Tropical Storm Response Prediction Using Surrogate Models

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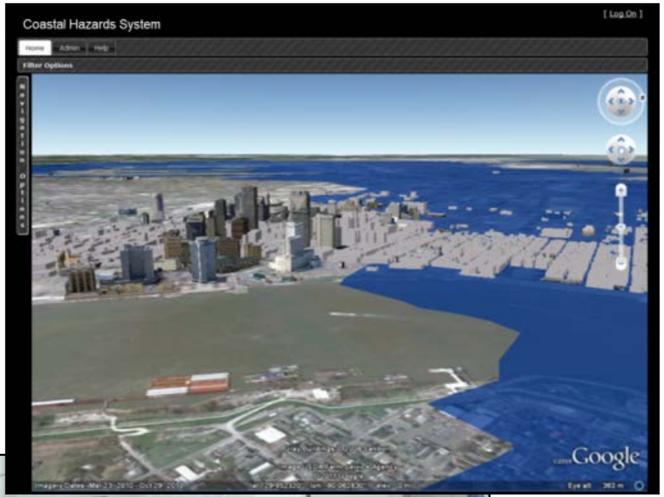
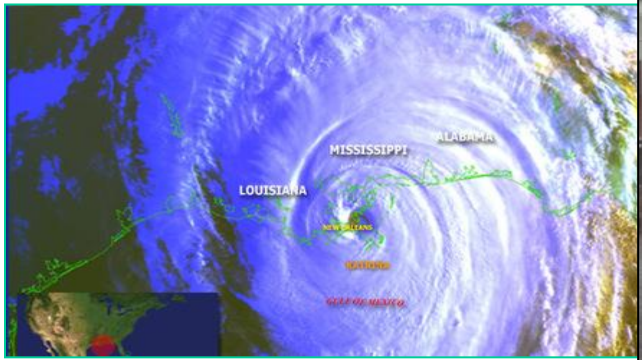




Motivation

- **Challenge**
  - Hurricane landfall location is highly uncertain
  - Present predictions are either stochastic/low fidelity or deterministic/medium fidelity/ad-hoc
  - High-fidelity (HF) modeling is resource intensive
  - Many scenarios required
  - Processes are nonlinear and complex
  - Model output is very high-dimensional
- **Support**
  - High spatial/temporal correlations
  - Regional HF modeling complete in some regions
  - Many robust approaches to surrogate modeling
  - Strong demand for high fidelity, rapid estimations for emergency management and real time/static risk assessment

