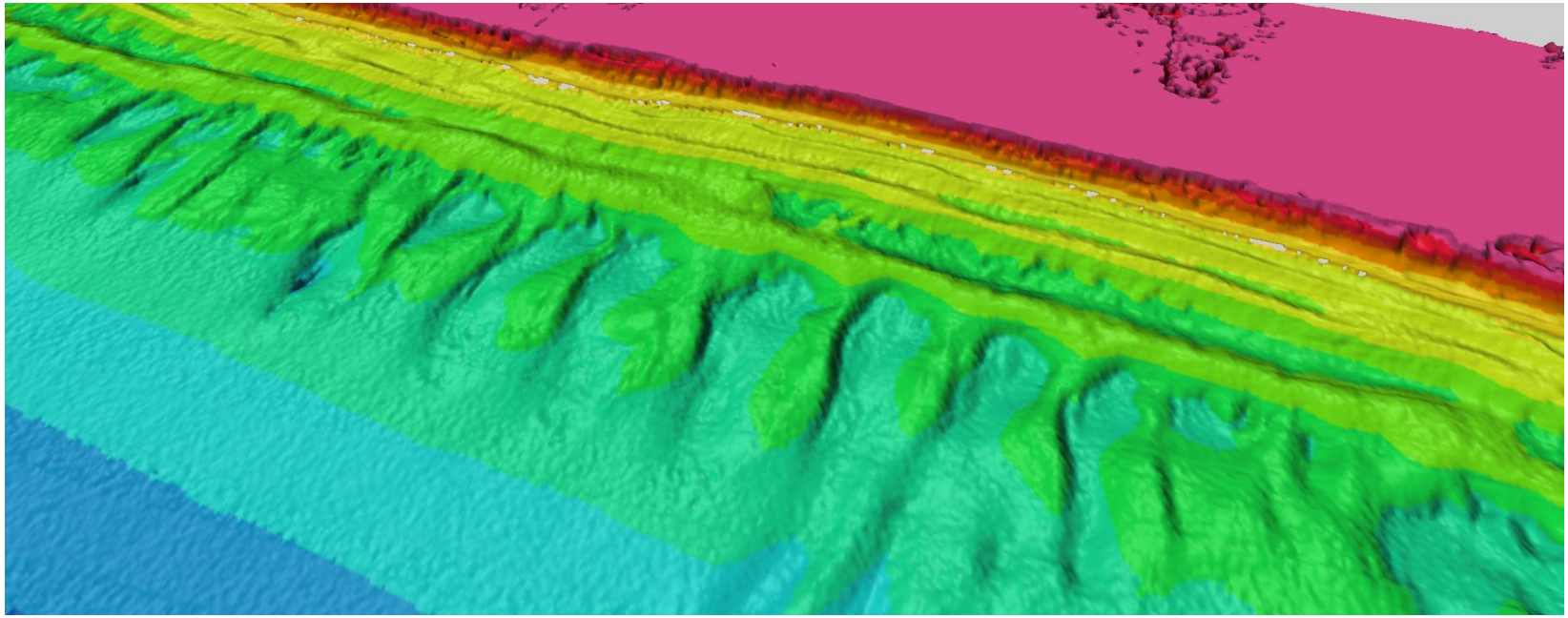
Relationship of Sandy Beach Coastal Morphology to Wave Climate using JALBTCX Lidar Datasets



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Lidar Datasets

- Starting with 2004 National Coastal Monitoring Program, there is now a decade of large scale bathymetric lidar for sandy coasts
- More data and at higher resolution than any other nearshore dataset in history
  - Repeated surveys at some locations
- What can we get out of this overall dataset?
- Year 2 of project

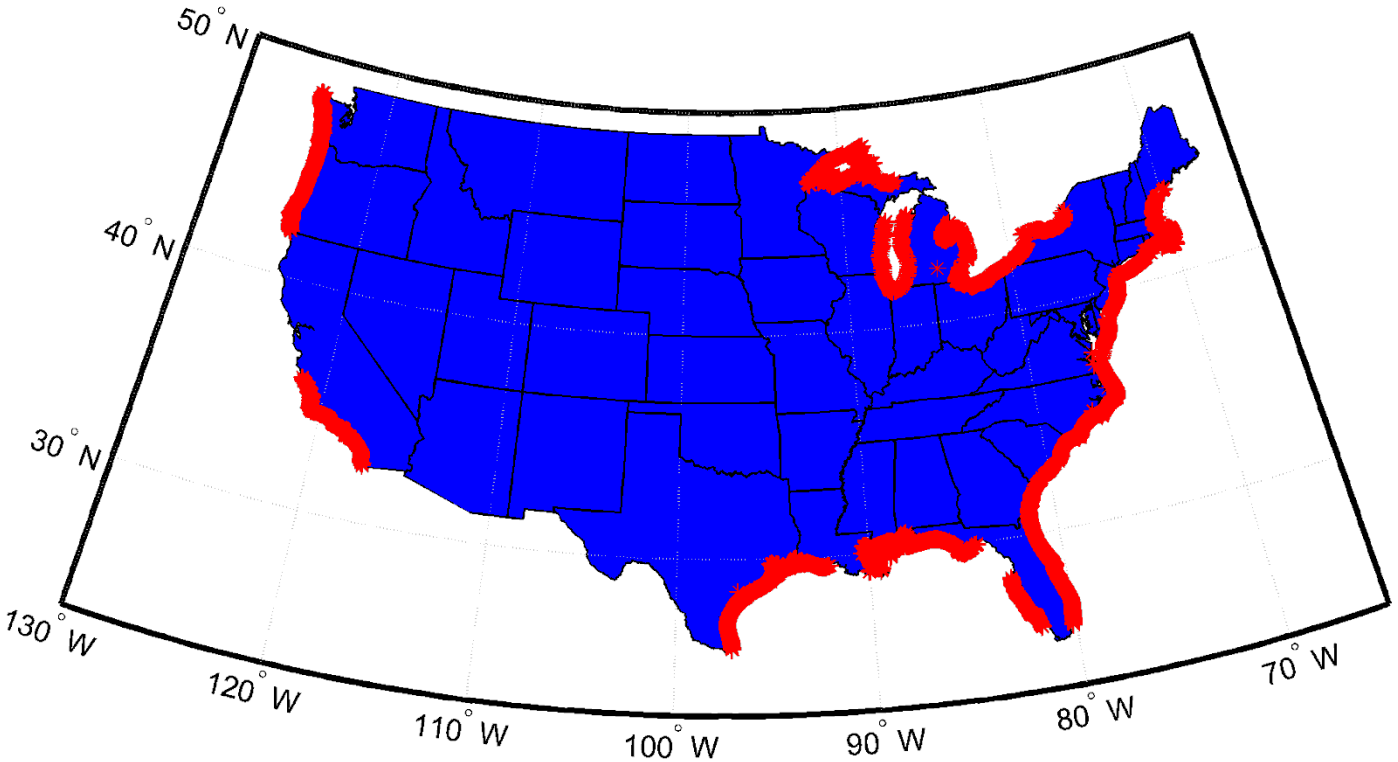
Fragment from Project Proposal

- Here we propose **to take the full JALBTCX dataset on open, sandy, shorelines** (*or as much as we can handle*) and **relate the morphology** (*slope, bar locations, alongshore structures, Wright and Short classification*) **to the local wave climate** (obtainable from WIS data), the recent wave history (obtainable from NOAA WWIII hindcasts), and sediment characteristics (from various sources).
- The increasing amount of lidar data available means that it is now very possible to **examine a very large number of sites with quite different wave and sediment conditions**, and to try to piece together an **overall picture of how sandy shorelines exist and develop, and at what length and time scales**.

JALBTCX Dataset

- Restrict to:
  - Continental US (No Hawaii, PR, Guam, …)
  - Open, sandy shorelines with bathymetric lidar and moderate shoreline curvature (>>1000m radius)
  - Reasonable water clarity
  - Available from NOAA Digital Coast
- 57 datasets considered for these purposes
  - Great Lakes
  - Atlantic Ocean
  - Pacific Ocean
  - Gulf of Mexico
  - Not all datasets will end up being useful

Dataset Locations



- Locations of all datasets under consideration
- Not all will be used:
  - Not sandy shorelines
  - Poor or no bathymetry

Year 1 Topics

1. Bar/Trough Analysis
2. Types of Bed Forms and locations

Year 2 Topics

1. Depth of Closure
2. Three Dimensional Analysis - Morphological Classification

Lidar Data Handling

- Much upkeep and storage required to store, access, and analyze many lidar files
- Semi-automated data handling necessary
- Create data structures, clean manually when required
- Two Main Types of processed data
  1. Point data at specified locations – can have gaps
  2. Interpolated data on regular grids – no gaps
- Different data types used for different purposes

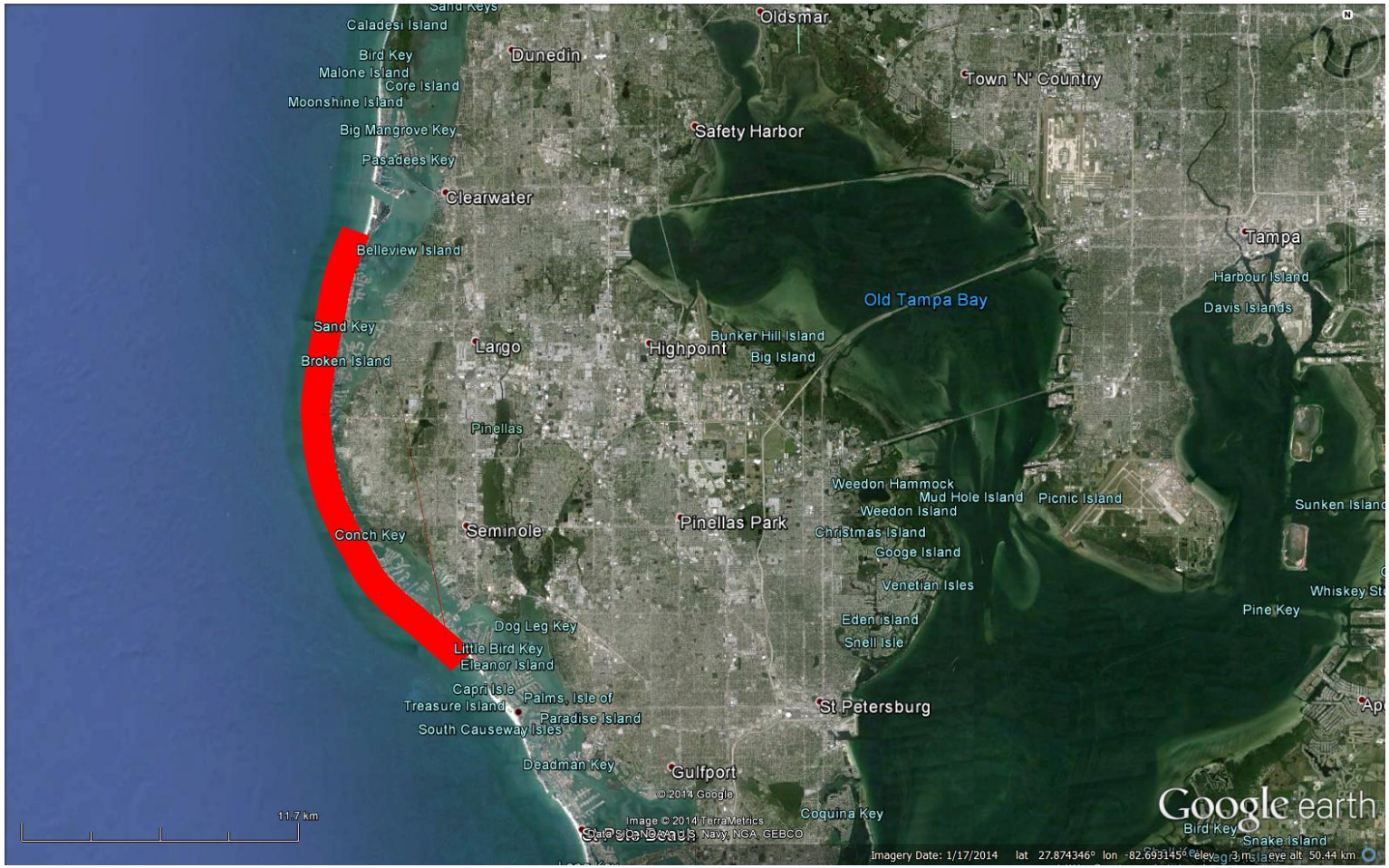
Shore-Oriented Transect Matrix Generation

