New Approaches for Evaluating Lidar-Derived Shoreline

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NOAA/NGS Coastal Mapping Program

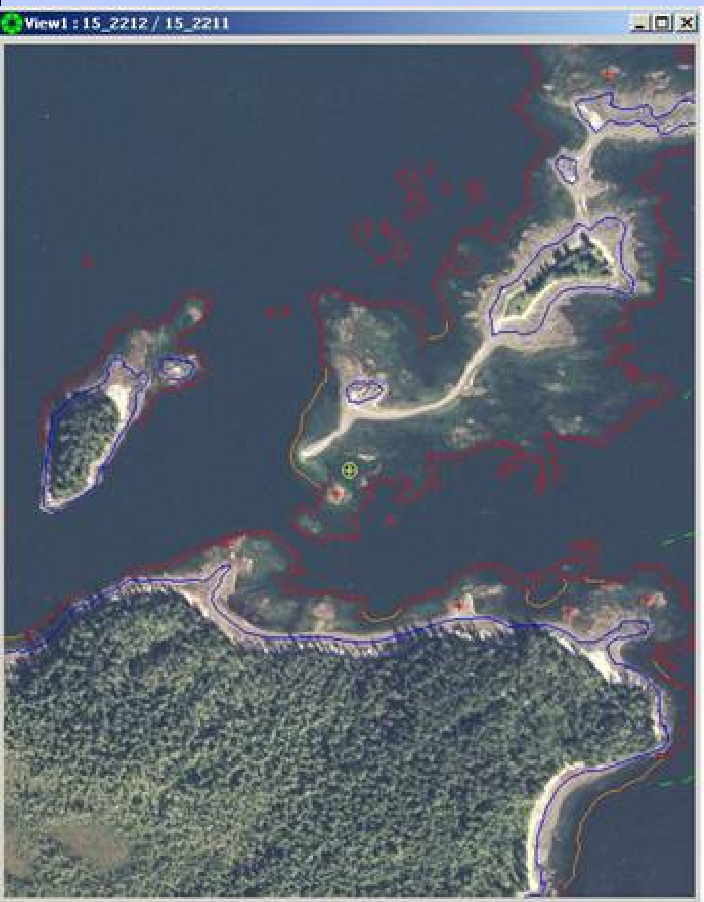
- Mandate: provide accurate, consistent, up-to-date National Shoreline
- Depicted on NOAA nautical charts
  - Treated as legal shoreline by many US agencies
- Other uses:
  - Coastal management
  - Coastal science
    - Understanding and responding to threats of climate change

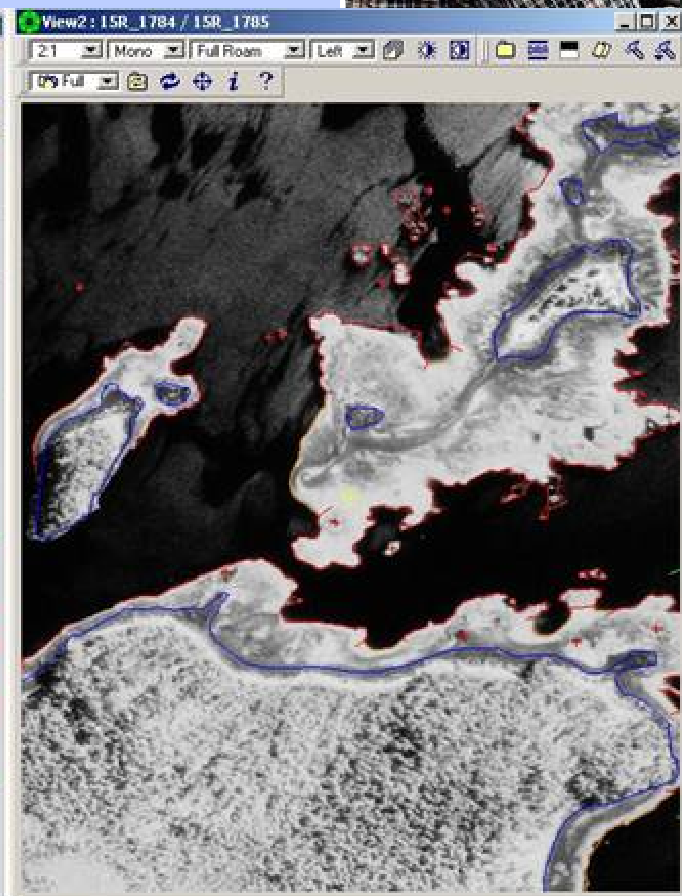
Conventional Method of Shoreline Mapping:

