ICCE 2018
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The State of the Art and Science of Coastal Engineering

PREDICTING COASTAL ROADWAY DAMAGE USING MODIFIED DISPERSION FUNCTIONS

UNIVERSITY OF SOUTH ALABAMA SYSTEMS ENGINEERING
RICE

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NIST Funded COE Research

- CSU COE in cooperation with NIST is developing an all-hazards model that considers all aspects of how a natural disaster affects a community and measure its resilience quantitatively.
- COE is coordinating a common data architecture by collaborating with the National Center for Supercomputing Applications to ensure that data is seamlessly integrated into a robust computationally efficient modeling environment identified as INCORE.
- INCORE allows users to optimize community disaster resilience planning and post-disaster recovery strategies intelligently using physics-based models of interdependent physical systems interaction with socioeconomic systems.

Partners

- Colorado State University
- CAL POLY POMONA
- ILLINOIS — UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
- The UNIVERSITY of OKLAHOMA
- Oregon State UNIVERSITY OSU
- RICE
- UNIVERISTY OF SOUTH ALABAMA
- TEXAS A&M UNIVERSITY
- TEXAS A&M UNIVERSITY KINGSVILLE
- UNIVERSITY of WASHINGTON

Galveston Test Bed Model

- County Road 257 on Follett's Island in Brazoria County, Texas had significant damage at various locations during Hurricane Ike in September 2008

"CR257 sustained catastrophic damage resulting from the tidal surge associated with the approach of Hurricane Ike. The damage ranged from partial failure of the edge of pavement to the complete obliteration of the pavement structure and embankment within the right-of-way. It appears that much of the damage occurred when the tidal surge began to recess and the water flow accelerated toward the gulf side of the island. Much of the pavement material was deposited on the beach side of the roadway." (Coast & Harbor Engineering 2009)