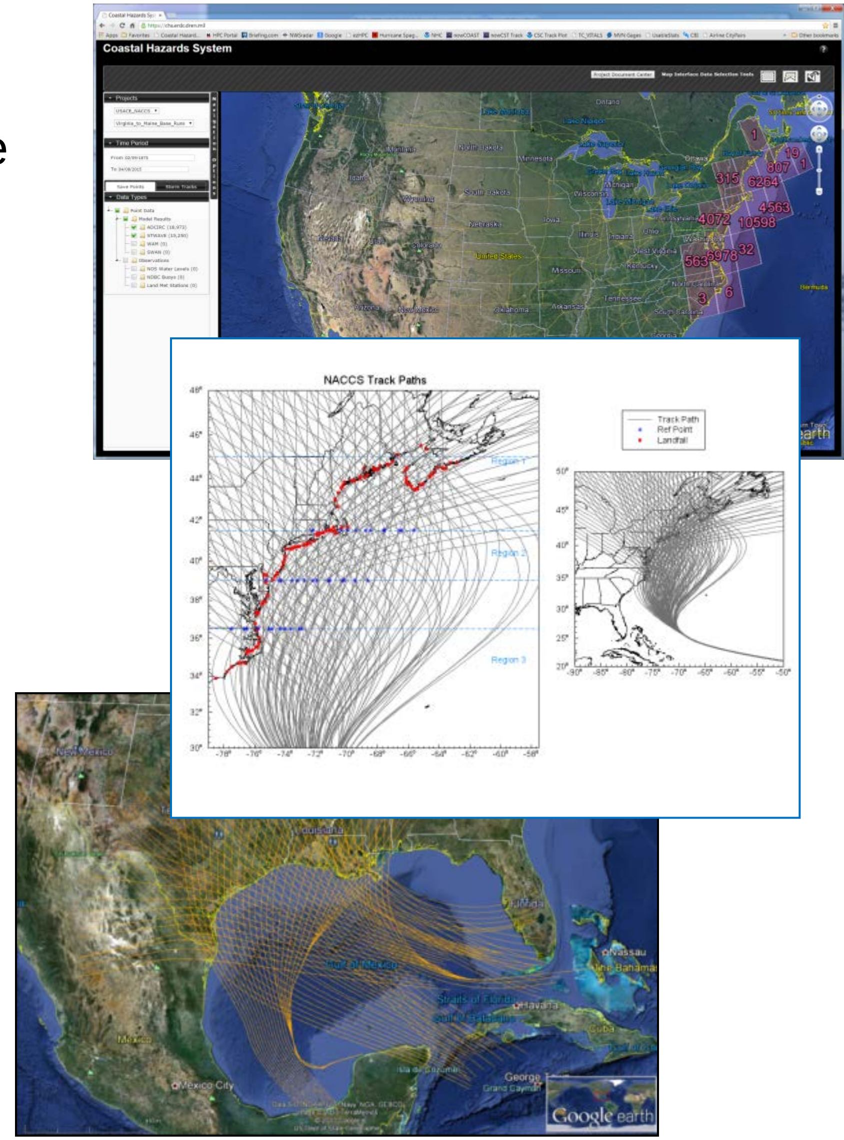
Surrogate Techniques: Data Driven

- Least squares regression
- Low dimensional spline interpolation
- Dimensional functions
- Polynomial chaos
- Response surface approximations
- **Artificial neural networks**
- **Kriging or Gaussian process emulation**

Surrogate Modeling

Unique Leveraging Opportunities

- Disk storage and wide band internet are relatively inexpensive
- Regional high-fidelity modeling is being done for federal projects
- Regional studies represent parameter and probability space with an efficient sample
- **Coastal Hazards System** data with NACCS, Gulf of Mexico data

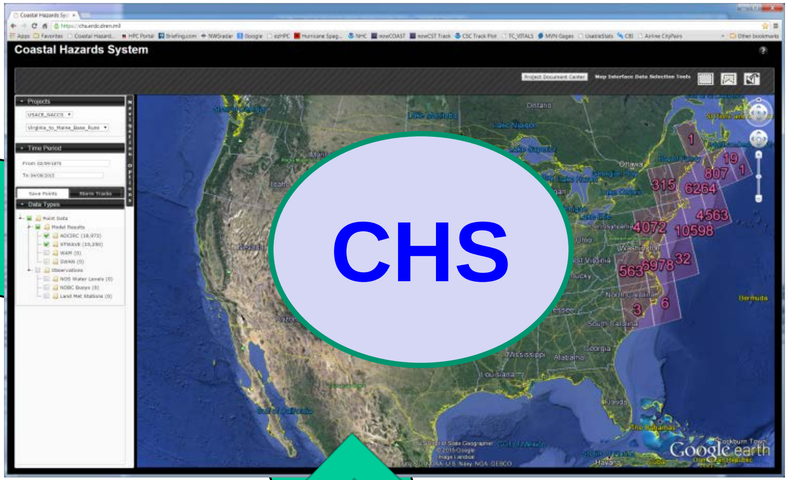


Coastal Hazards System

Storm Selection

Characterization of Storm Climate (Forcing)

- Tropical Cyclones (Synthetic) → Development of JPM Storm Set
- Extra-tropical Cyclones (Historical) → Development of Composite Storm Set



Climate and Hydro Modeling

PBL Cyclone Model (Wind and Pressure Fields) → WAM (Regional) → Coupler

ADCIRC

Coupler

STWAVE (Nearshore)

- Water level (storm surge, astronomical tide, SLC)
- Currents
- Wind speed, direction
- Wave height, period, direction