Stereo compilation from tide-coordinated aerial imagery

RGB imagery

IR imagery

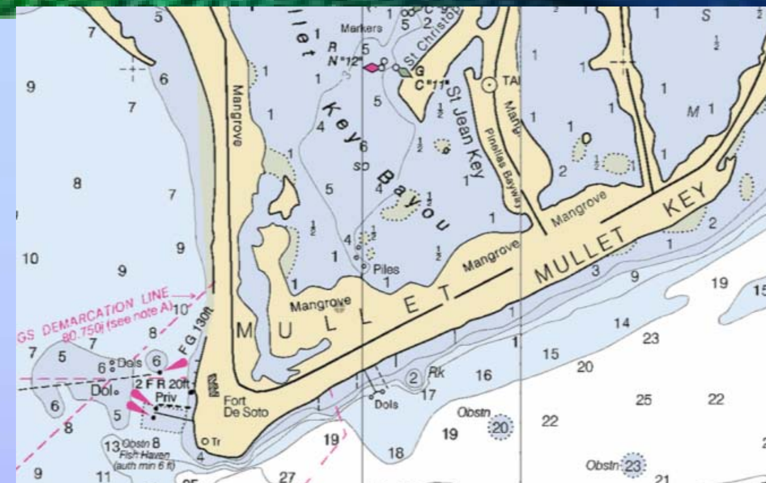




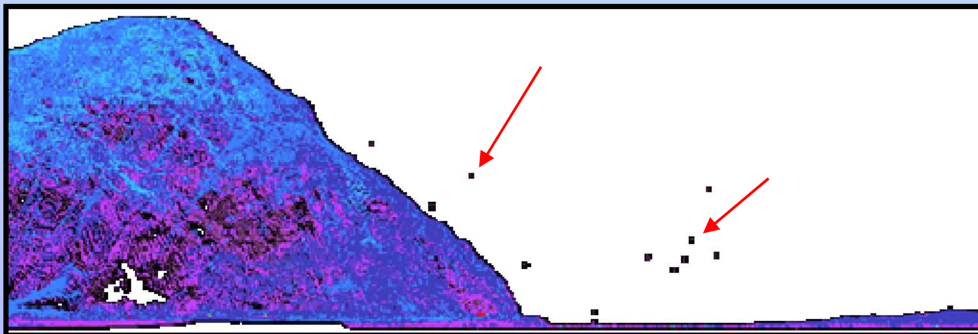
Benefits of Lidar-Derived Shoreline

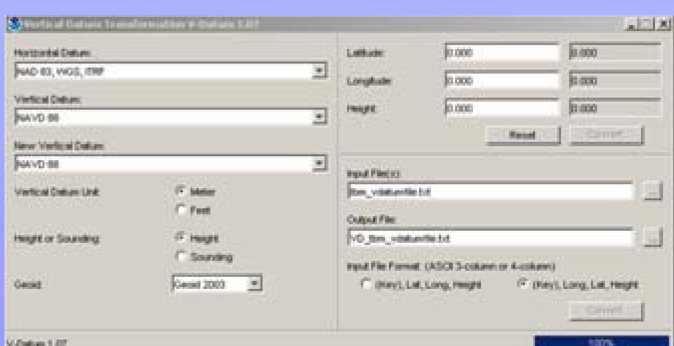
- Provides consistent, non-interpreted shoreline
  - Minimizes variability and subjectivity
- Tide-coordination requirements are not as stringent as with photogrammetric methods
- Can (*theoretically*) enable multiple tidally-based shorelines (e.g., MHW & MLLW) to be derived from a single dataset
  - But typically very difficult in practice!

Lidar Shoreline Extraction

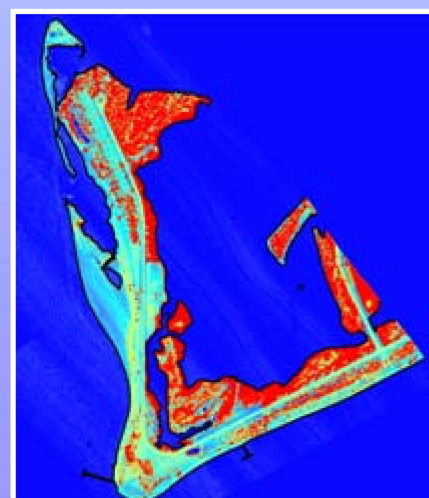


Edit Lidar Point Cloud





VDatum



Contour Shoreline from DEM

Editing, Attribution, and QA/QC

Lidar-Derived Shoreline Uncertainty Analysis

- Why do we need uncertainty analysis?
  - Produce accuracy metdata
  - Needed to satisfy the requirements of IHO S-44
  - Inform internal policy decisions
    - Where and when to collect lidar
    - Acquisition and processing guidelines/SOPs
    - Evaluating methods of achieving future improvements in efficiency and/or accuracy
  - Enable uncertainty analysis in downstream products
    - E.g., shoreline change rate estimates
    - Since coastal science is increasingly being used to inform policy makers, it is our responsibility, as mapping scientists, to provide good uncertainty analyses in a readily-understandable manner!

Methods

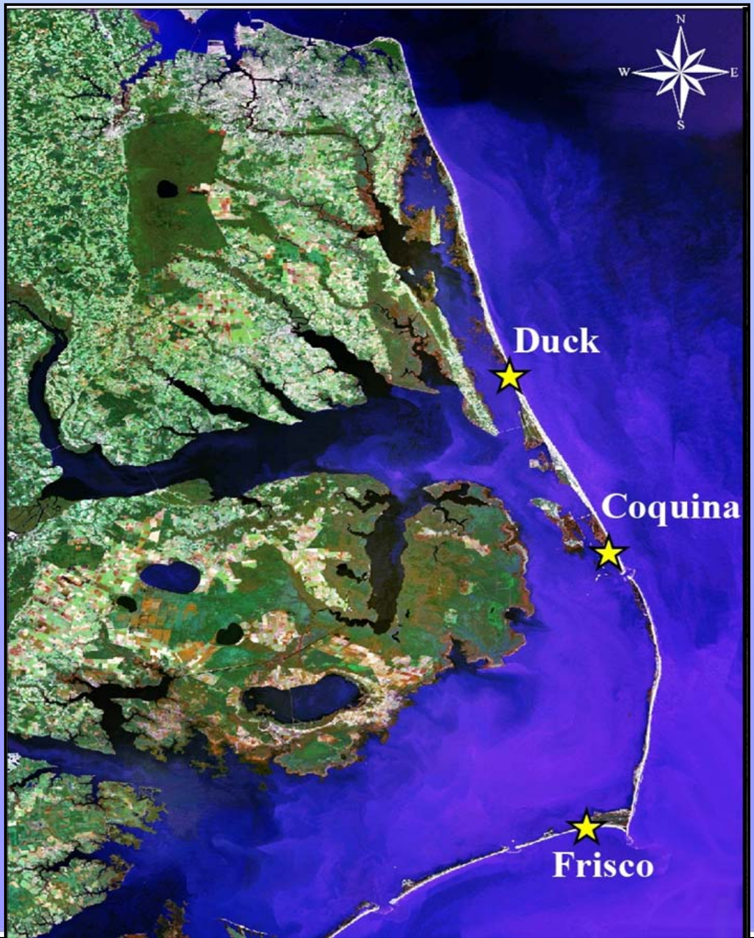
We propose and investigate two methods to approach this difficulty:

1. **Empirical Approach**: field survey provides reliable estimates of uncertainty based on observations tied to tidal benchmarks with high-precision integrated GPS and laser-level system.
2. **Stochastic Approach**: Monte Carlo simulation of the product construction process that allows us to estimate the plausible variation of the observed product shoreline, given what we know about the observations that are used to derive it.