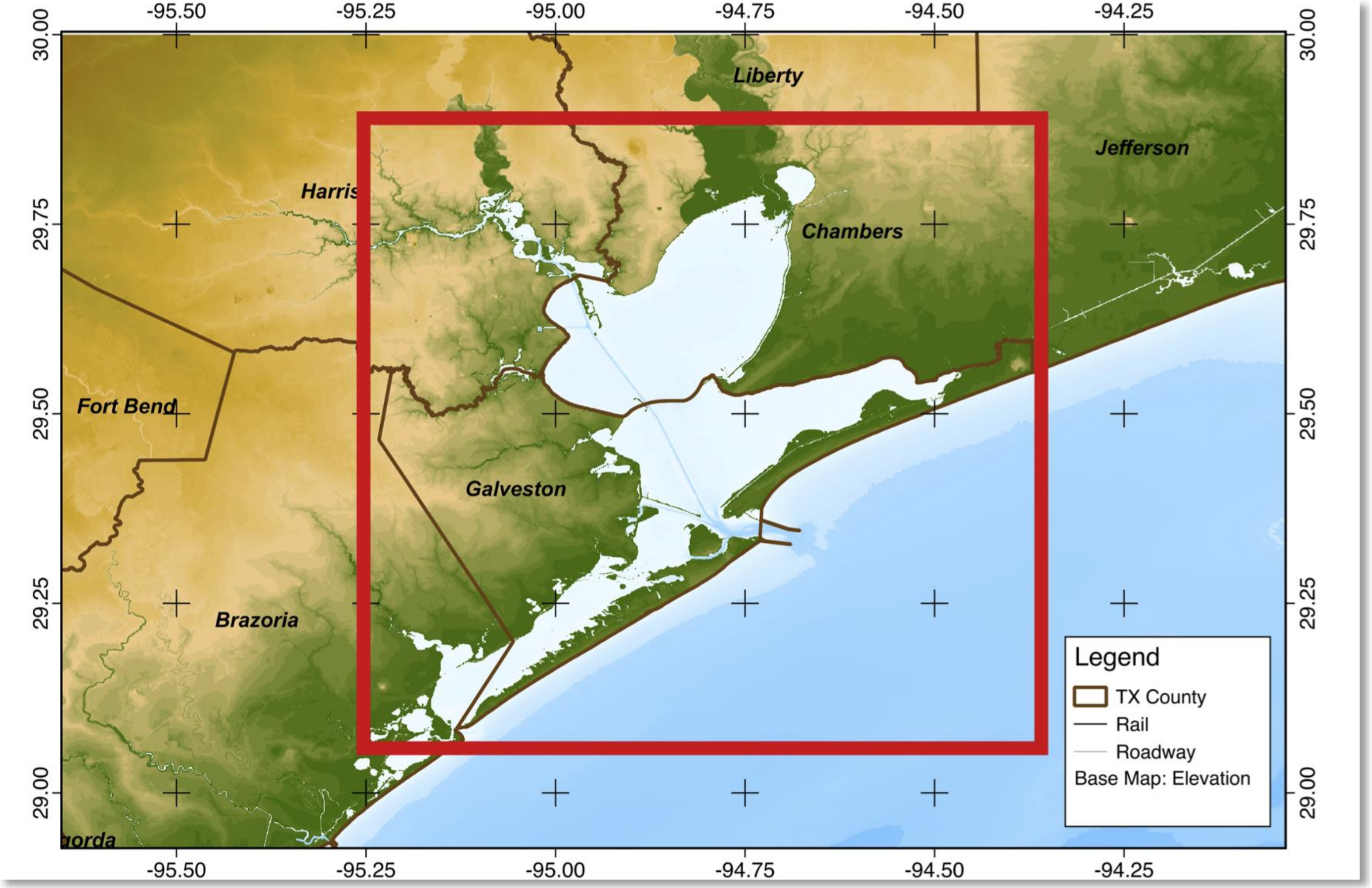
Galveston Test Bed Model Research Team

- **Collaborators:** Dan Cox (OSU), Andre Barbosa (OSU), Eun Cha (UIUC), Jong Sung Lee (UIUC), Jamie Padgett (Rice), Walter Peacock (TAMU), Shannon Van Zandt (TAMU), Dorothy Reed (UW), John van de Lindt (CSU), Elaina Sutley (KU), Bret Webb (USA), Greg Holland (NCAR), Sara Hamideh (Iowa State)
- **Post-Docs & PhDs:** Navid Attary (CSU), Mohammad Ameri (CSU), Yanlin Guo (CSU), Nathanael Rosenheim (TAMU), Maria Watson (TAMU), Kijin Seong (TAMU), Donghwan Gu (TAMU), Yu Xiao(TAMU), Ioannis Gidaris (Rice), Sushreyo Misra (Rice), Tori Johnson (OSU), Stanley Wang (UW), Jose Leon (UW), Garland Pennison (USA), Xian He (UIUC)