- For open beach analysis, helpful to create regular shoreline-following data grid

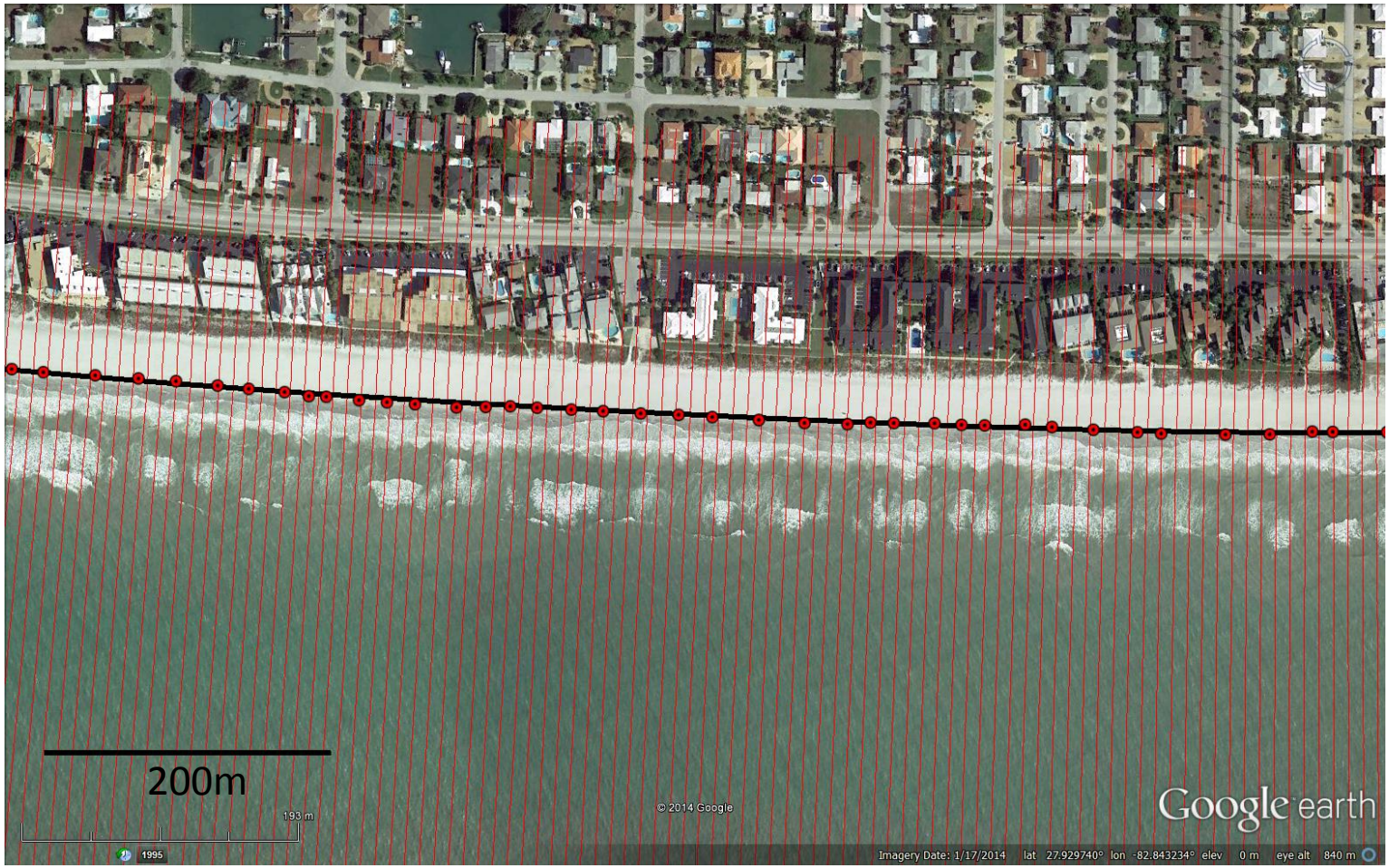
1. Create nominal shoreline data points
   - Export sea level contour (or lake level) from Fledermaus
2. Create polygon enclosing section of interest
3. Fit least-squares spline from contour points to define shoreline
4. Mark every 10 m along shore: find and save tangent and perpendicular directions
5. Create transects going 1000m offshore, 200m onshore with 5m cross-shore spacing

- More than 2000 km of sandy transects (so far)

Example Transects



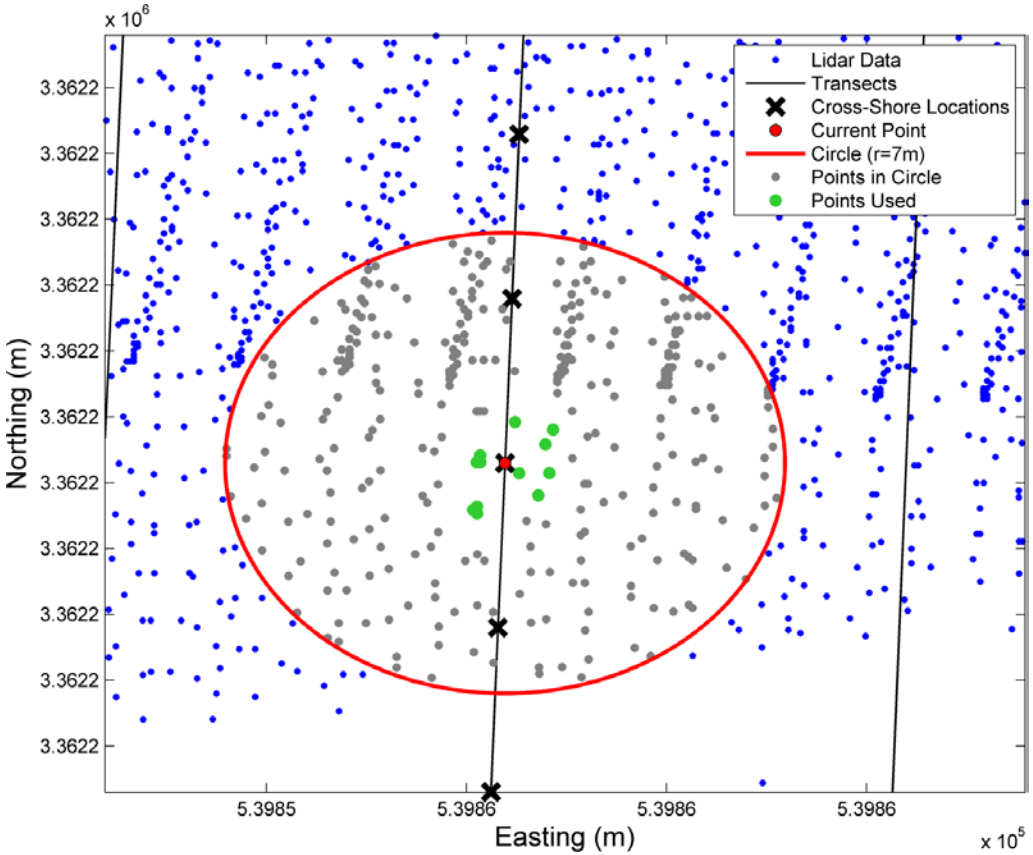
Example Transects



Type 1 Data: Bathymetry at Discrete Points – With Gaps

- At each point in each transect for each survey, try to find bathymetry
- Fit a local polynomial surface to each raw data point within a given range
- Bathymetry at point is the value of the polynomial
- Many quality control tests: reject if it does not pass them
- There will be gaps – do not try to fill them
- Type 1 data is suitable for looking at bathymetric changes – use data from different surveys

Type 1 Example

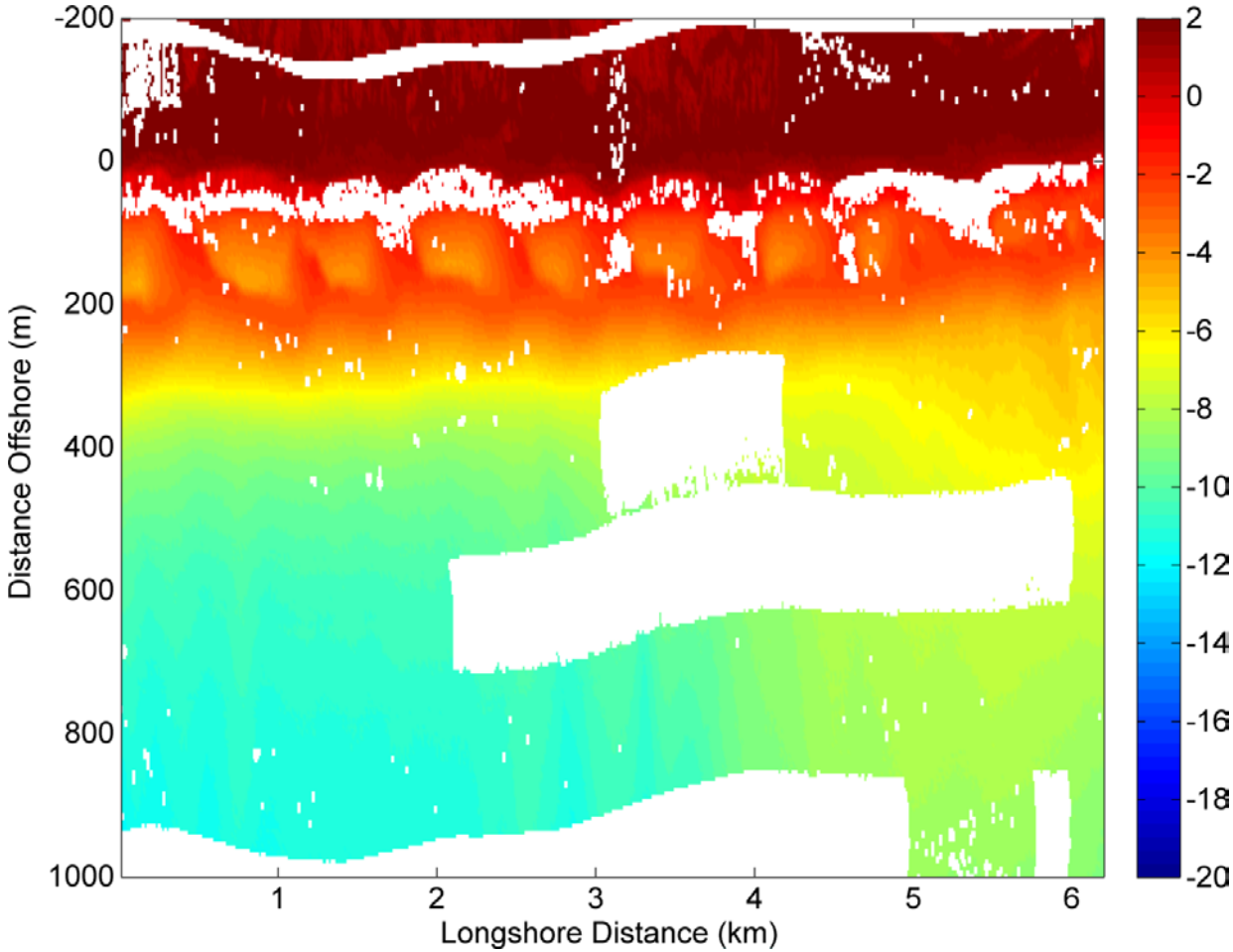


1. Look in circle for points
2. Divide into quadrants
3. Find nearest points in quadrants
4. Is location within convex hull of selected points?
5. Polynomial interpolation
6. Quality Control