Response Statistics

Combined Joint Probability

↓

Annual Exceedance Probability
Average Recurrence Interval
Confidence Levels

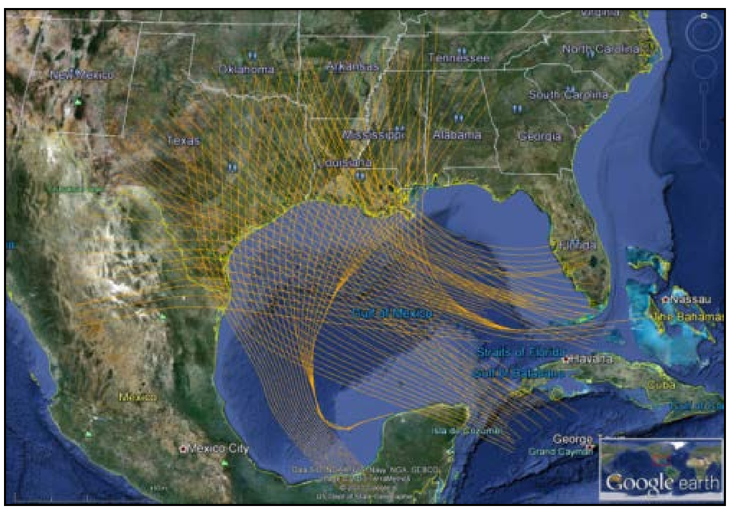
Coastal Hazards System

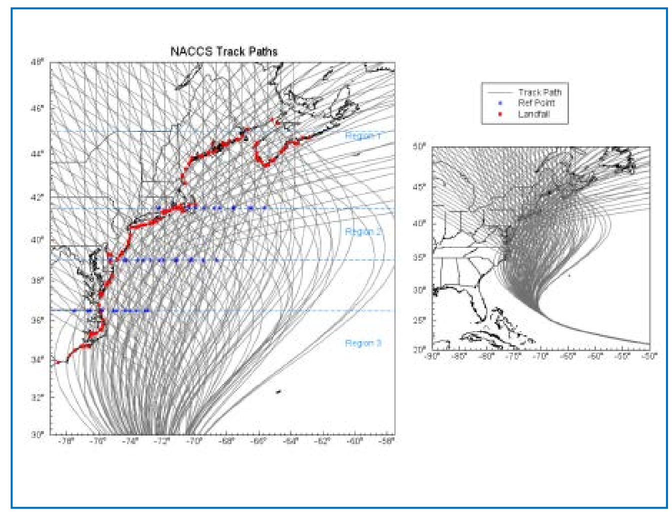
LA/MS – 446 storms

- C_p: 900 - 975 mb
- V_f: 11 – 33 km/hr
- R_{max}: 11 – 51 km

NACCS – 1050 storms

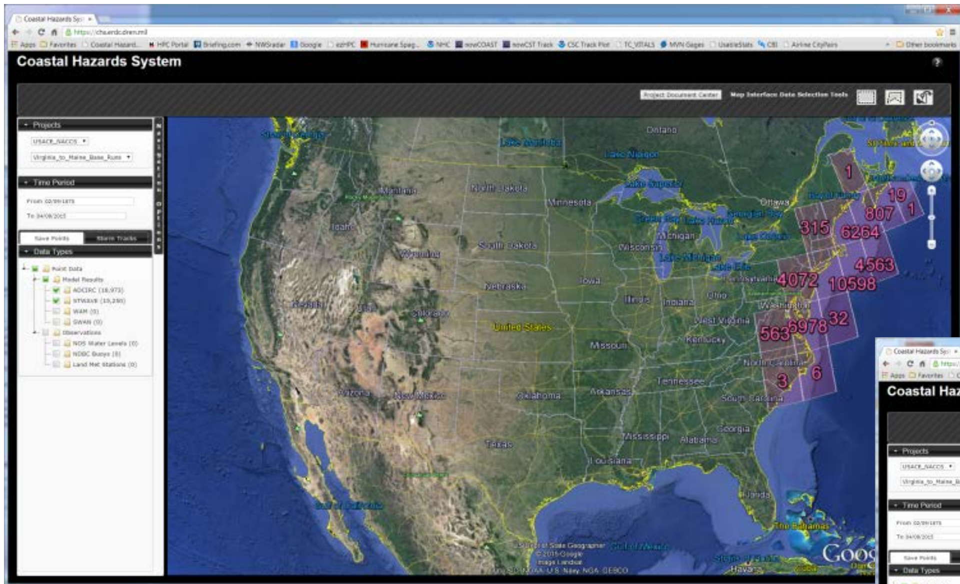
- C_p: 915 – 985 mb
- V_f: 12 – 88 km/hr
- R_{max}: 25 – 174 km