- **NIST collaborators:** Long Phan, Marc Levitan, Maria Dillard, Ken Harrison

Galveston Coastal Hazards Modeling

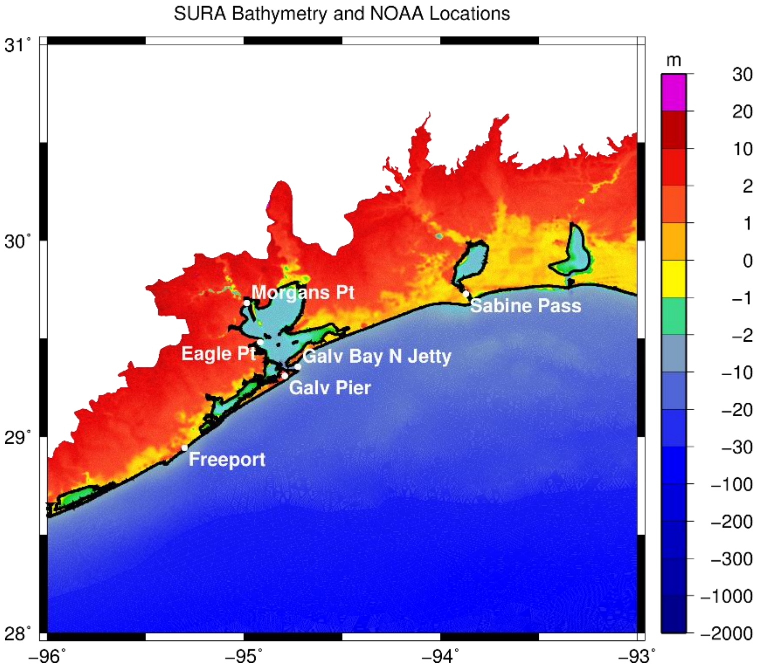
- Hurricane Ike Hindcast
- ADCIRC+SWAN
- Tides
- Storm Surge
- Waves
- Flow
- Winds (proprietary)
- Coarse Mesh (1st effort)
- Fine Mesh (2nd effort)
- Meshes cover entire Gulf of Mexico and NW Atlantic
- 3.4M Nodes

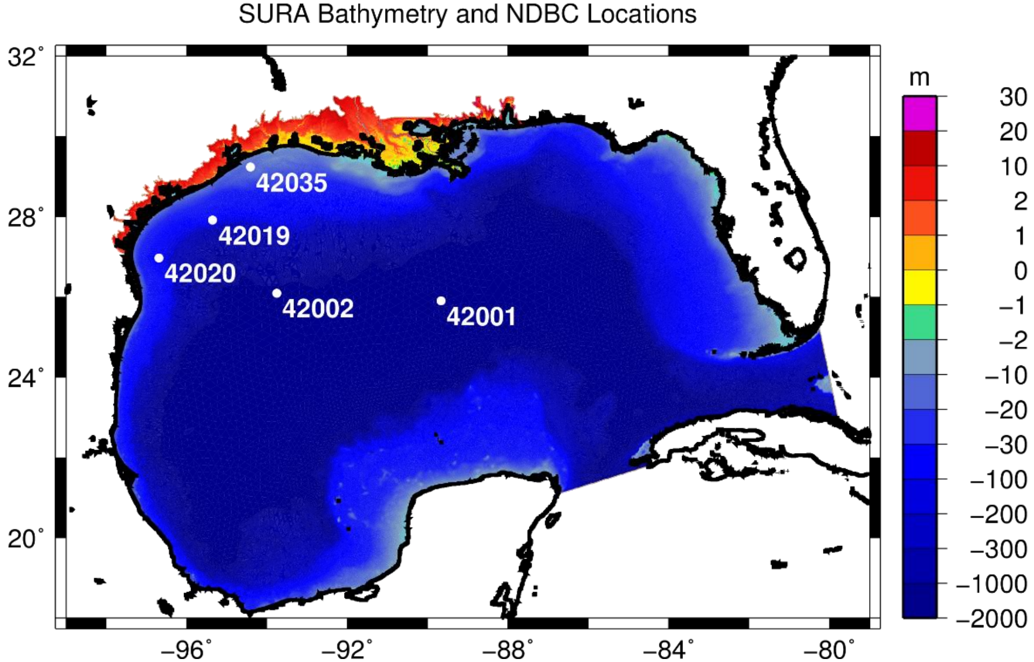
Coastal Modeling by Bret Webb



Galveston Coastal Modeling Validation

- Surge Hydrographs (±11%)
- High Water Marks (80% within ±0.5 m)
- Waves (±12%)
- Errors Reduced with High Resolution Mesh