Study site: NC Outer Banks

Airborne Survey: Spring, 2008:

- **Optech ALTM 3100**
- **Applanix DSS DualCAM**



Lidar –derived MHW shorelines

- Duck: 5° slope
- Coquinta: 2° slope
- Frisco: 2° slope

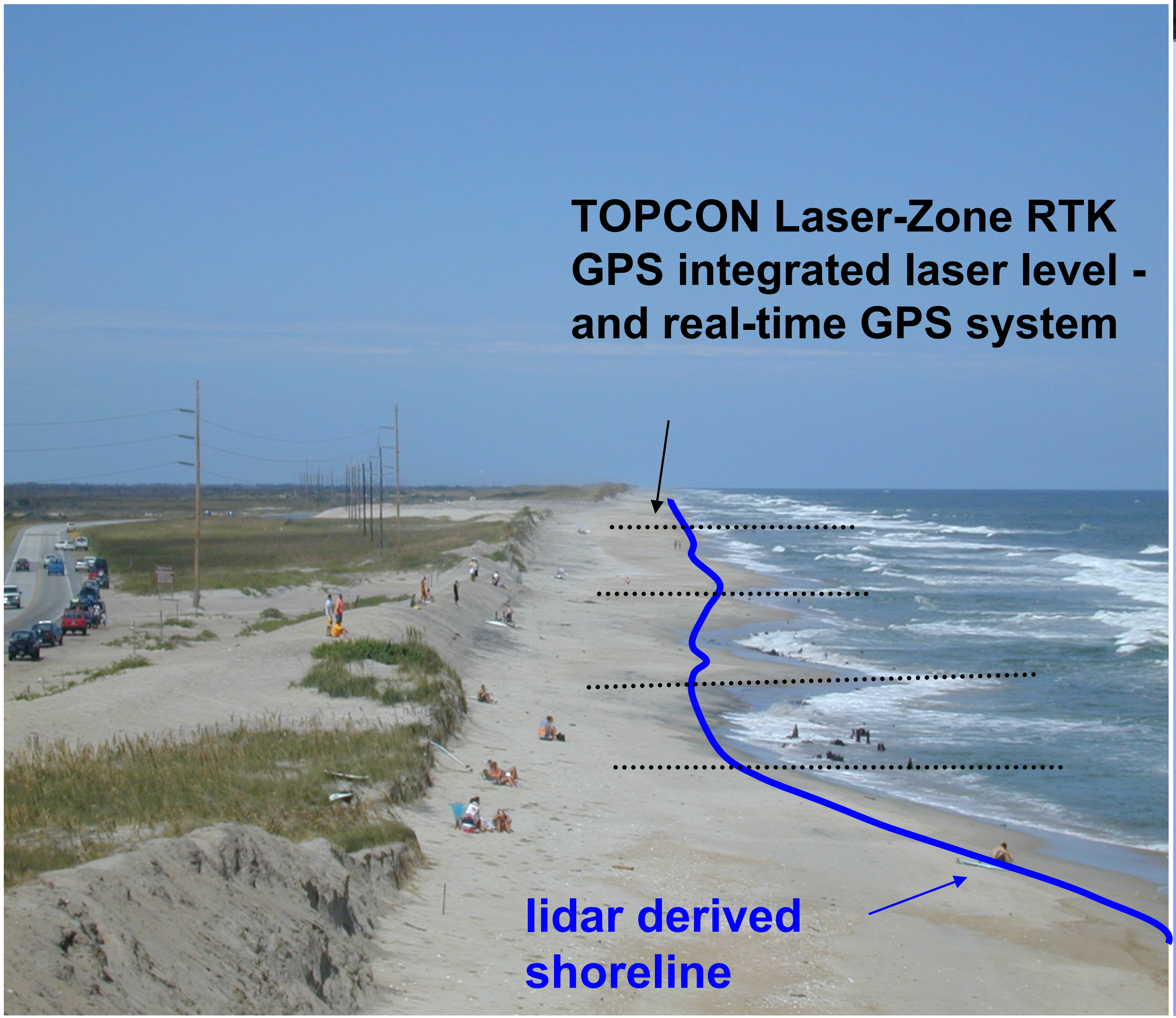
Field Survey

Shoreline Transects:

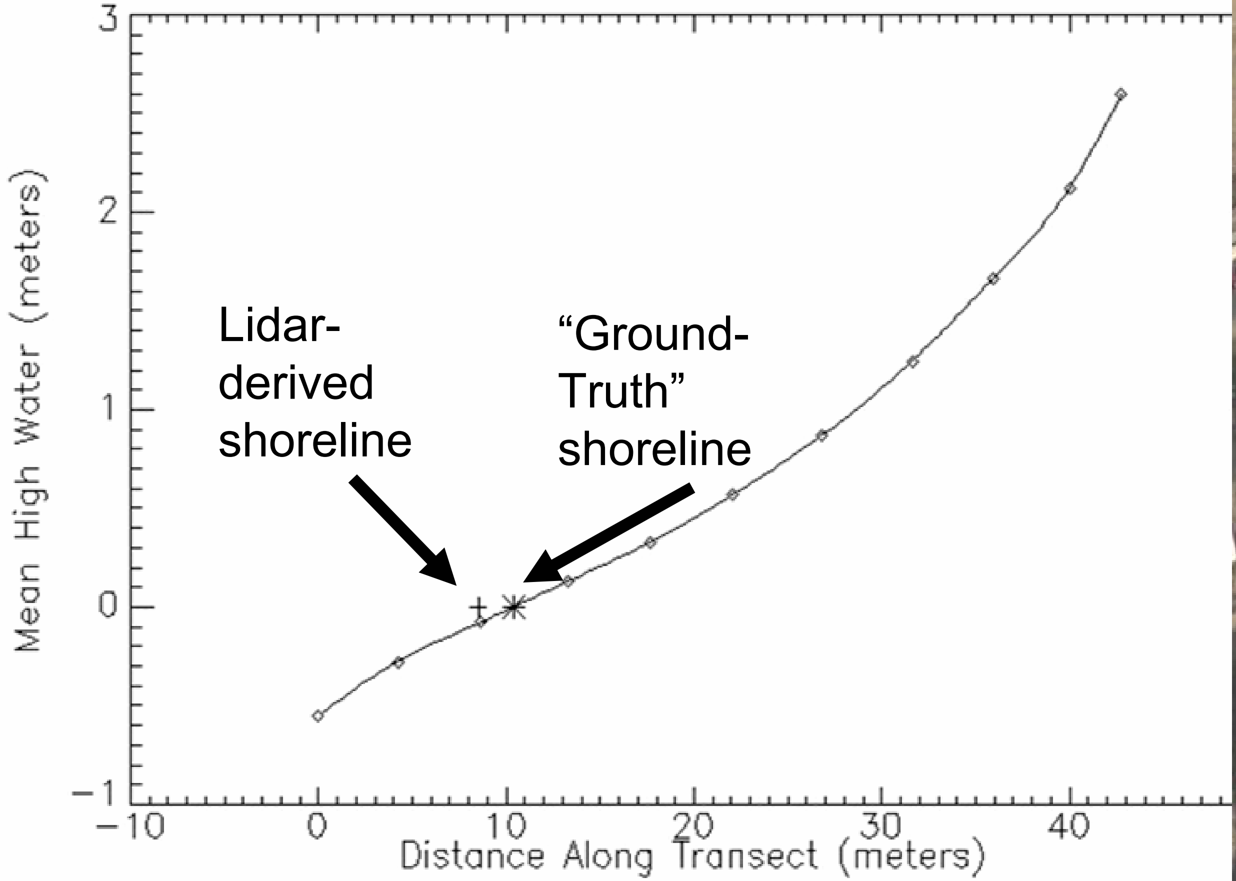
- **Instrument:** Topcon Laser-Zone integrated laser level and real-time GPS systems
- **Spacing:** ~10m spacing between transects, ~5m spacing of points along each transect
- **Horizontal Positioning:** NAD 83 (CORS96) coordinates computed from RTK GPS component of system
- **Vertical:** Direct tidal datum tie by running levels from NOAA tide stations