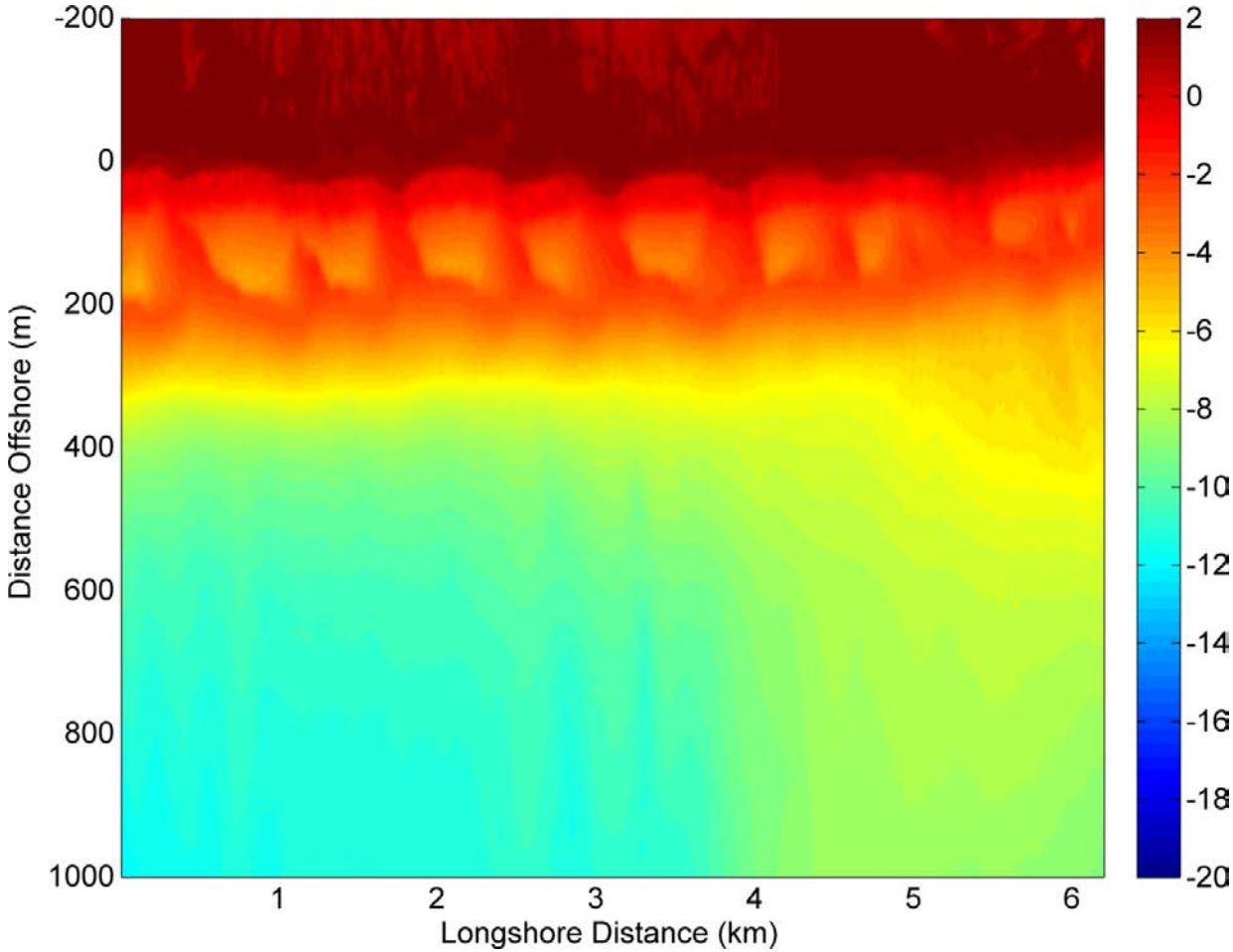
Type 2 Bathymetry – No Gaps

- Take results of Type 1 Bathymetry: Individual points with gaps where there is not enough data
- Interpolate using penalized least squares regression based on a three-dimensional discrete cosine transform to create a full transect grid
- Can use to investigate overall morphological forms using powerful numerical techniques that rely on a complete dataset
- Do not use to study change at discrete points

Before Interpolation



After Interpolation



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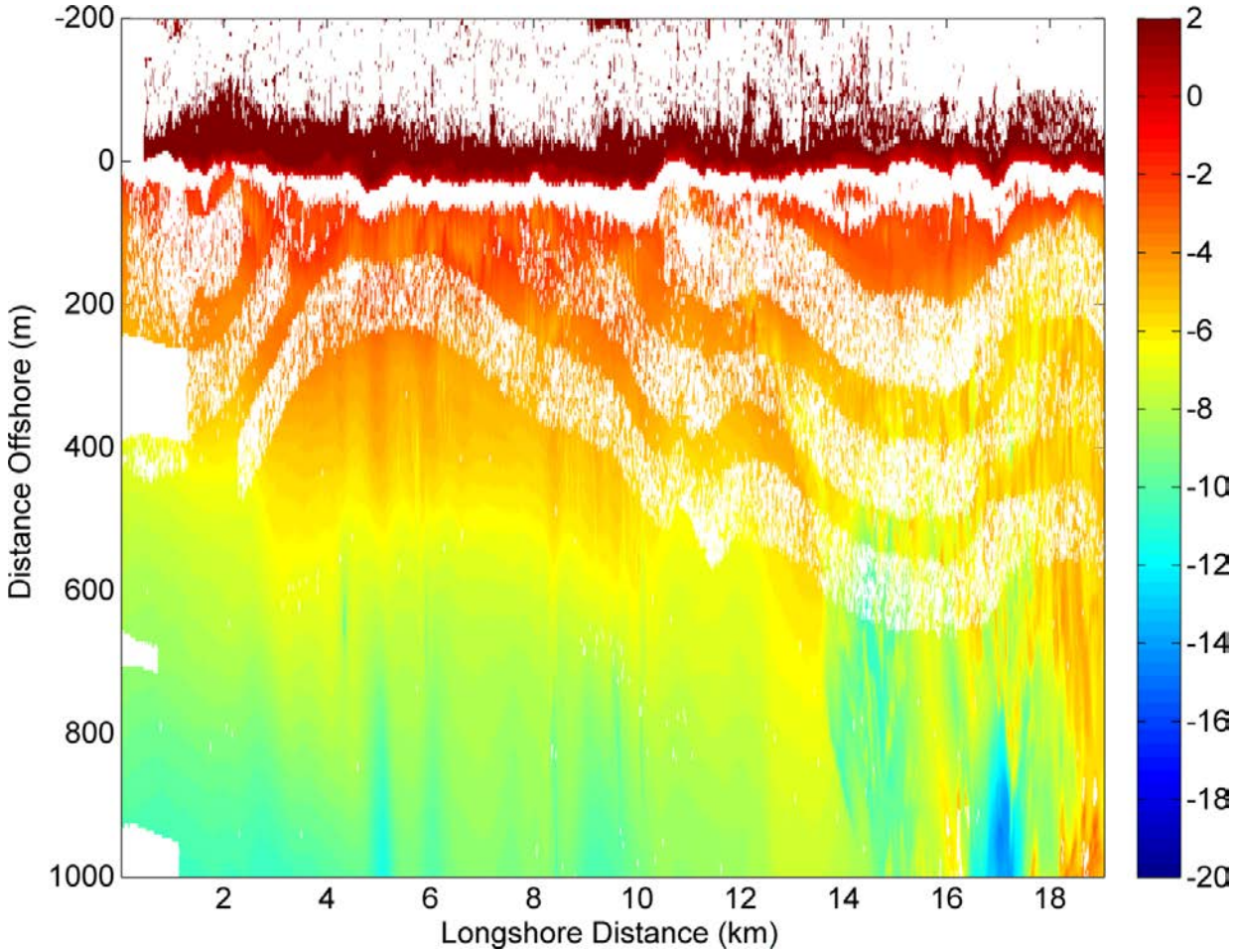

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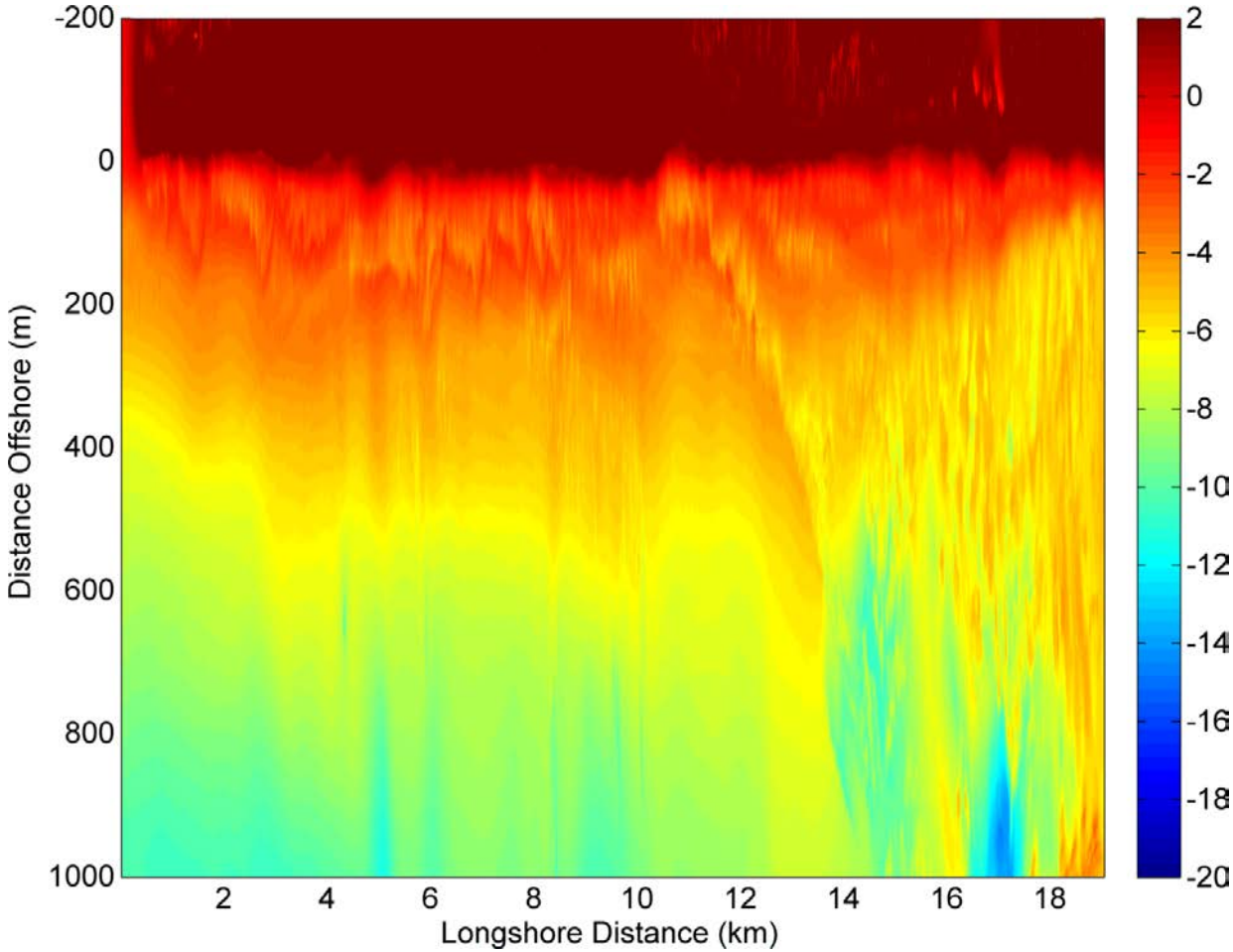