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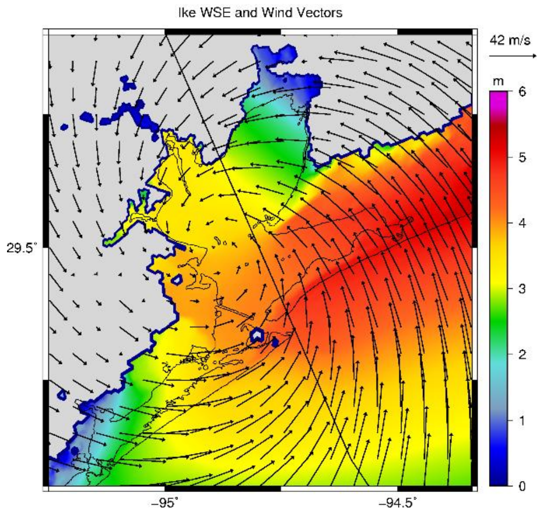
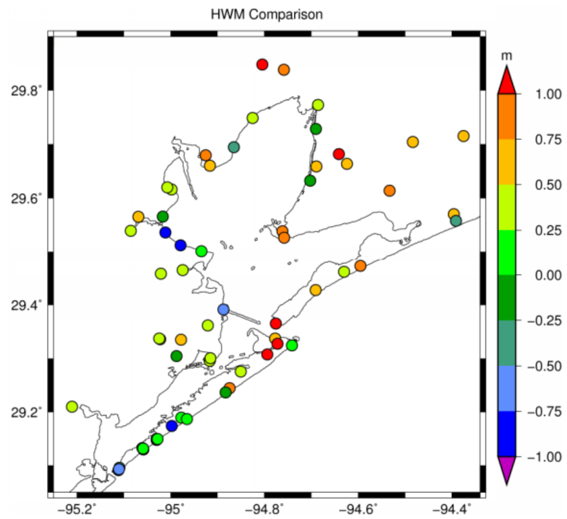
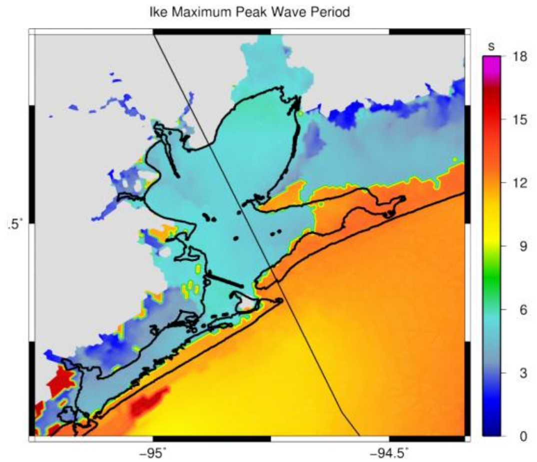
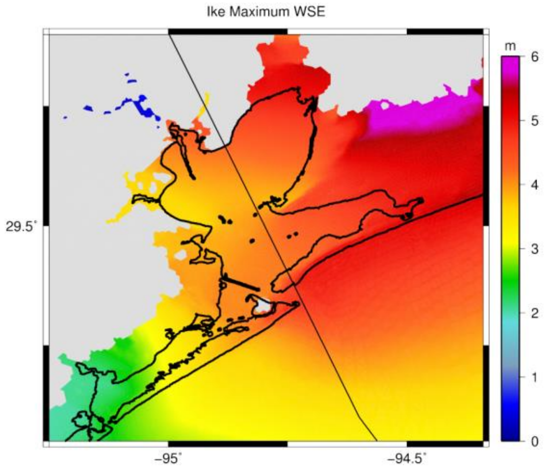
Galveston Coastal Modeling Intensity Measures