Accuracy Site	Tide Station	Vertical Benchmark ID	Number of Transects
Duck	8651370	FW0686	20
Coquina	8652587	EX0141	12
Frisco	8654400	EX0249	25

Field-Survey: Shoreline Transects



Extracting ground-truth MHW points from transects



Empirically-determined shoreline positional accuracy

	Frisco		Coquina		Duck	
	cubic spline	linear	cubic spline	linear	cubic spline	linear
$RMSE_{HOR}$	0.36	0.36	0.43	0.47	0.54	0.55
Mean distance between lidar-derived MHW and Topcon-measured transects	0.32	0.32	0.39	0.43	0.44	0.48
Std. Deviation of distance between lidar-derived MHW and Topcon-measured transects	0.16	0.17	0.17	0.19	0.32	0.28
NSSDA Accuracy (95% Circular Error)	0.60	0.63	0.74	0.81	0.93	0.93

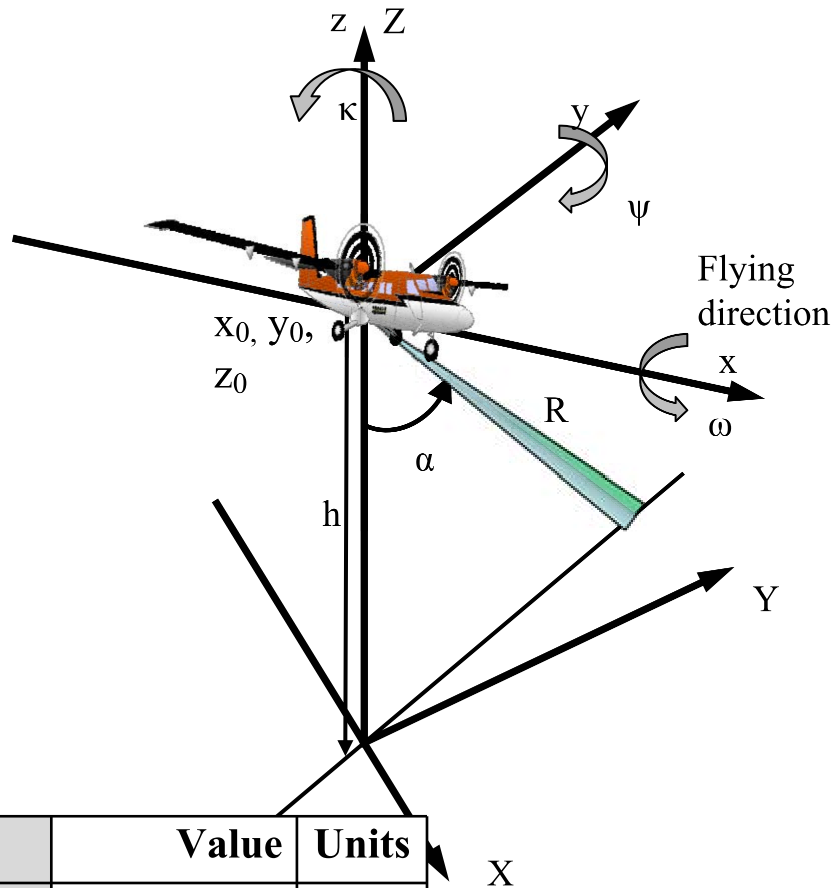
Empirical Approach: Benefits

- Integrated laser-level-RTK GPS shown to work very well for this type of field accuracy assessment
- By running integrated laser level transects from NOAA tidal benchmarks, obtain ground truth that are (a) independent of, and (b) significantly higher accuracy than test data (lidar-derived shoreline)
- Computations can be done following Federal Geographic Data Committee’s National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998)

Stochastic Uncertainty Analysis: Motivation

- Empirical (field-survey-based) approach is infeasible for large-scale deployment
  - Not practical or cost effective to send field crew out to do extensive field survey for each and every shoreline project
- Satisfy IHO S-44 specs, which mandate that: "A statistical method, combining all *uncertainty sources, for determining positioning uncertainty should be adopted*"
- Perform sensitivity analysis
- Inform internal (NGS Coastal Mapping Board) decisions
  - Example: can we fly higher in certain areas and still meet specs?