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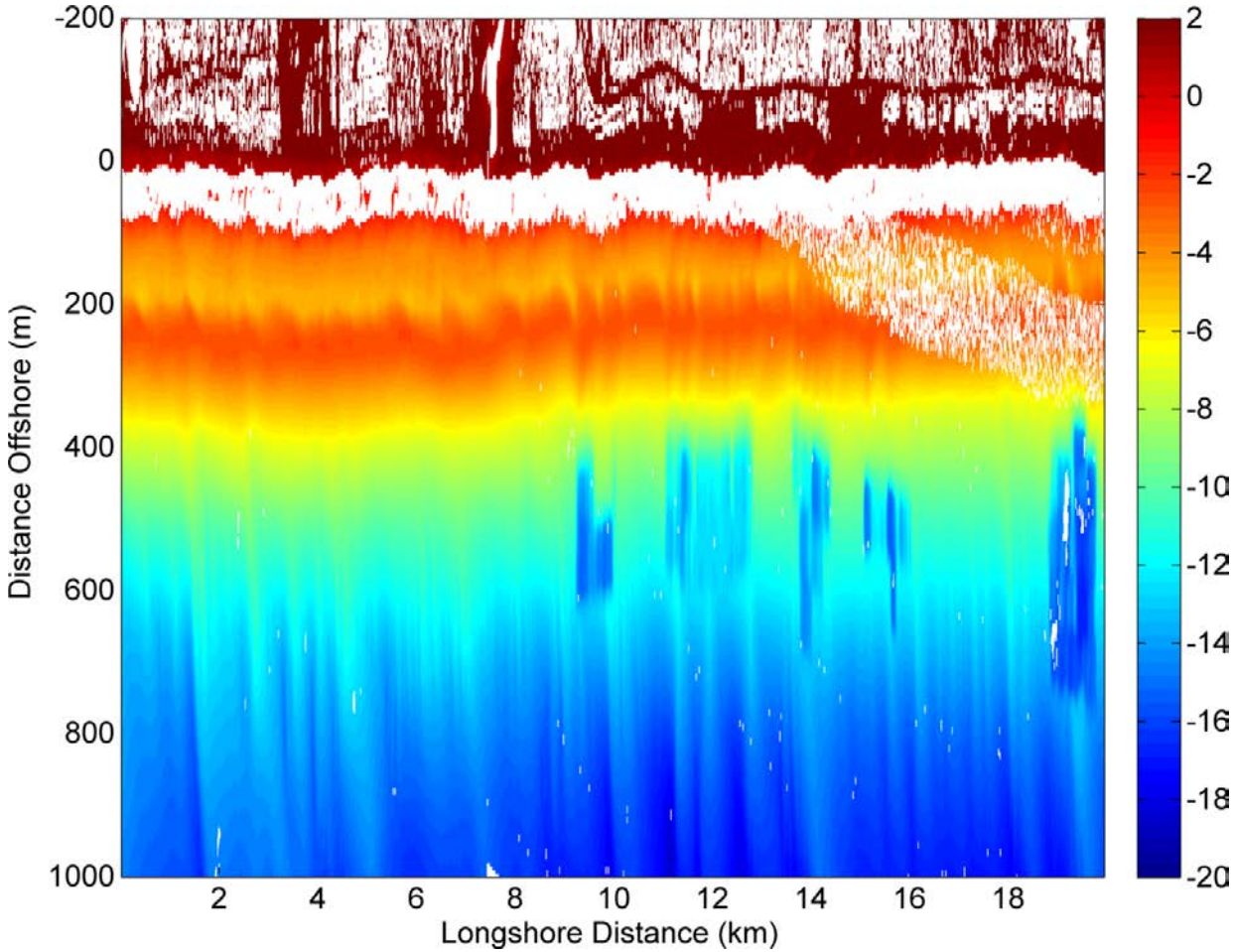

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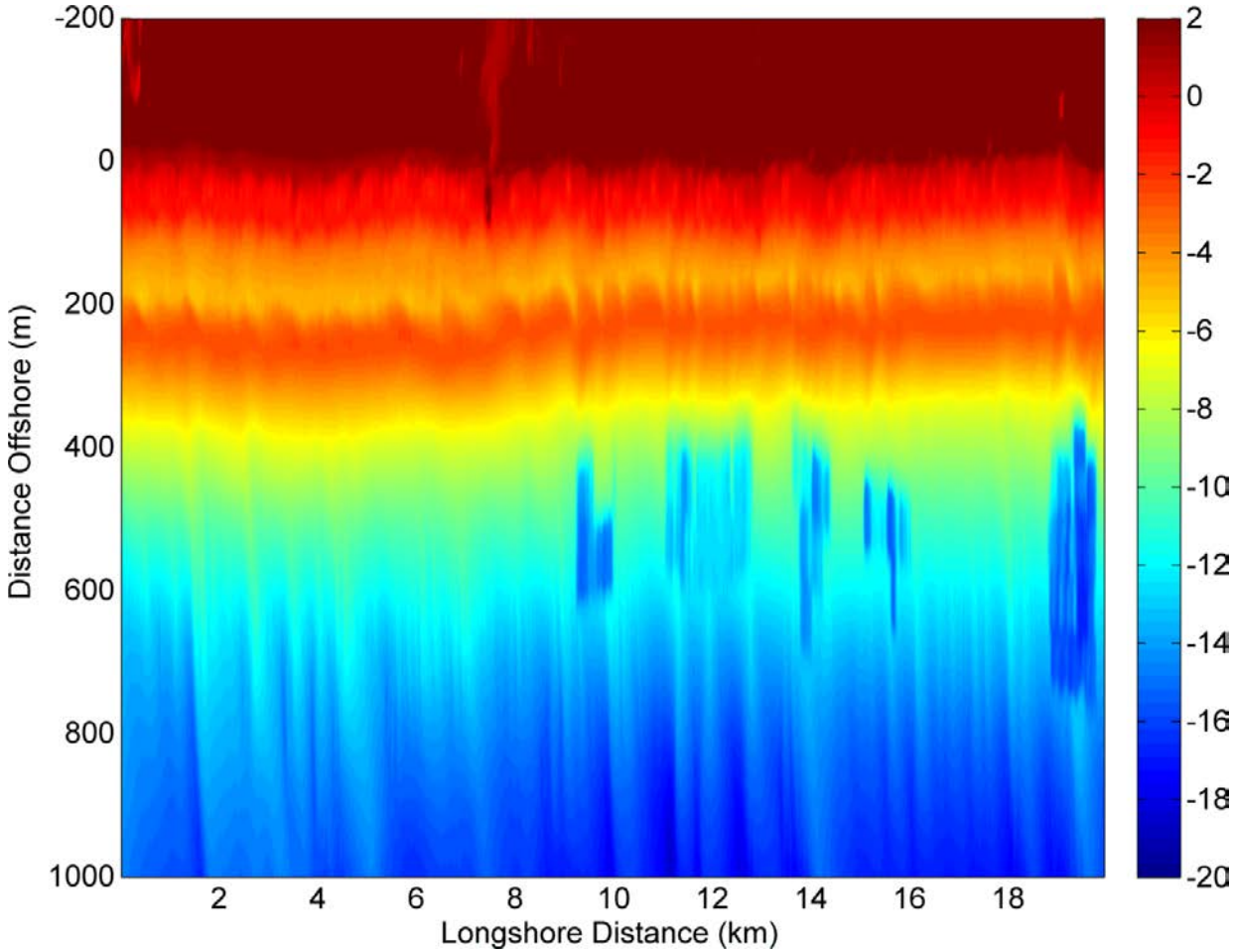
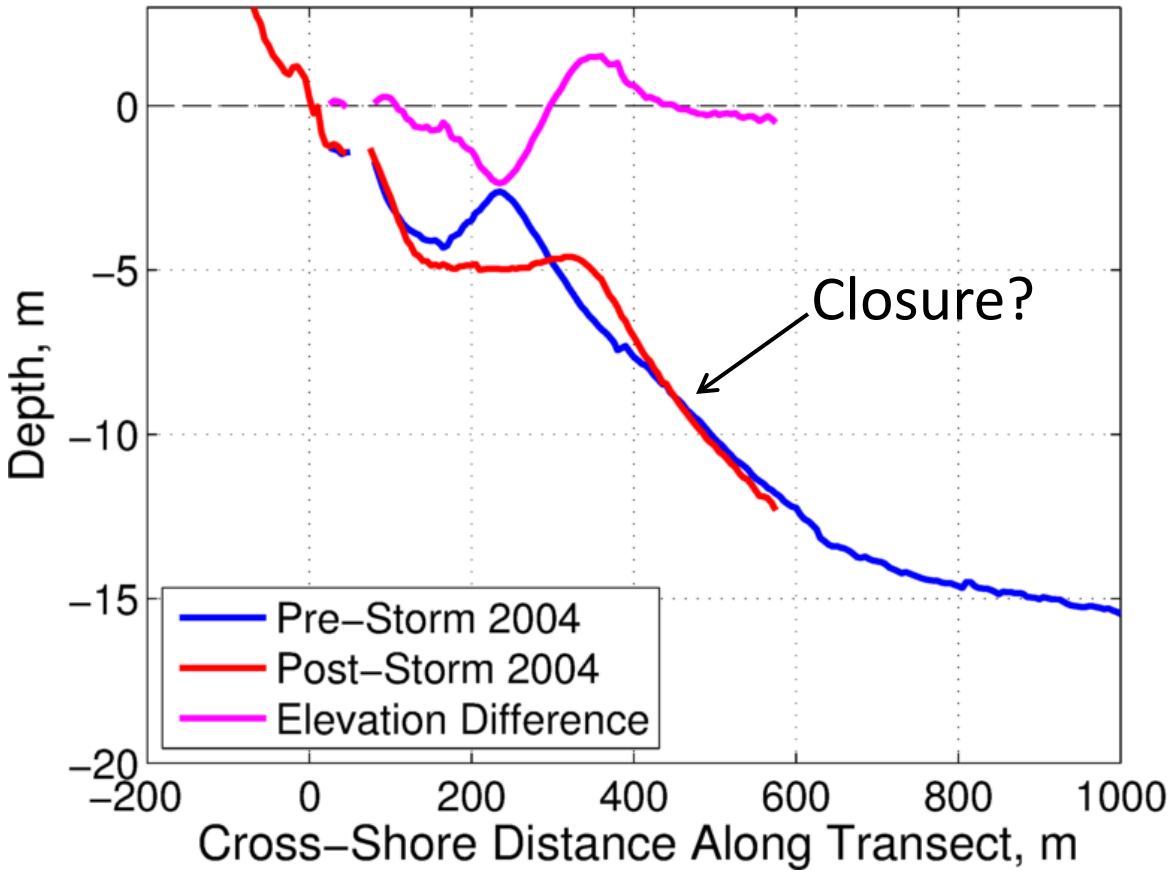