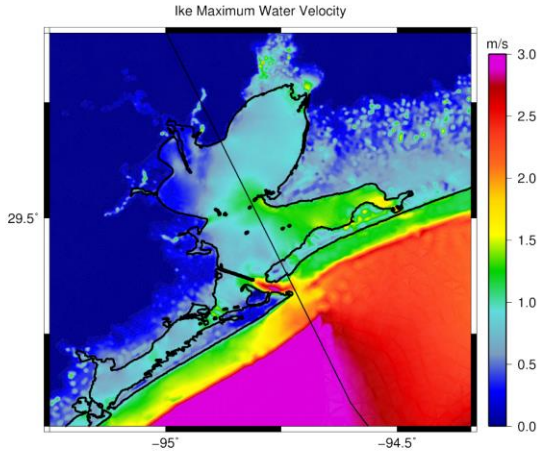


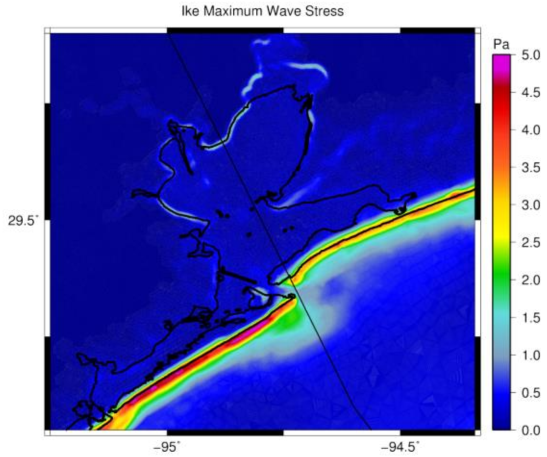


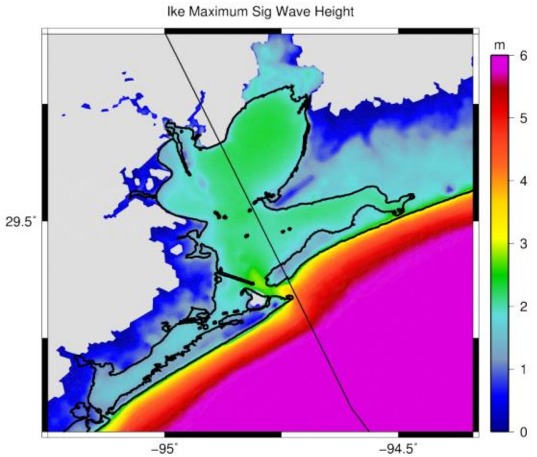


Peak Intensity Data

- Maximum Intensity
- Time Series (Peak IMs)
- Wind Fields
- Water Velocity
- Surge Elevation
- Flood Depth
- Wave Ht/Period/Dir

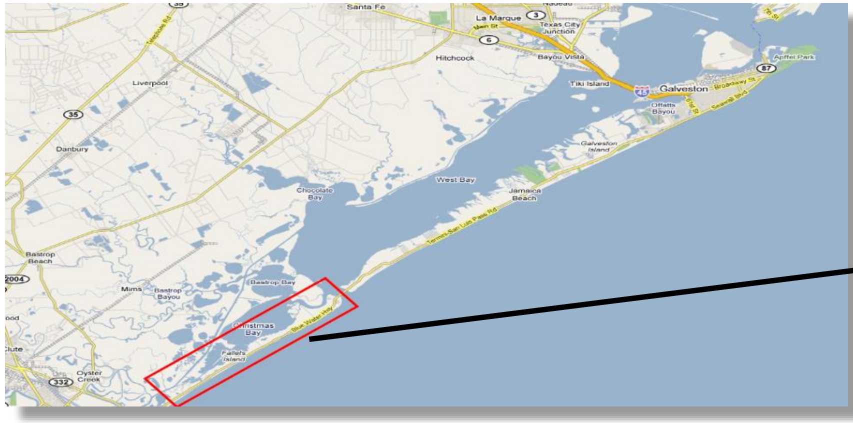


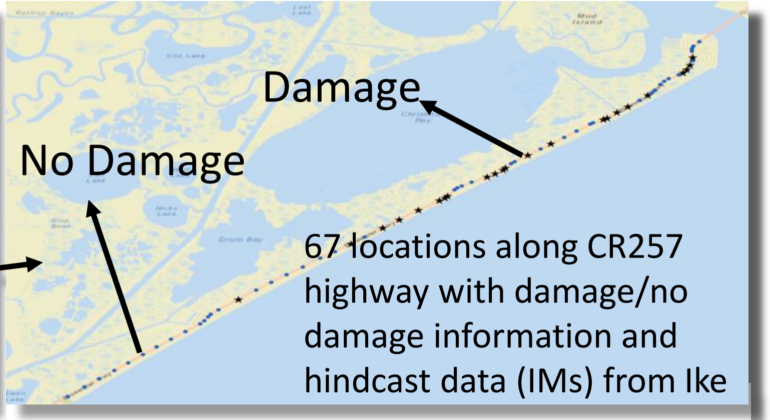


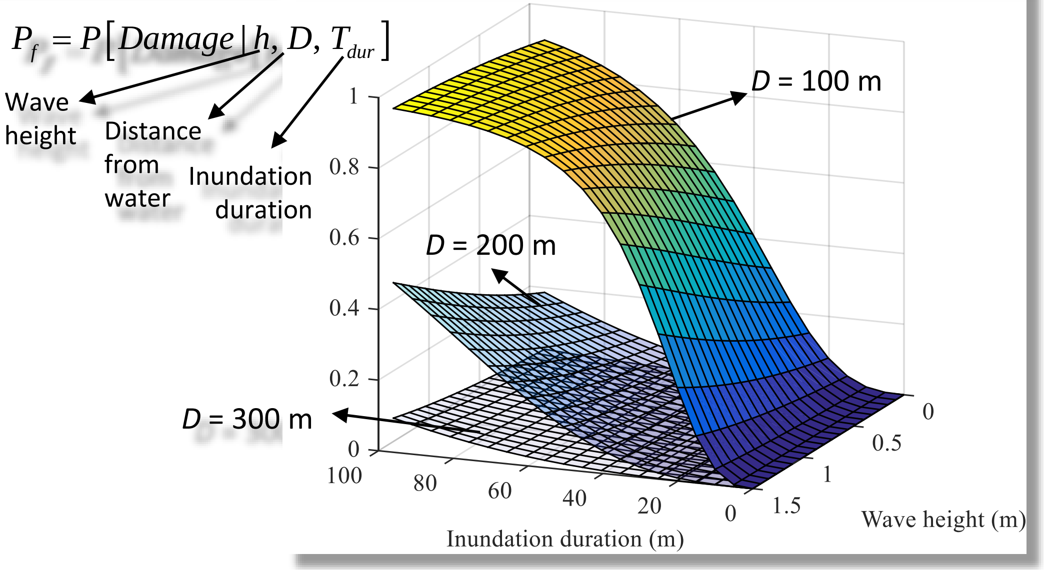


CR 257 Roadway Fragility Model

Tier 1 roadway fragility surface models developed by Ioannis Gidaris & Jamie Padgett demonstrate that critical variables predicting likelihood of failure include wave height, offset distance of road from water, and inundation duration.