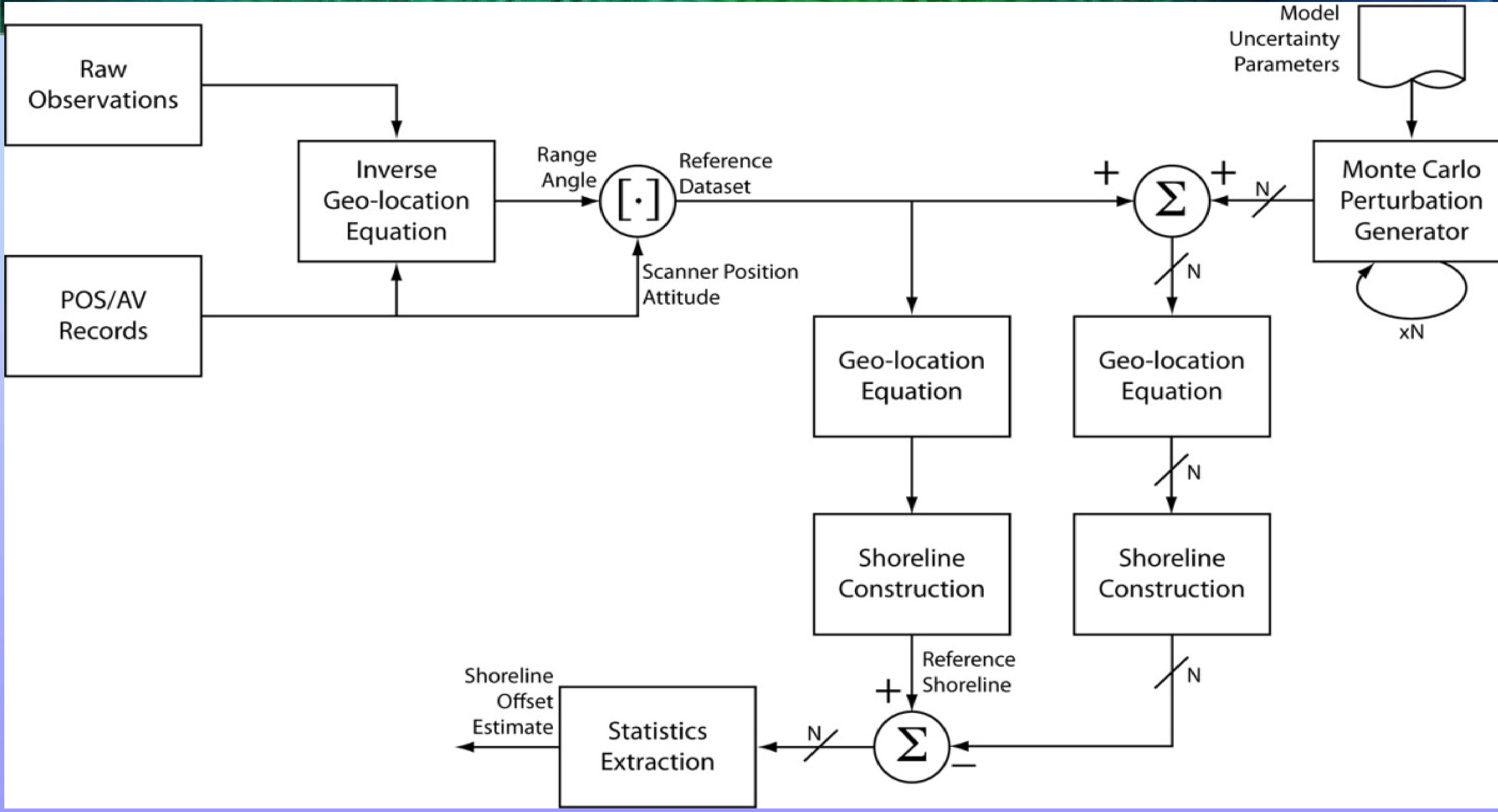
Uncertainty Parameters



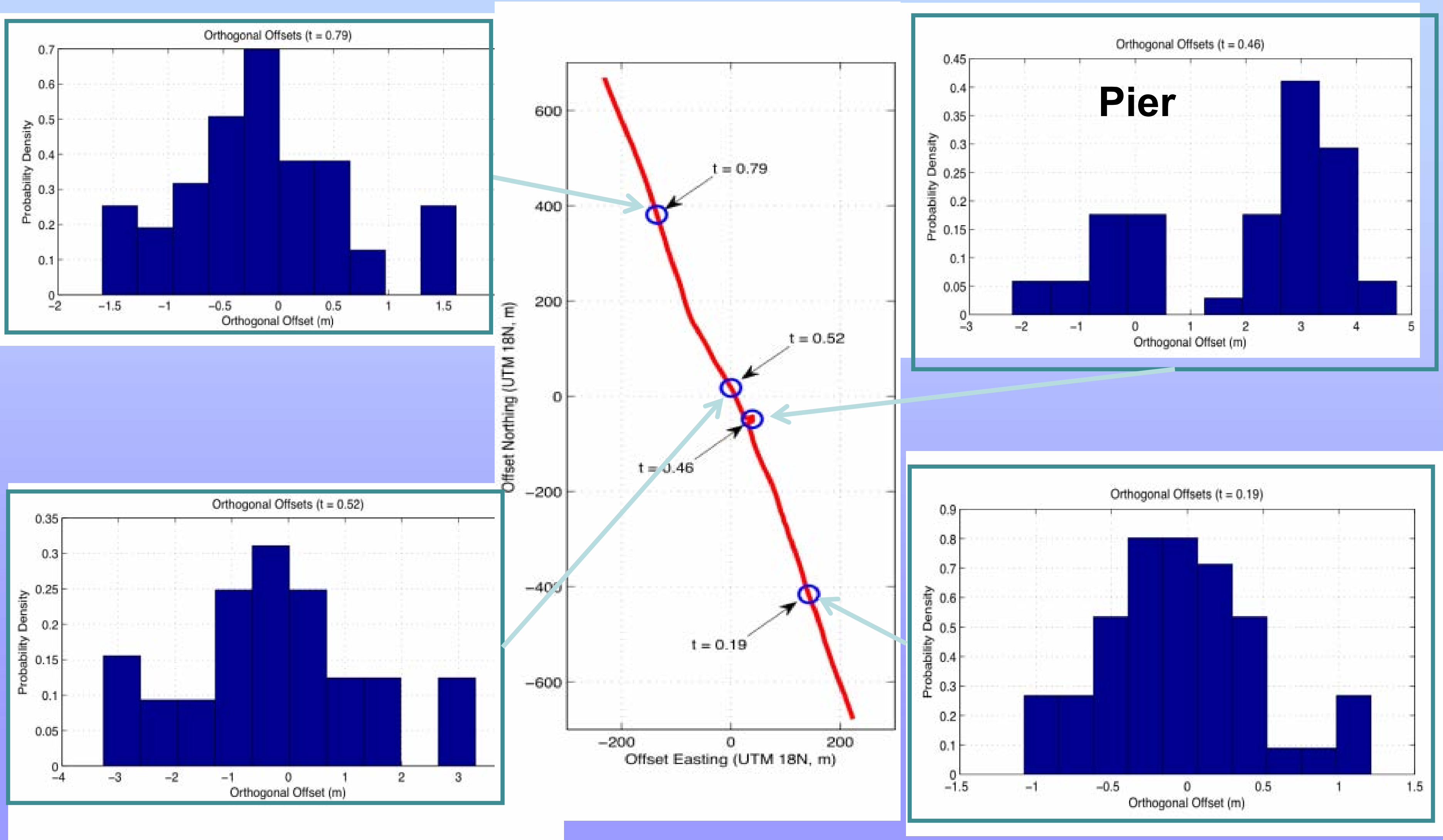
Variable	Value	Units	Variable	Value	Units
(XYZ) Offsets	50	mm	Roll Measurement	0.003	deg.
Roll Offset	0.0006	deg.	Pitch Measurement	0.003	deg.
Pitch Offset	0.0006	deg.	Heading Measurement	0.004	deg.
Heading Offset	0.0012	deg.	Range Measurement	50	mm
GPS Absolute	80	mm	Angle Measurement	0.001	deg.
GPS Relative	10	mm	Refraction Angle	0.0011	deg.
			Latency Angle	0.005	deg.
			Torsion Coefficient	7.3614×10^{-5}	N/A