Depth of Closure

- In shallow water, waves continually rework sandy bathymetry
  - Changes on time scales of days to weeks
- In deeper water, bathymetric changes are smaller and slower
- Eventually, there reaches a depth where bathymetric changes are “insignificant”
  - **Depth of closure**
- Extremely important concept for design – how do we estimate this?

Closure for Transect near Panama City, FL



- Depth changes become smaller as depths increase
- Closure may be somewhere around 10m
- Depends on closure criteria
- May be better to examine statistically

Existing Studies

- Hallermeier: Biweekly surveys from Duck, NC, out to 8m depth.
  - Uses He, Significant Wave Height exceeded for 12 hours over survey period
  - Limited to 1-2km alongshore.
  - 6cm change criterion to determine closure.
  - Only included erosive events. Compared observed vs predicted to establish coefficients, forcing regression through the origin.
  - No extreme hurricane landfalls

- Robertson: used lidar data and a method similar to Hallermeier (30cm change criteria)

- Others: Larson, Larson & Kraus, Birkemeier

Depth of Closure Lidar Analysis

- Take all locations with good repeated bathymetries and with Wave Information Studies (WIS) data covering the periods between surveys
- Use all available bathymetry and wave information to study depth changes
  - Right now, Gulf of Mexico the only region with all appropriate data
  - Atlantic Ocean WIS data for the appropriate periods was released a few weeks ago, but has not yet been incorporated

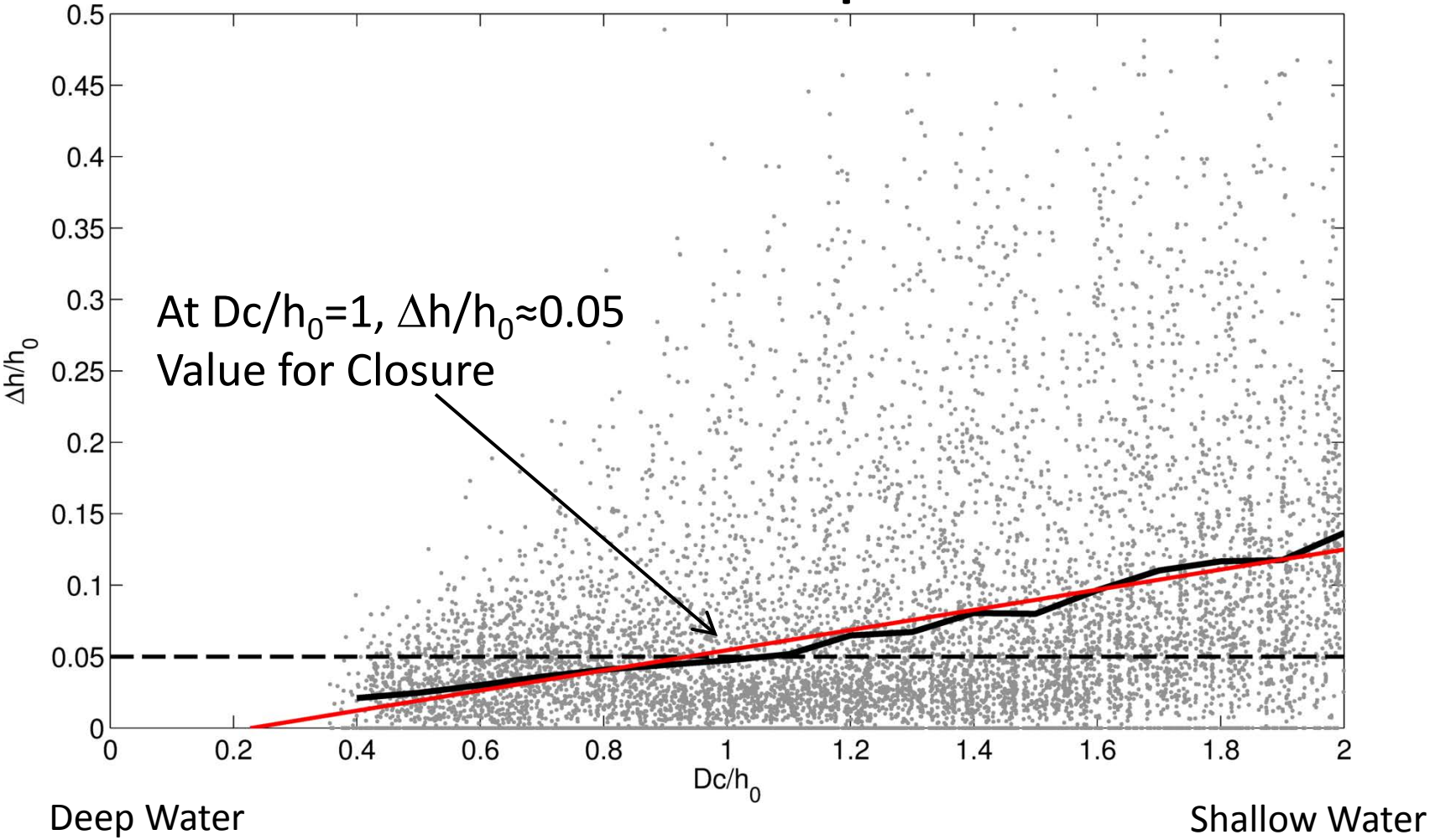
Data Processing

- Type 1 bathymetry (with gaps)
- Exclude all locations with dredging, old borrow pits, jetties or other manmade features
- Divide transects into 2km alongshore sections
- In each section:
  1. Find all locations with data from different pairs of surveys
  2. Divide into depth bins based on initial depth
  3. Calculate the variance of observed change Δh in each depth bin
  4. Subtract the variances of lidar surveys to obtain best estimate of actual Δh variance in each bin
  5. RMS depth change in each bin for 2km section is output

Depth of Closure Analysis

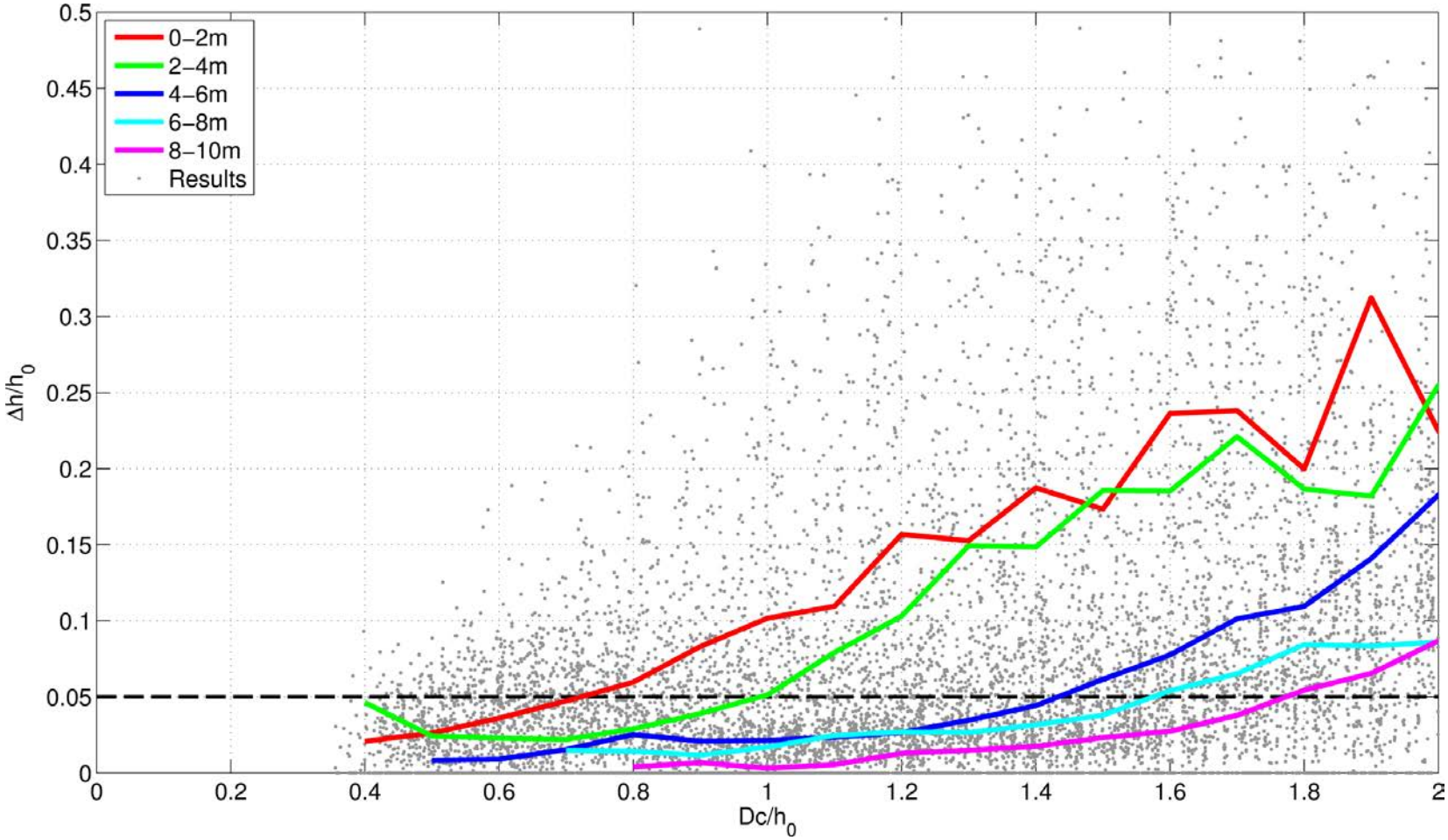
- Given RMS depth change for each depth bin in each 2km section, how do we compute depth of closure?
  - Many different bathymetries, wave climates
- Create Dimensionless Groups $\Delta h / h_0, \quad D_c / h_0$
  - Depth of closure is when $\Delta h / h_0$ decreases below threshold
  - Use to evaluate various depths of closure, D_c