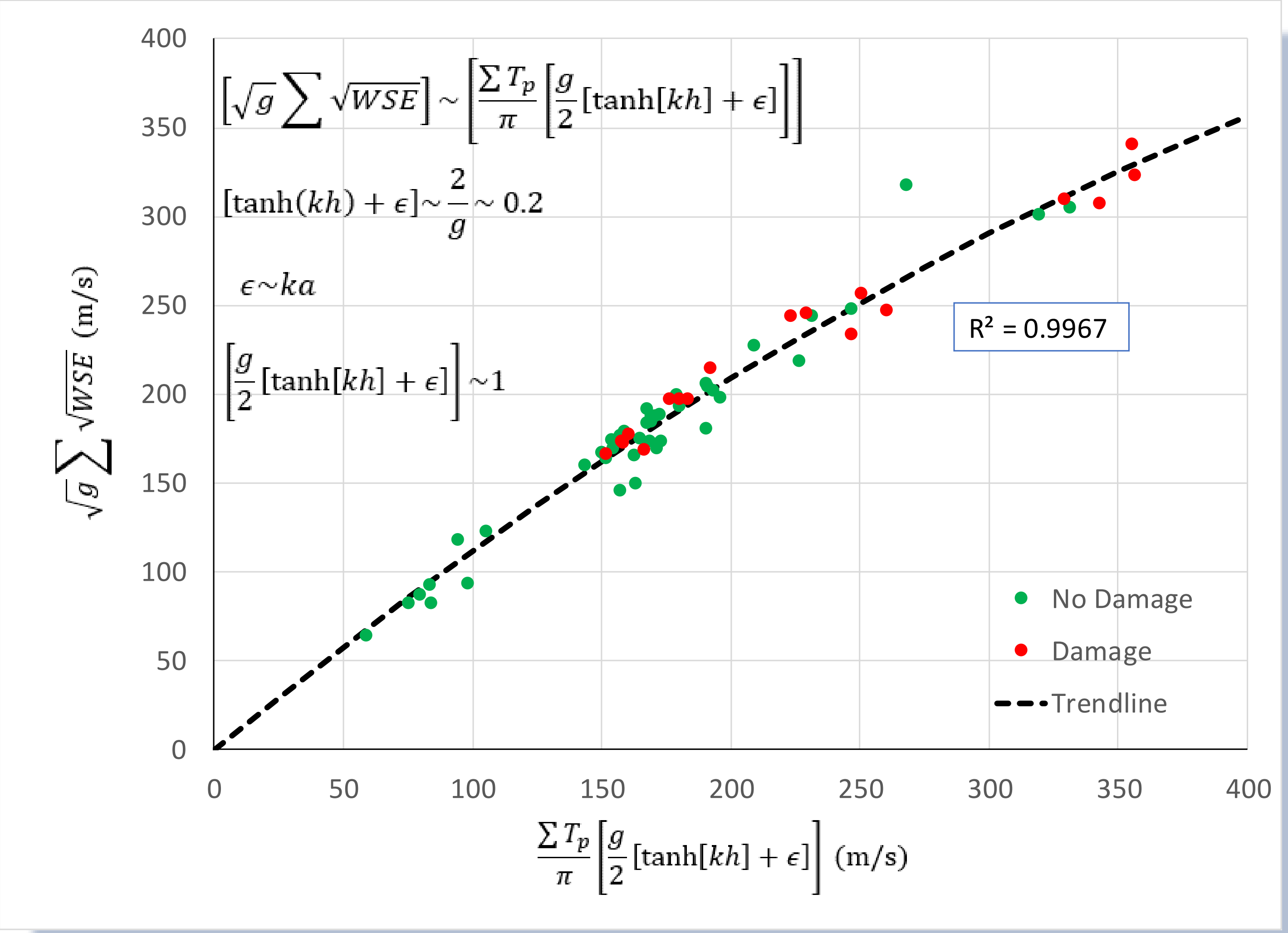


Peak Intensity Measures from Model Data

- Model output data were extracted along CR 257 between Galveston and Surfside, Texas as hourly peak intensity measures (IM) (locations shown in Google Earth image below).
- Data were initially evaluated for multiple variables assessing significance and correlation relative to likelihood of damage. Fragility function was developed for Tier 1 model.
- Analysis determined that cumulative celerity dispersion functions strongly predict likelihood of damage. Peak hourly IM data are aggregated only when road overtops at 67 data points.