(All values are reported at one standard deviation)

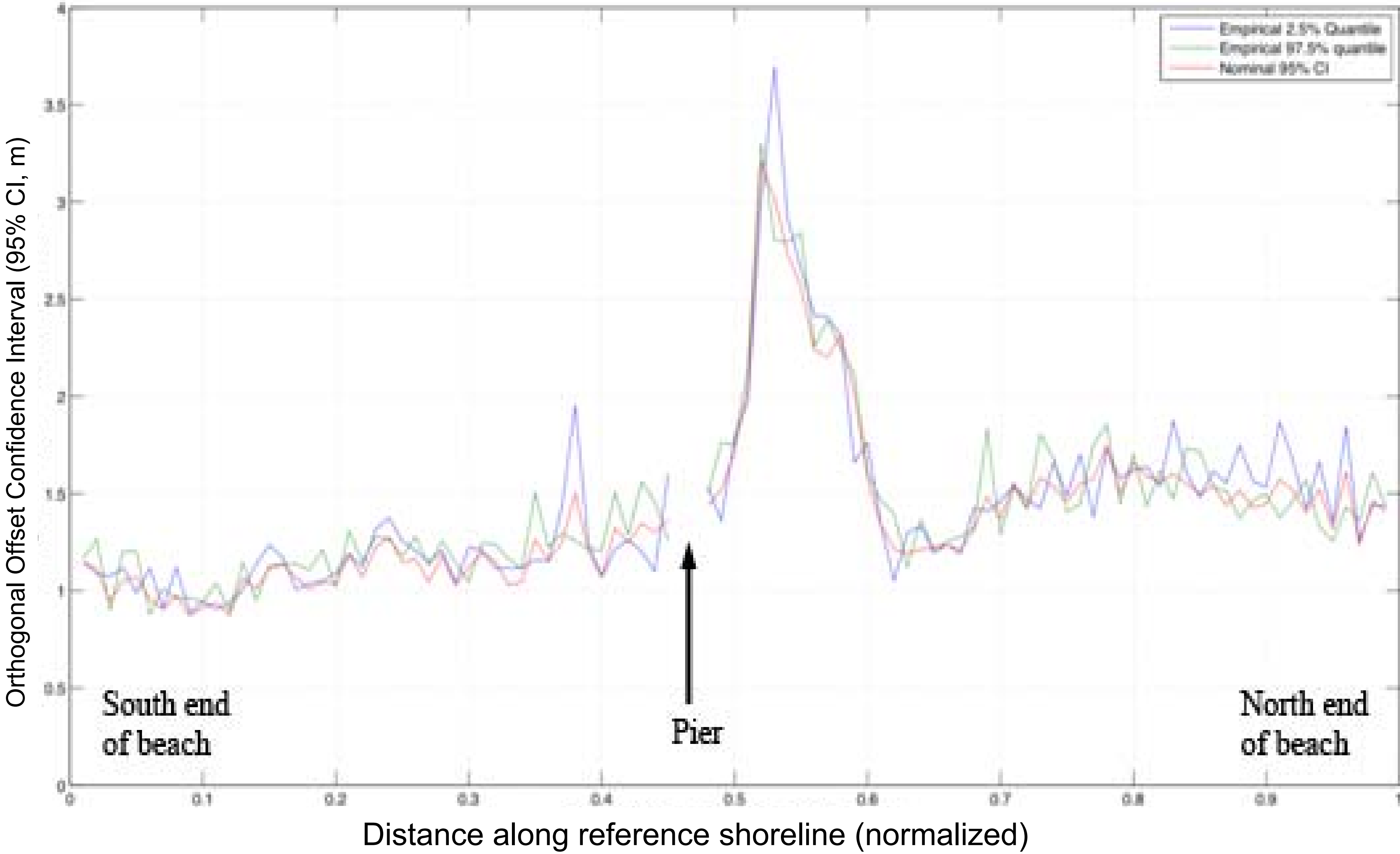
Configuration of Monte Carlo Analysis Method



