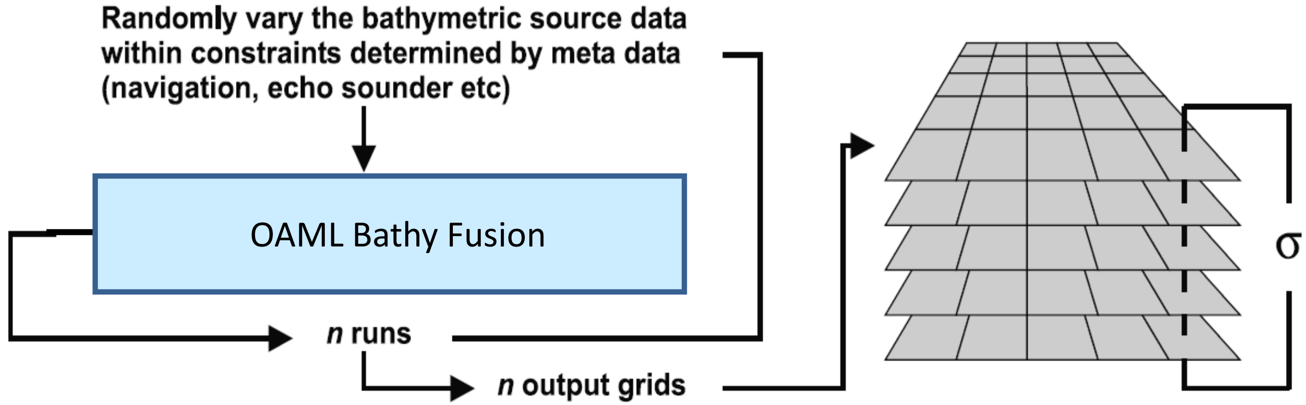
- A, B, C only have one bin populated

$$P(Y = y) = P(Y = y \mid A = a, B = b, C = c)$$

- A, B, C only have multiple bins populated

$$P(Y = y_i) = \sum_j \sum_k \sum_l \{P(Y = y_i \mid A = a_j, B = b_k, C = c_l) \times P(A = a_j) P(B = b_k) P(C = c_l)\}$$

Monte Carlo Training



(Adapted from Jakobbson et al. (2002) *JGR,* VolB12, art2358)

- Uncertainty assessed from Monte Carlo simulations
  1. Perturb sounding positions "*n*" times
     - *Gaussian distribution of perturbed positions*
     - *Horizontal/navigation positioning error = 1σ of Gaussian perturbation*
  2. Obtain standard deviation of the "*n*" bathymetry layers
  3. Change horizontal error to next navigation error and repeat 1 & 2
  4. Create CPT of standard deviations with horizontal error and slope using bivariate histogram at end of simulations.