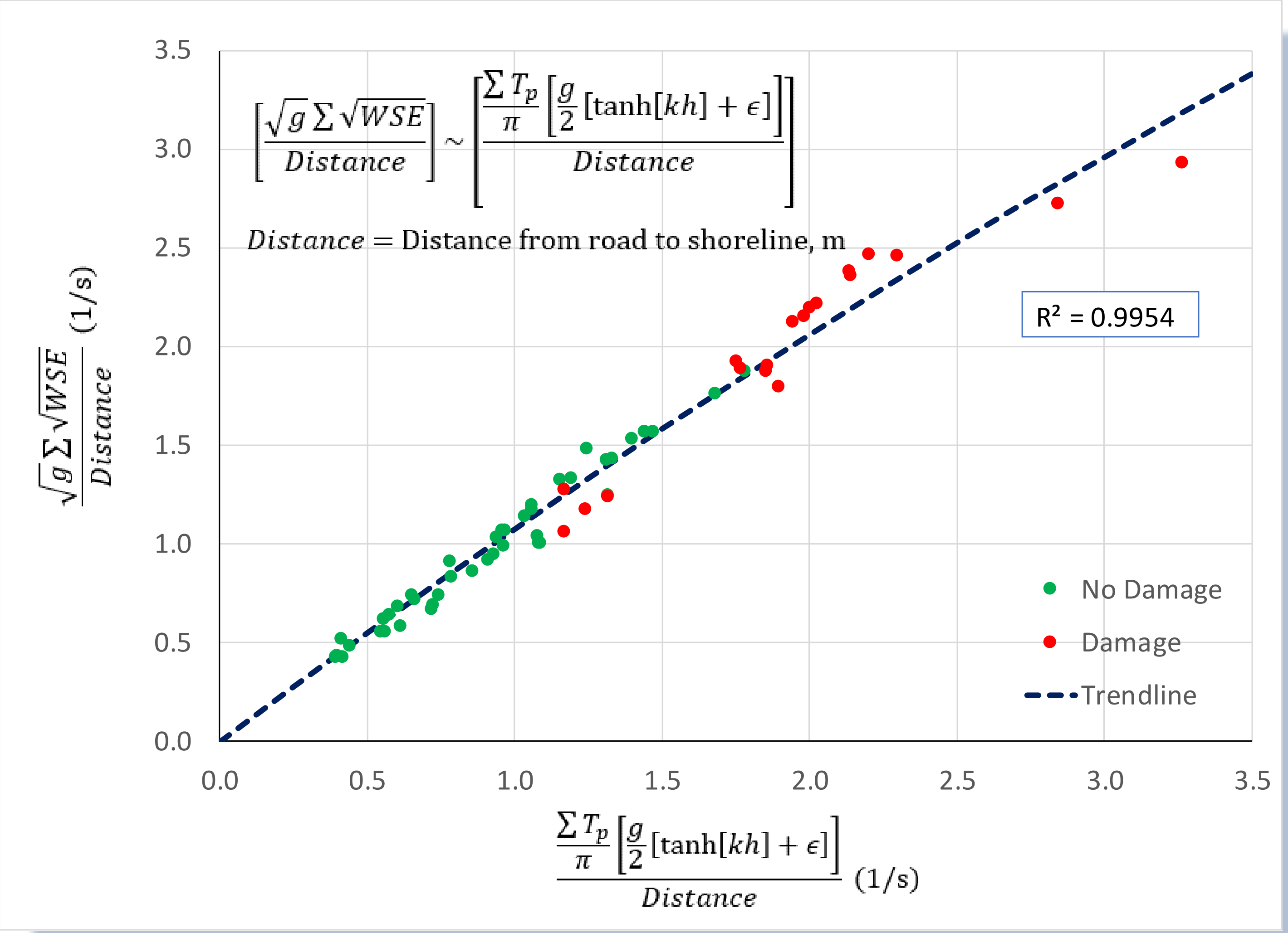
Correlation of Cumulative Celerity Equations

- FINDING #1: Gravity wave celerity dispersion functions computed using cumulative water surface elevation and cumulative wave period hourly peak IMs for overtopping flows are strongly correlated and approximately equal in value for event duration.



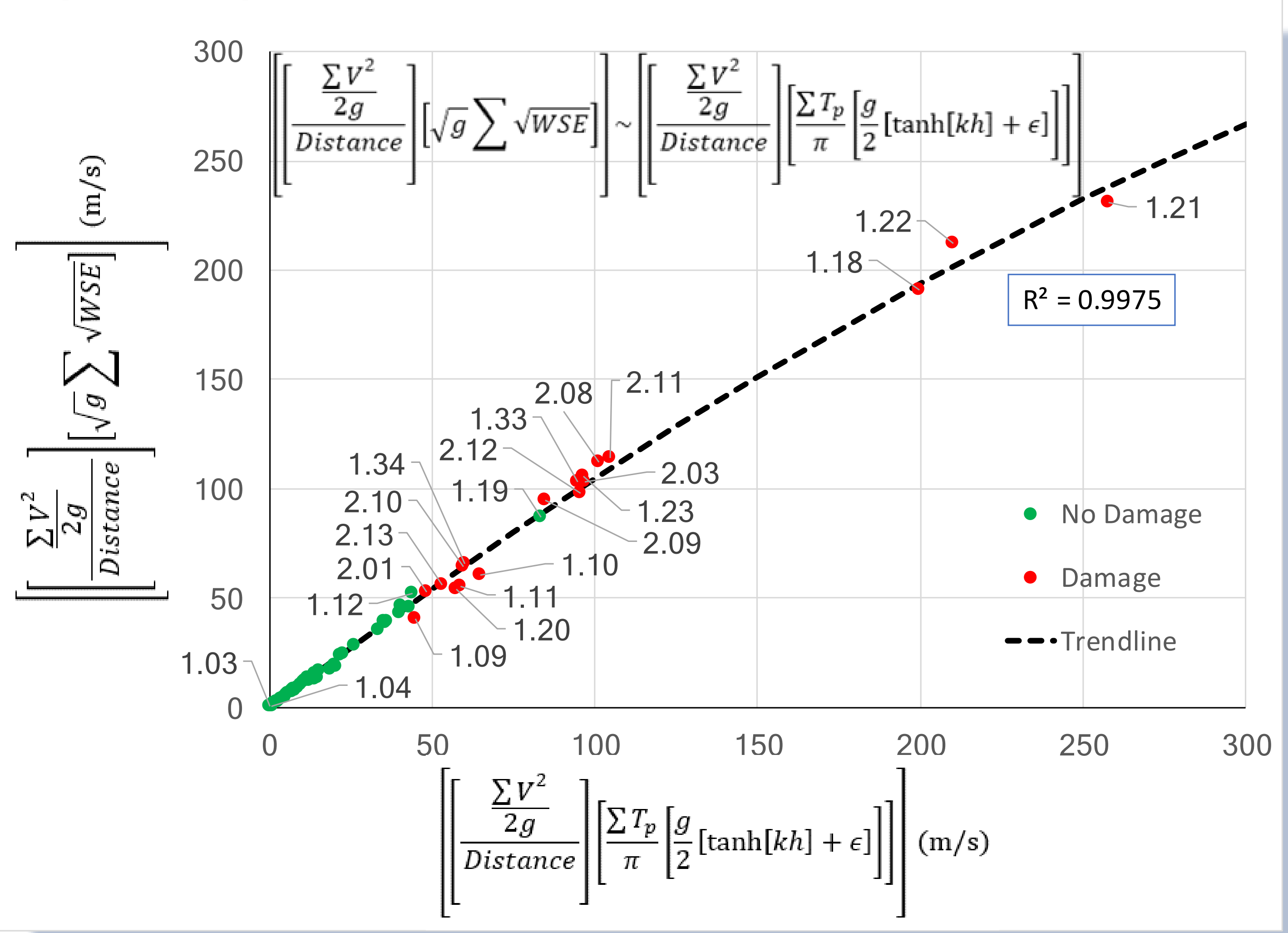
Distance of Road to Shoreline is Critical Gradient