Overall Cloud and Mean using Hallermeier's Equation



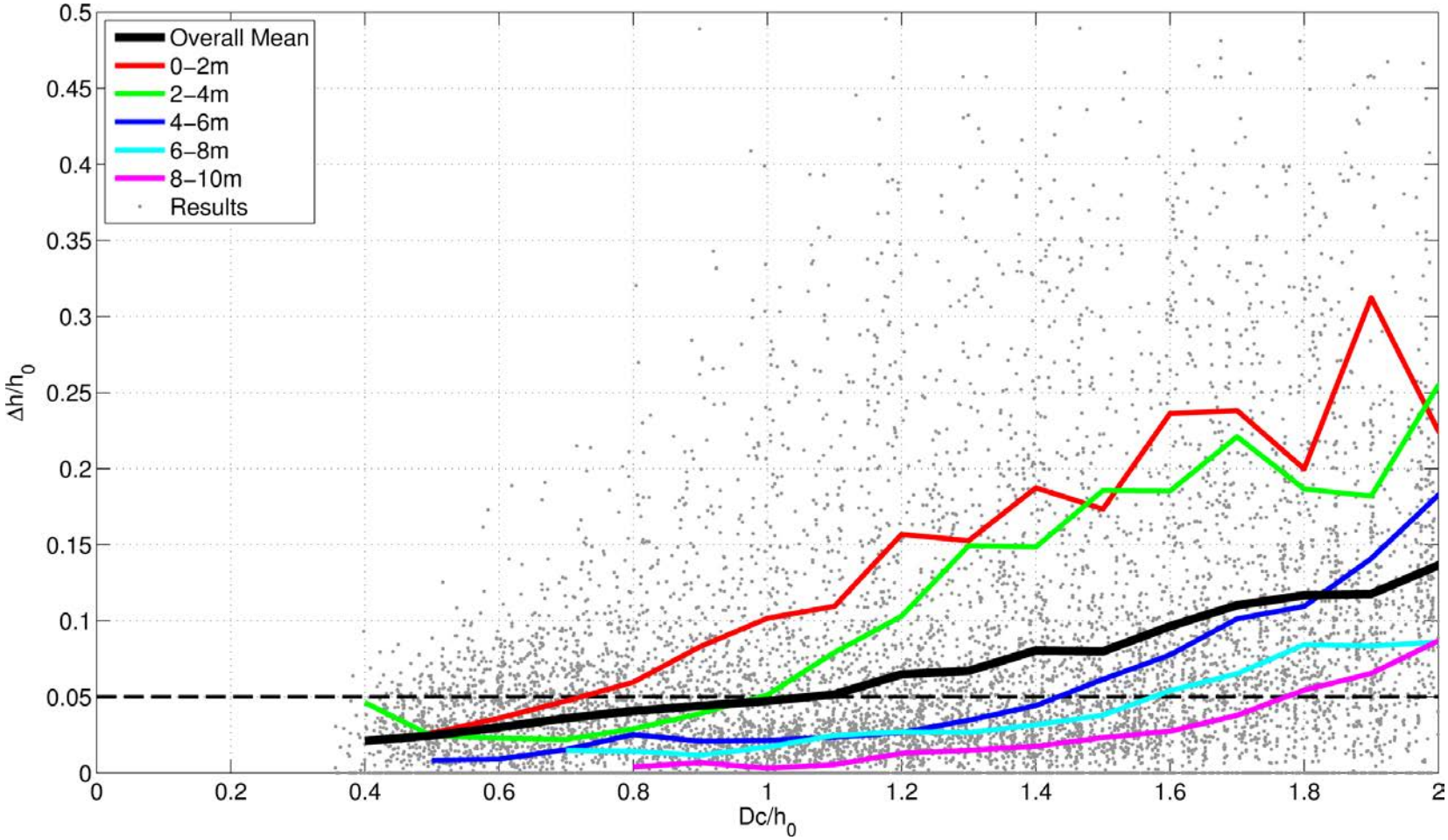
- Cloud shows scatter, but very good fit to mean
- Good enough?

Hallermeier's Equation – Different Wave Height Groups



- Very large differences in behavior for different sized waves
- Behavior is not universal

Hallermeier's Equation – Different Wave Height Groups



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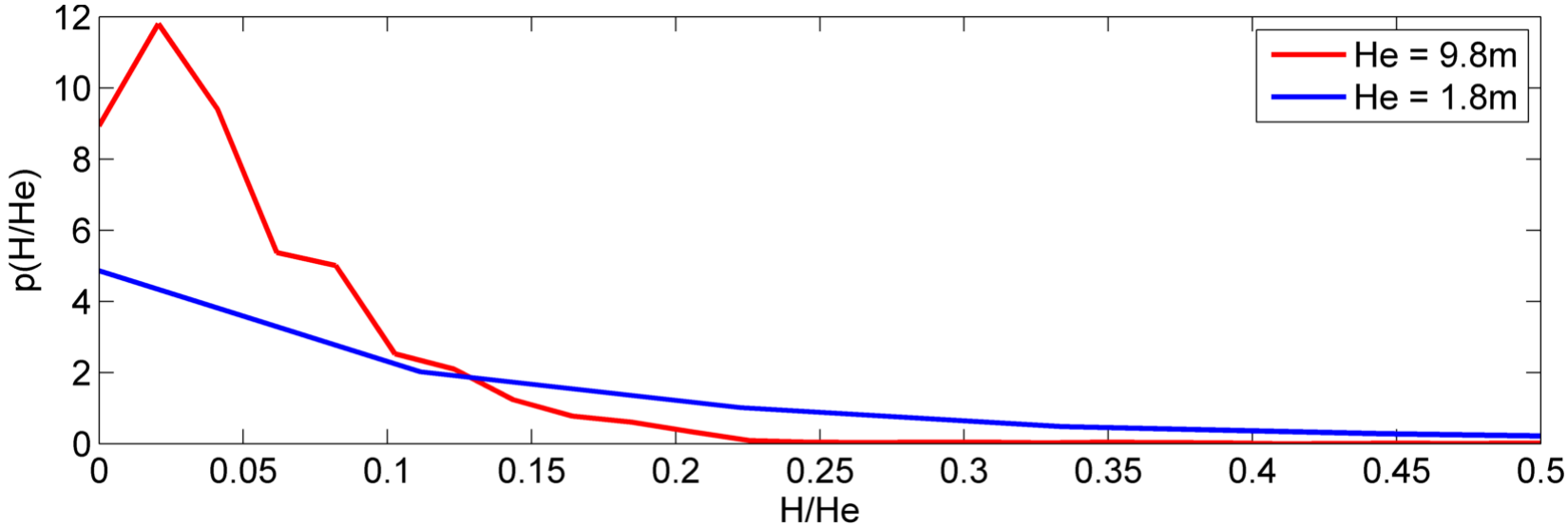
Probability Density Functions of Wave Heights



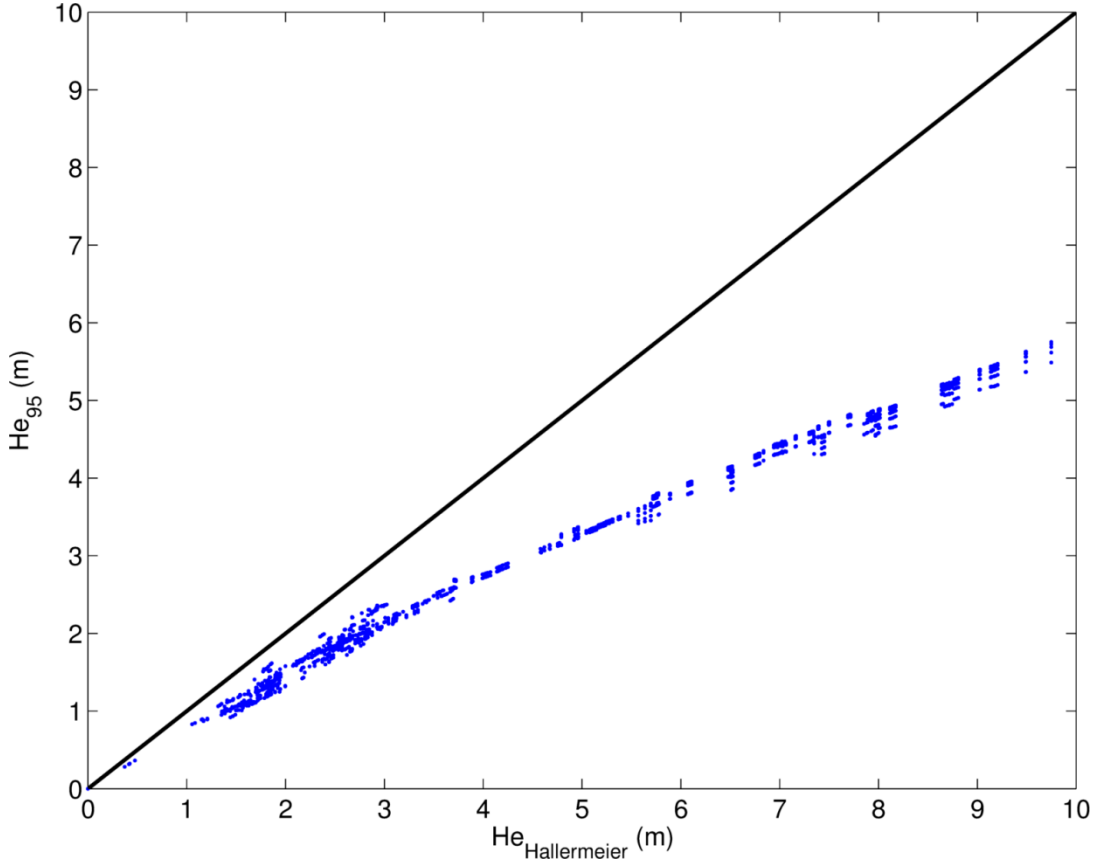
- Sites with large He had very different probability density functions compared to sites with small He
  - A single wave height may not be sufficient to characterize conditions
  - How do we better represent wave conditions for closure analysis?