Distributions of offsets

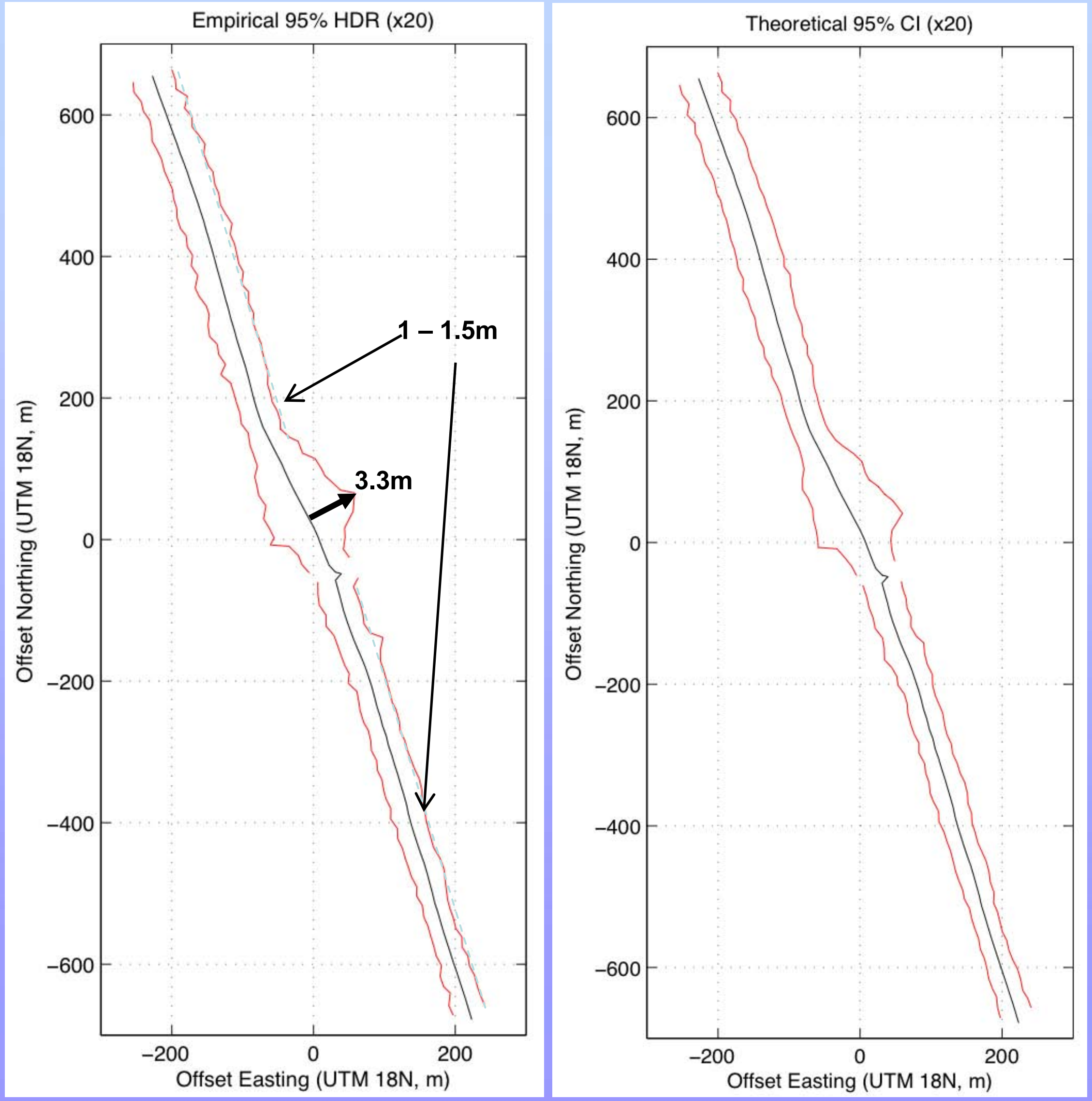


1D Horizontal uncertainty estimates



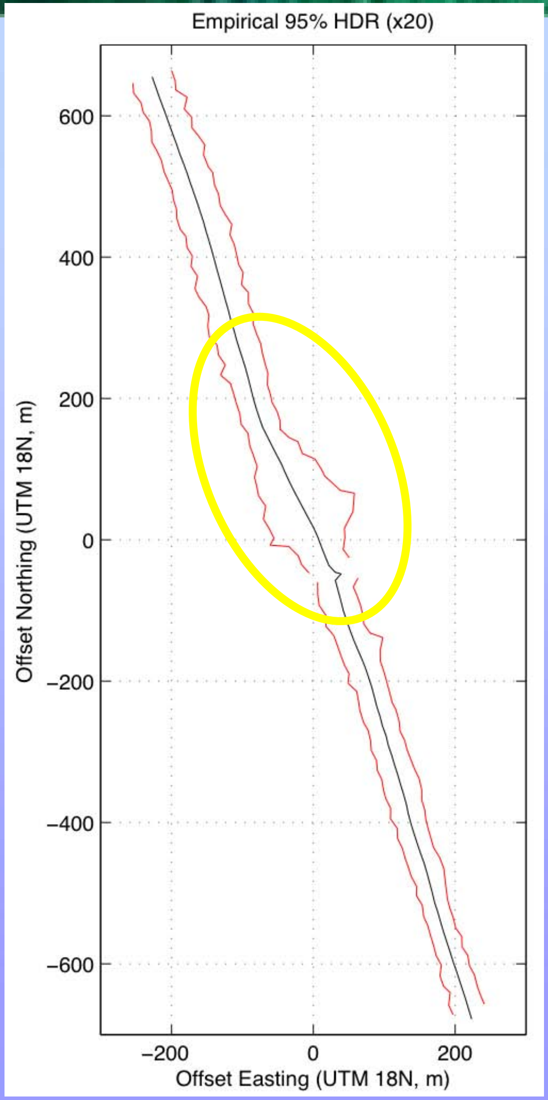
2D Stochastic model results

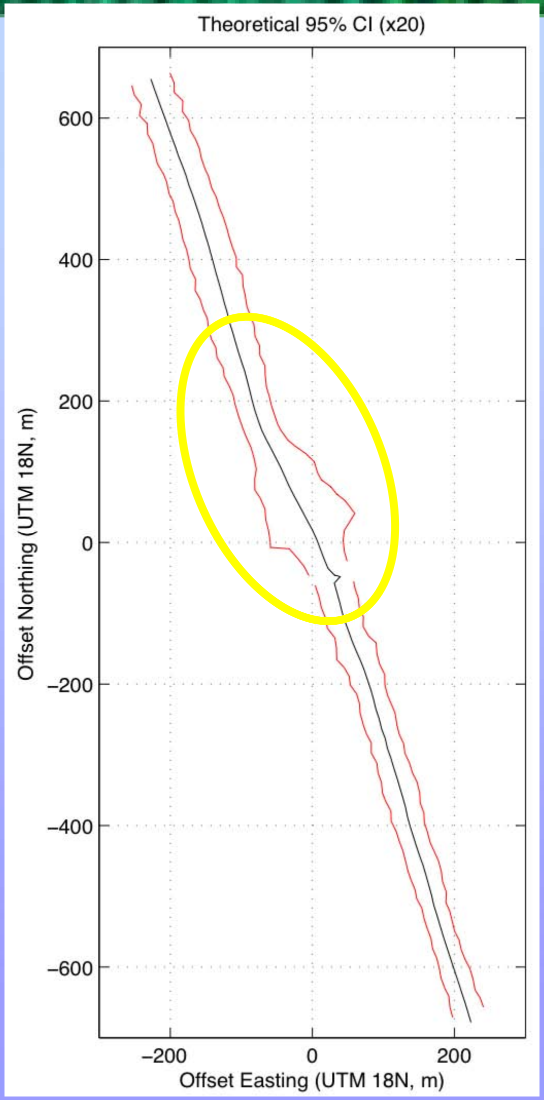
Empirical bounds computed from the data

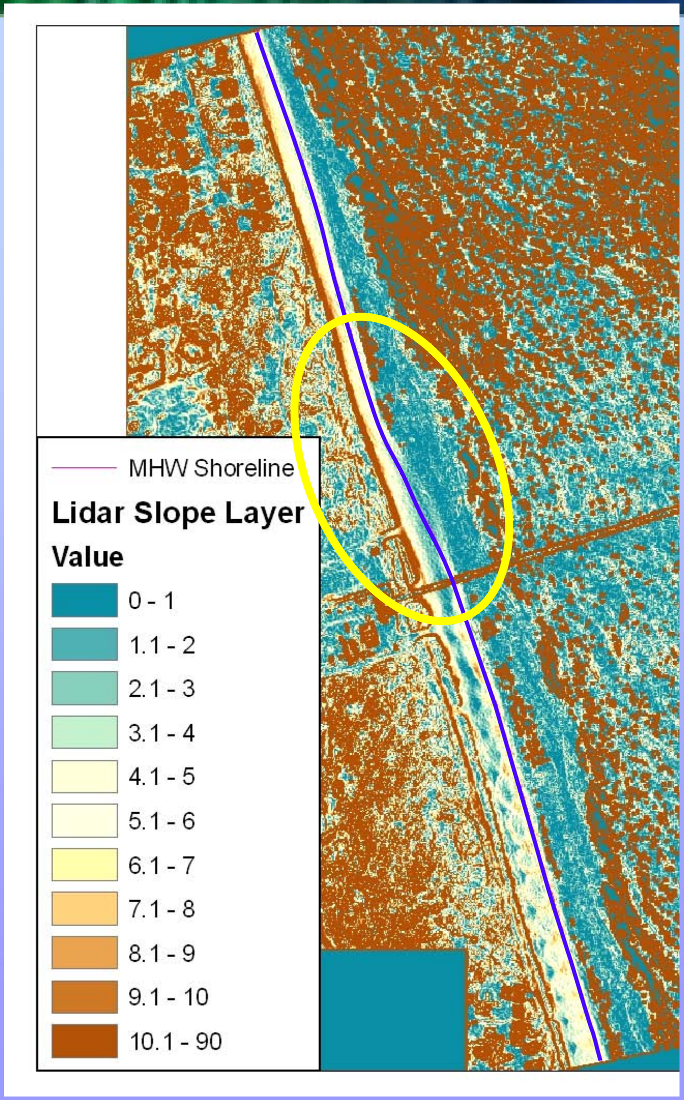


Reference shoreline outer 95% CI bounds as estimated using the Monte Carlo method

Stochastic model
(Beach slope)

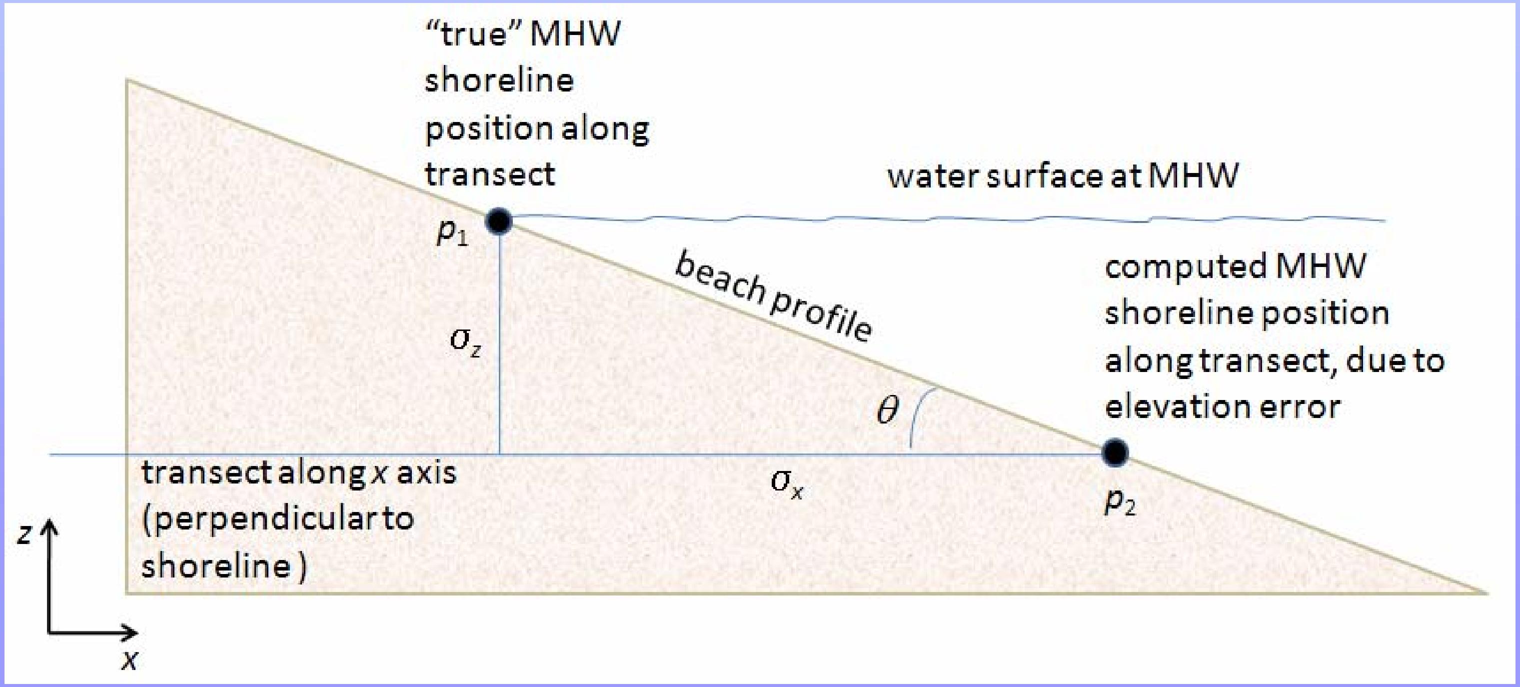






Empirically-determined shoreline positional accuracy

$$\Delta x = \frac{1}{tan\theta} \Delta z_{lidar\ bias}$$



Stochastic Approach: Discussion

- Stochastic results are consistent with those determined through field campaign
  - Uncertainties on the order of 1.0-1.5 m through most of project area, with increases to 3.3 m (95%) in low-slope areas
  - Method is at least first-order accurate
  - Although algorithm isn't fed any *a priori* info about beach slope, we see strong correlation of output uncertainties with beach slope (as expected)
- Fidelity depends heavily on input uncertainty estimates for the raw measurements
- Not yet implemented in production, but we believe computational complexity will be acceptable

Conclusions and Future Work

- Future work will focus on:
  - Assessing/refining component uncertainties
  - Testing in different areas
  - Tuning size of the ensemble
  - Making “production-ready” (including consideration of computational complexity, development of user-friendly interfaces, etc.)
  - Extending to photogrammetrically-derived shoreline

Thank You

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