- FINDING #2: Cumulative functions vary based on approximate distance from CR 257 to shoreline measured at mean sea level from pre-event aerials. Distribution of function as a gradient relative to setback distance of the roadway improves damage grouping.

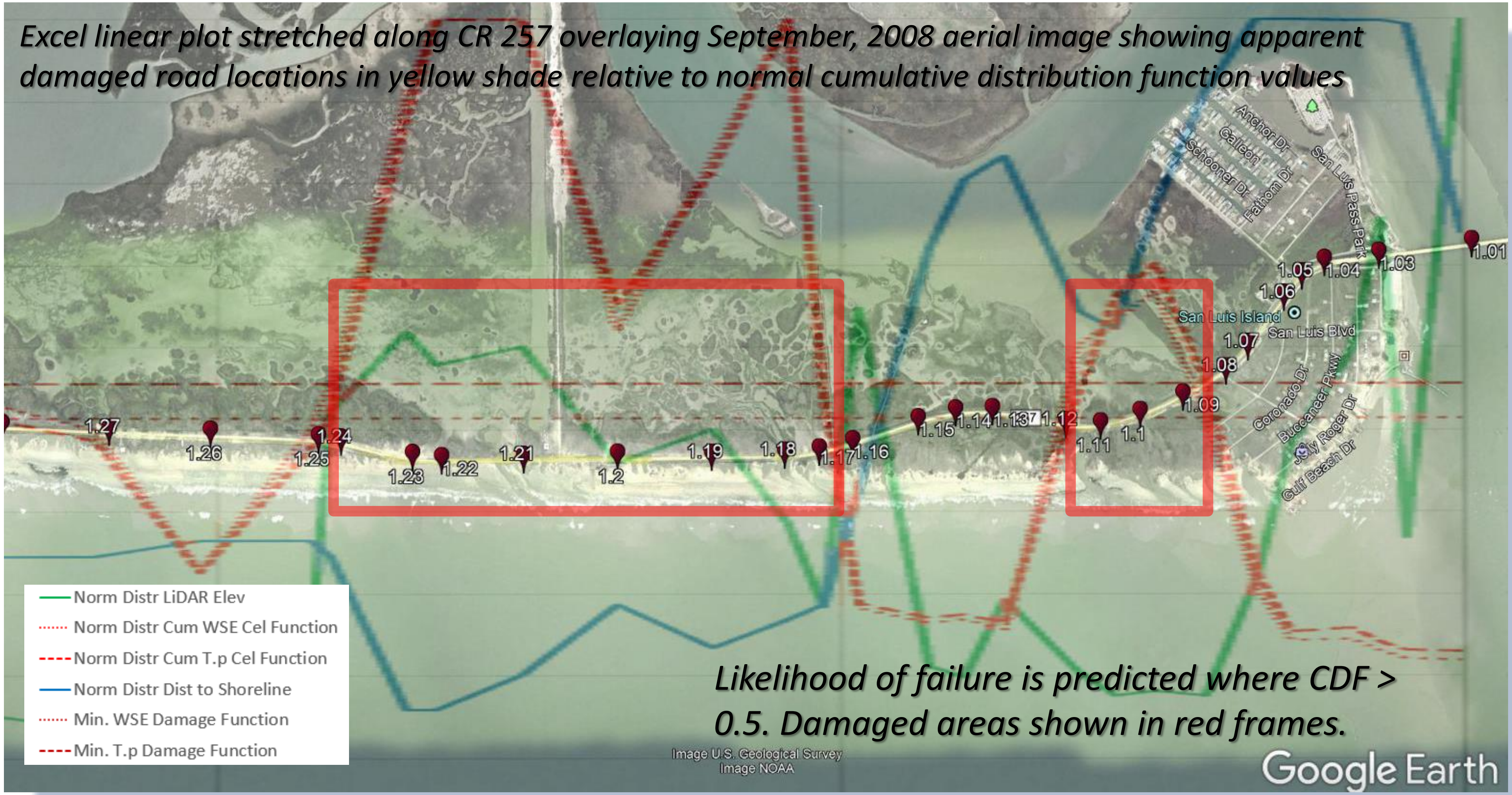


Cumulative Celerity Dispersion (CCD) Function

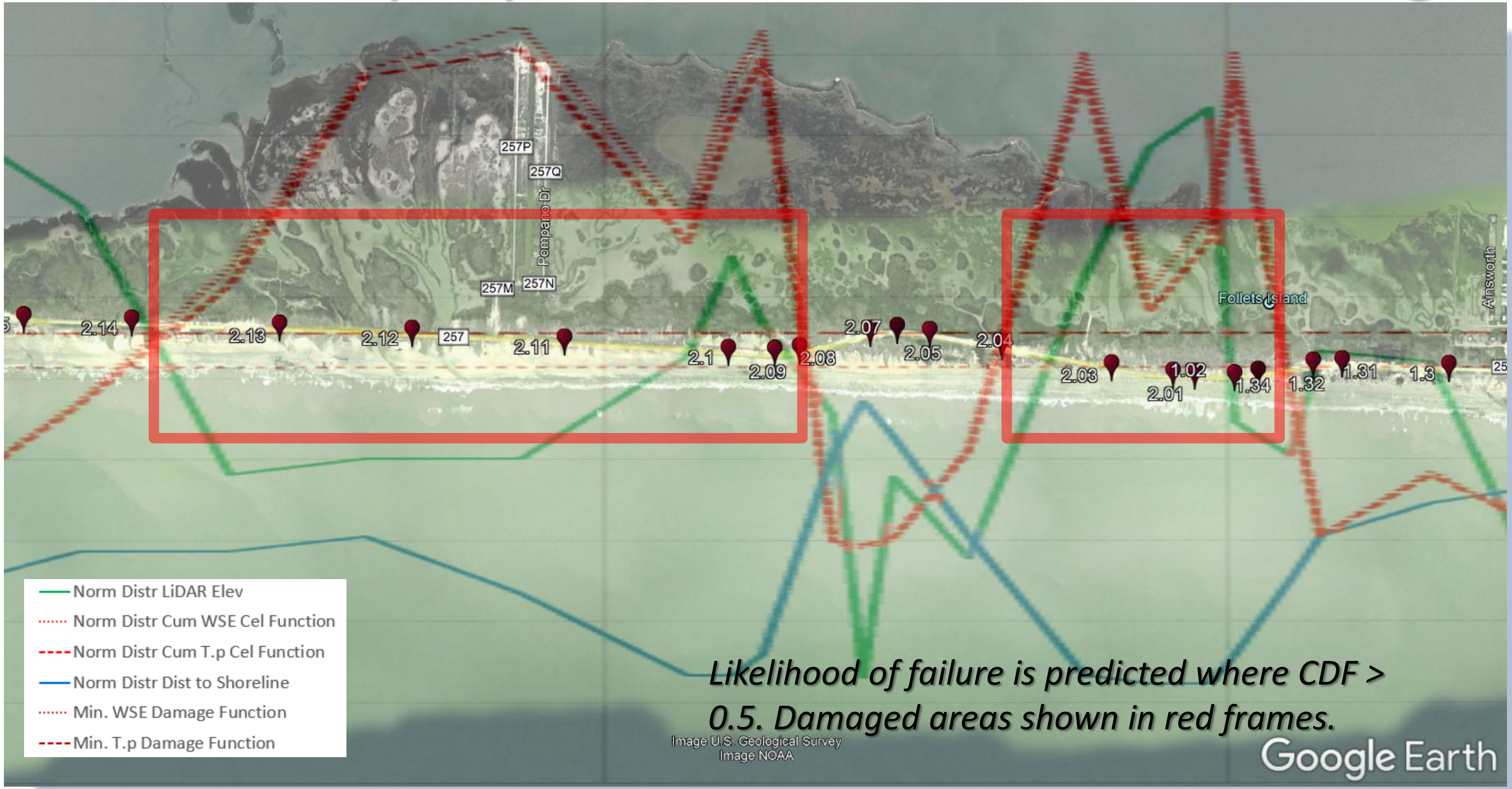
- FINDING #3: Cumulative current velocity accounts for velocity head at overtopping flow. Resultant value is reported as velocity head per unit distance measured between road and shoreline times cumulative celerity. Comparing cumulative function progression for event assists with validating likely damage failure modes. Critical threshold value for predicting likely damage along CR 257 is CCD value greater than 42 m s[-1].



CCD values predict damage likelihood with…



CDF values proportional to levels of damage



Using Failure to improve the Likelihood of Success

- When does damage occur? Cumulative CCD damage threshold values are exceeded soon after velocity vectors reverse direction creating strong ebb currents, confirming observed backflow damage.
- Moderate damage failure modes? Ebb currents inundate saturated roads and create overtopping flow scour conditions.
- Major damage failure modes? Wave breaking appears to be forced due to critical depth flow over the road. Steepened waves interact with strong ebb currents on saturated road pavement structure with resulting forcings. These forcings mechanics are being evaluated with wave flume experiments.

If CCD functions using peak intensity measures strongly predict likelihood of road failure, then model can also be used to reduce failure probability.

Improve road system resiliency by reducing fragility model uncertainties.