Redefinition of Wave Heights and Periods

- It is clear that a single wave height is not truly representative of the overall climate
- Introduce additional statistical measures of wave properties to try to improve performance
  - He_{50}, He_{75}, He_{90}, He_{95}, etc.
  - H_{95} is significant wave height exceeded on 95% of measurements, and so on
  - $He_{95} = \frac{1}{2}\left(He + H_{95}\right)$
- See if this will improve performance for different wave climatologies
  - Requires recalibration of formulas

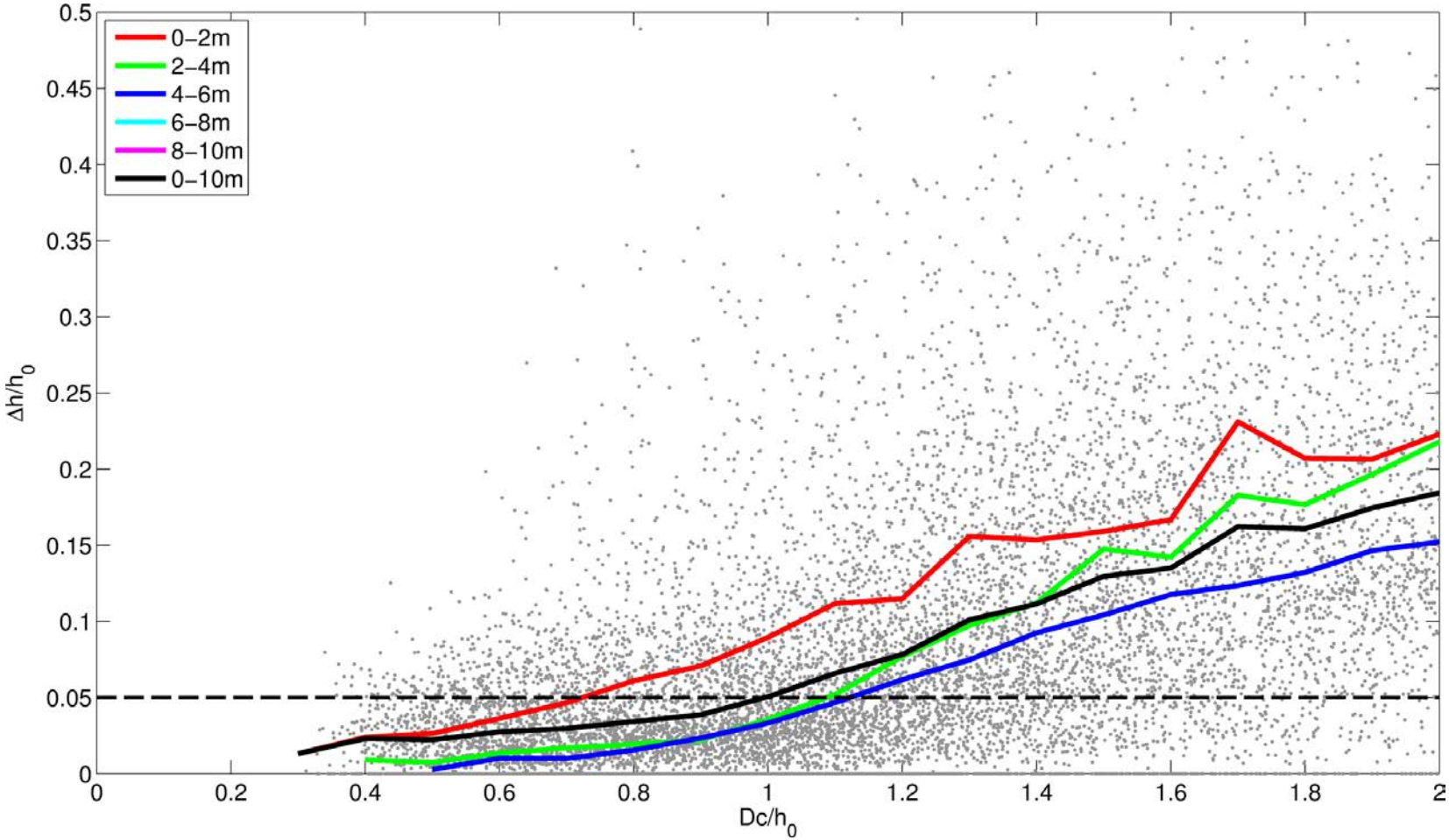
$$D_{c95} = X_1 He_{95}\left(1 + X_2 \frac{He_{95}}{gT_{e95}^2}\right)$$

Hallermeier He vs Revised He_{95}

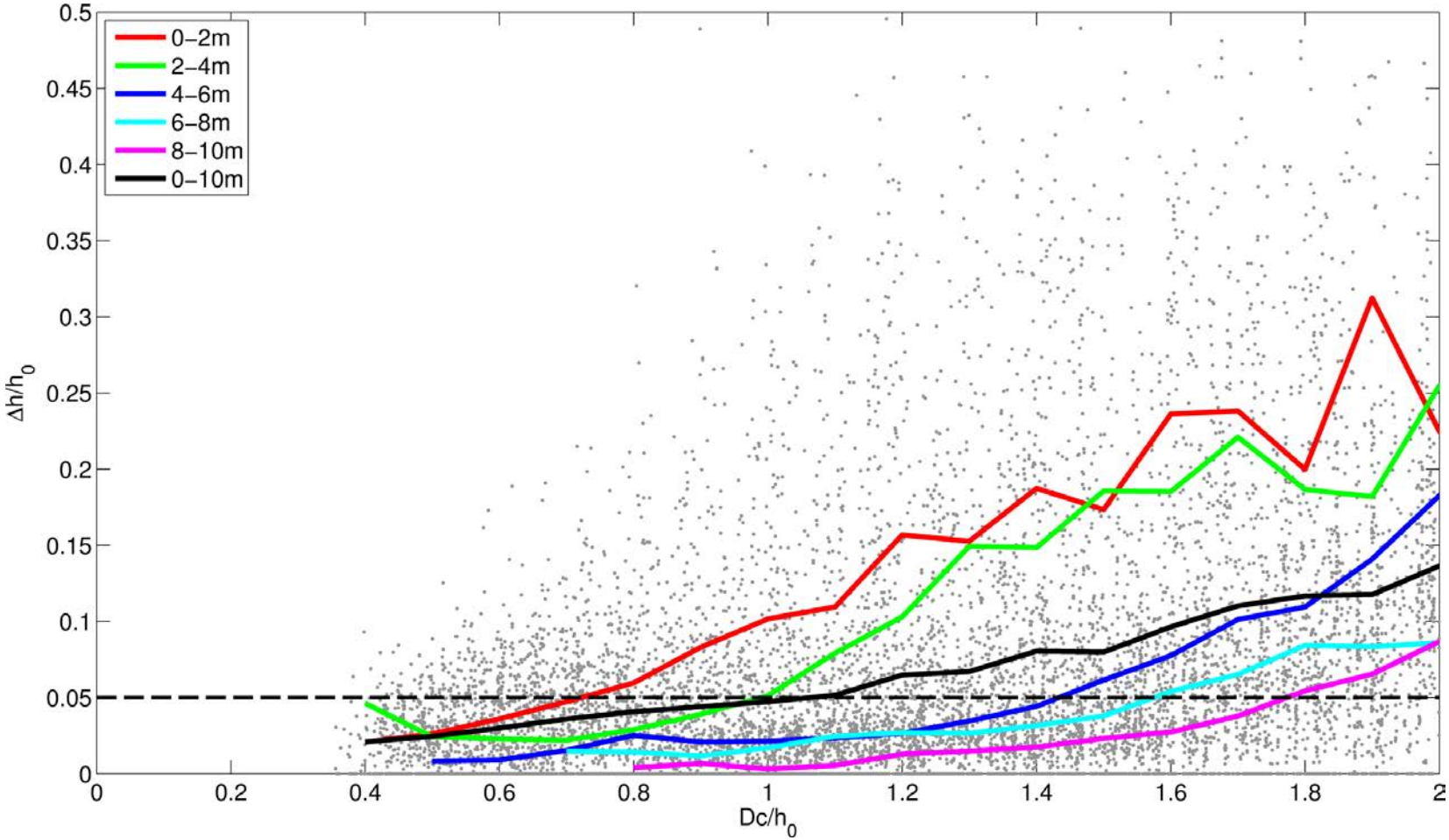


- He_{95} is always smaller than He
- Significant curvature – not just a straight line

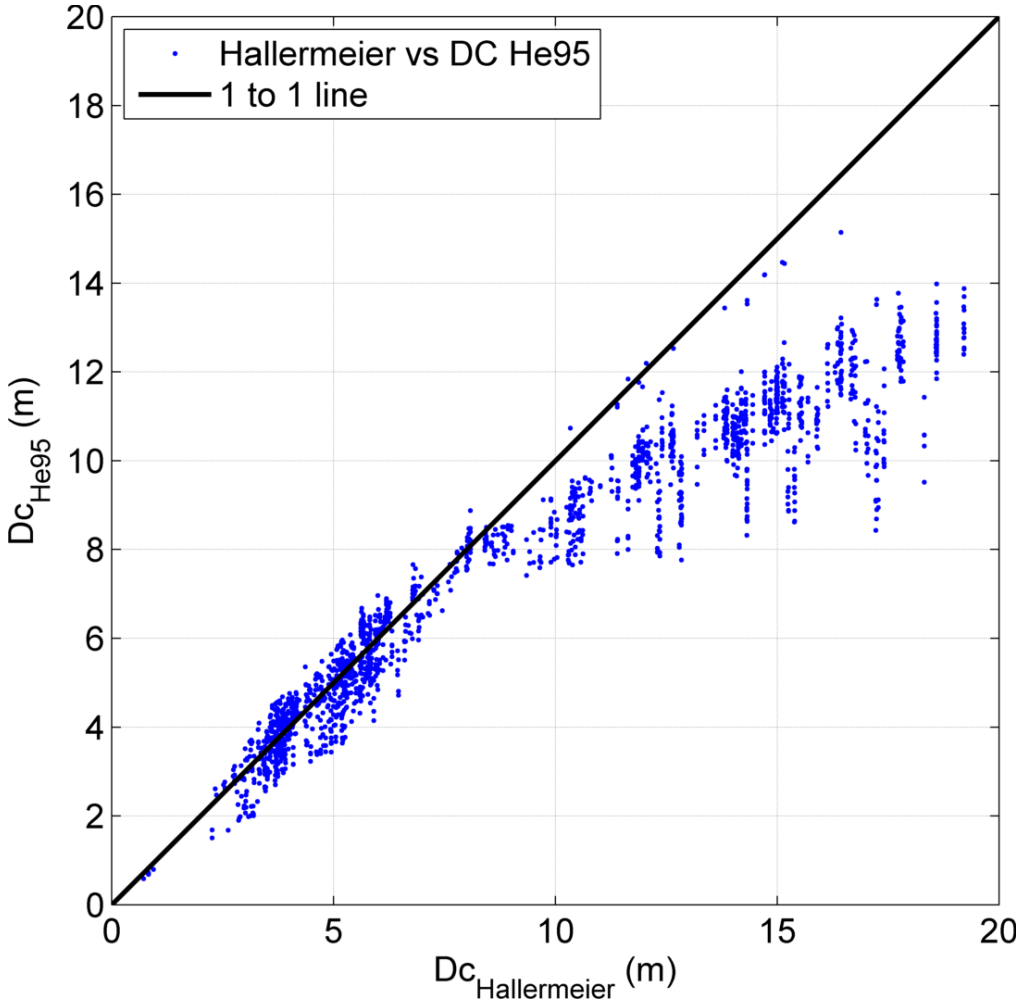
Depth of Closure He_{95}



Depth of Closure Hallermeier



Comparison between Hallermeier and New Depths of Closure



- Similar results for small Dc, but new results show smaller depth of closure for large waves
- Clearly shows the effects of different wave height probabilities on Dc
- To be revised using Atlantic data
  - Less of a hurricane dominated climate

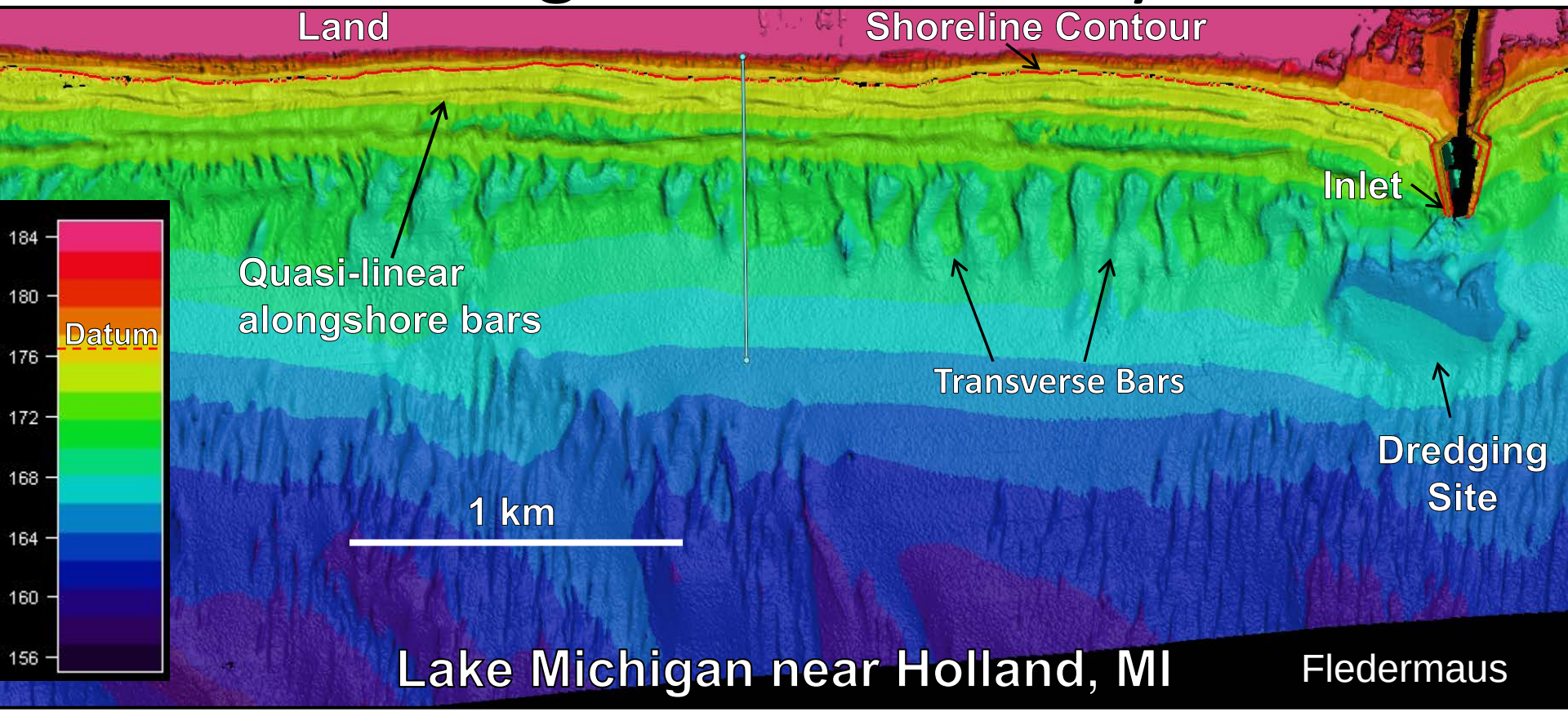
Depth of Closure

- It is clear that redefinition of wave heights and periods can improve performance
- Need to incorporate Atlantic Ocean data into analysis
  - Have data, but need to redo analysis
- Still remains to be seen if behavior is only a function of wave height
  - Currents and tides will be important in regions of small waves, but are not included here
- On track to finish this summer

Three Dimensional Bathymetric Variations

- Classification of three dimensional beach state is one of the primary goals of this project
- Now mainly descriptive: Wright and Short (1984) and subsequent papers
- How to classify quantitatively and automatically?
  - What are the appropriate parameters
- Very short description of recent work on identification of longshore features
  - Must use Type 2 bathymetry (no gaps)
  - Many more candidate bathymetries
  - Still in progress

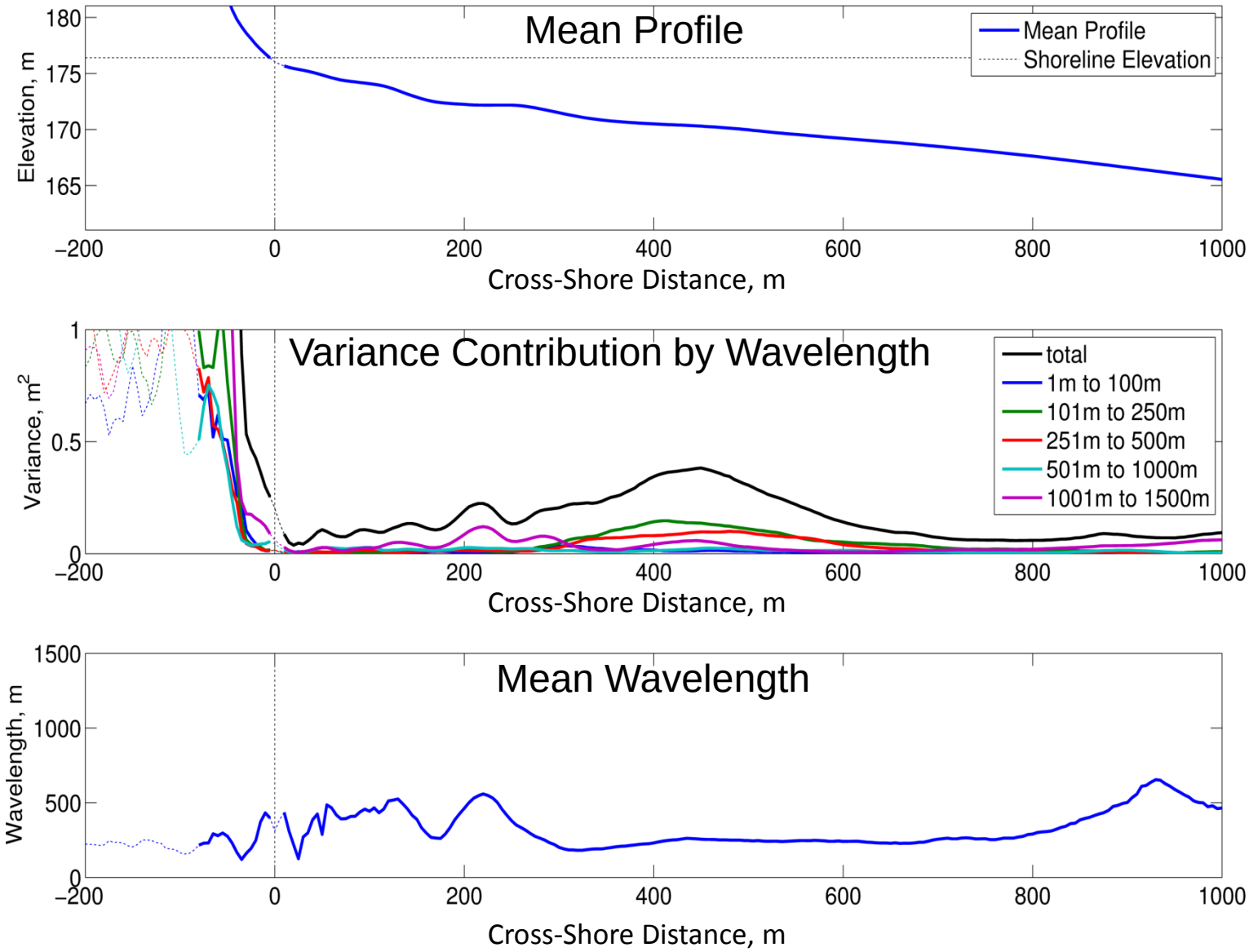
Longshore Variability



- Morphologic features are present at a variety of wavelength in the longshore direction (e.g. transverse bars)
- Wavelengths and amplitudes of features vary moving offshore.

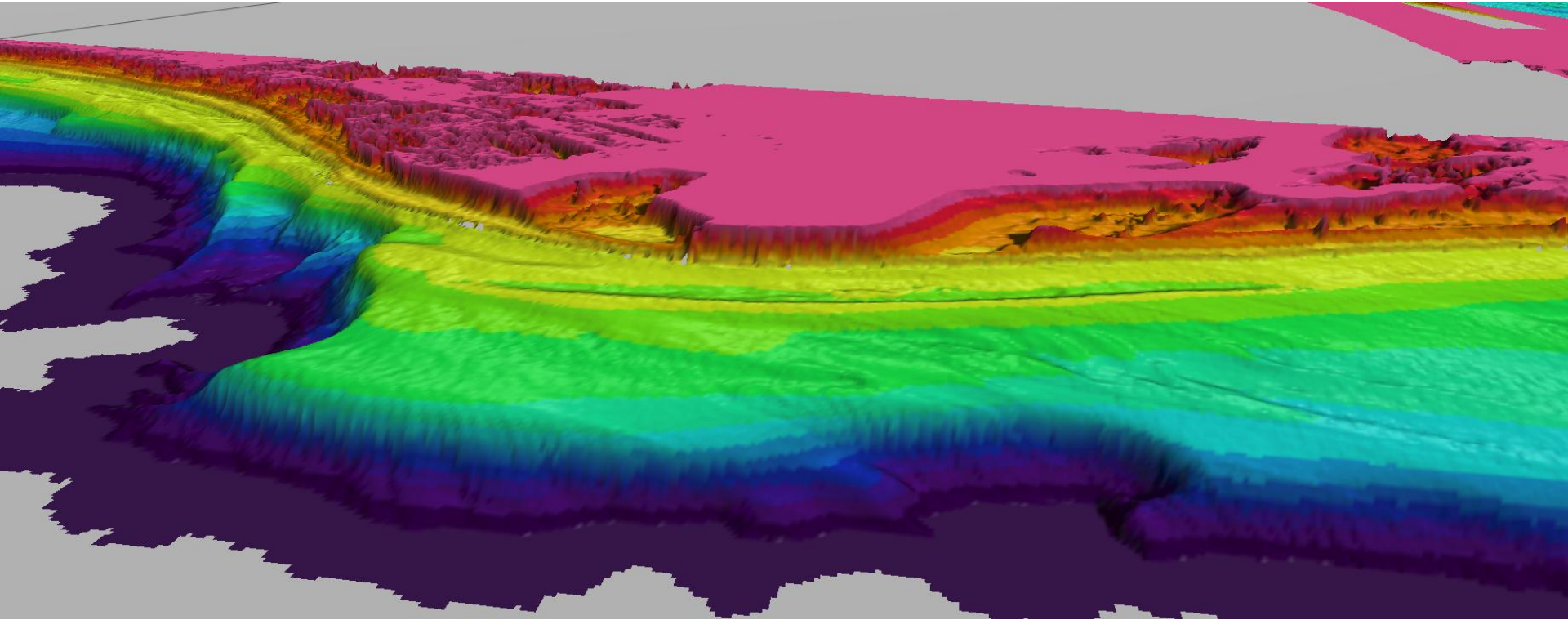
Use Alongshore Spectral Analysis to identify significant wavelength components.

Longshore Variability



Conclusions and Future Work

- Continuing work on Depth of Closure with Atlantic Data
- Extension of three dimensional analysis to automatic quantification of beach states
  - Relation to wave climate
  - Commonalities in morphology
  - Features observed
- Methods to represent findings for professional practice
  - Online access?
  - Rules and Parameterizations?

Acknowledgements

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