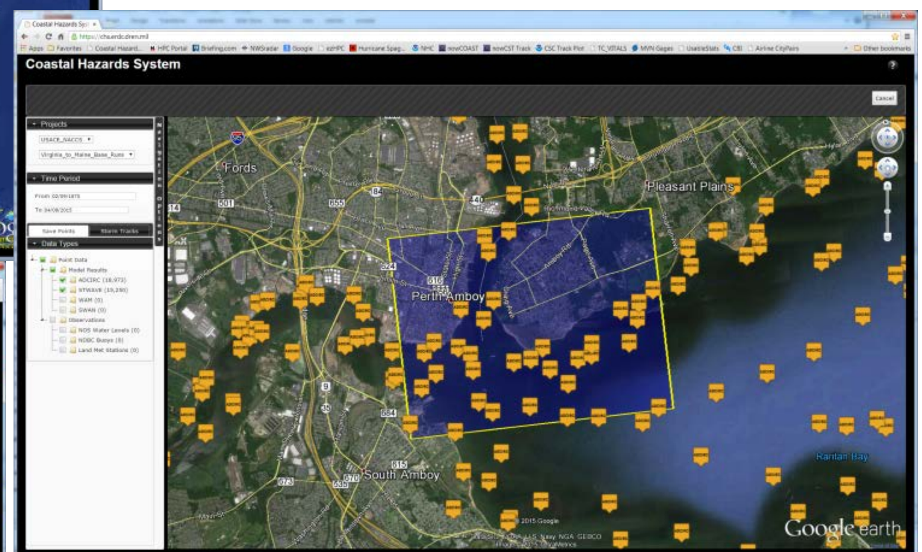


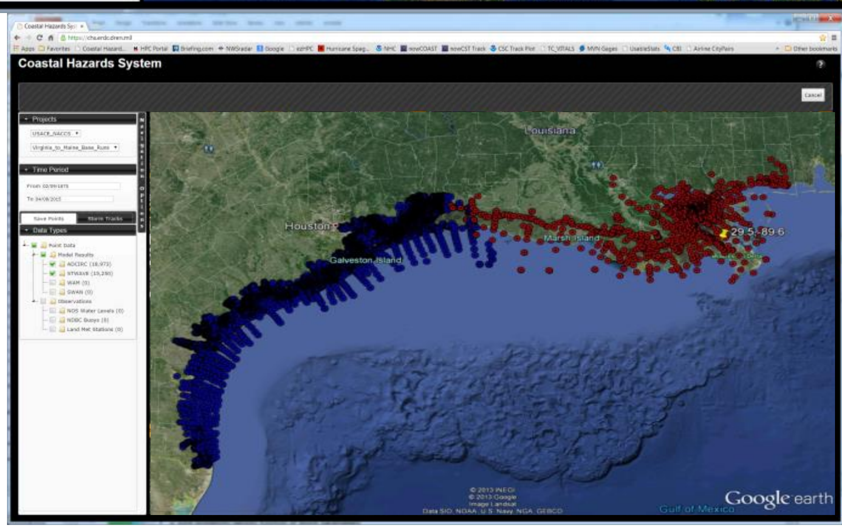


Coastal Hazards System

- **NACCS: 19k points**
- **LA/MS/TX: 10k points**
- **LA grid: 200k points**



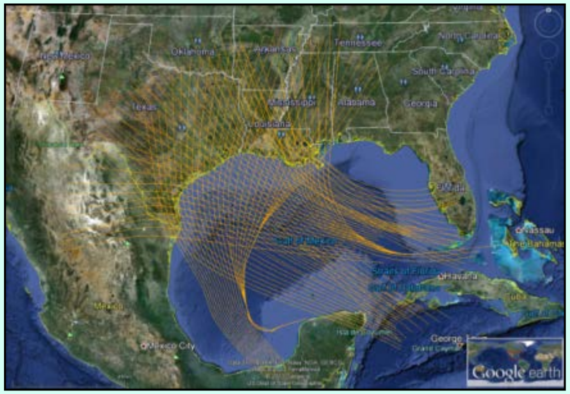




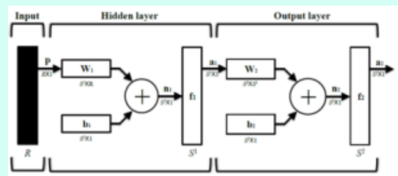
Surrogate Strategy

Study Overview

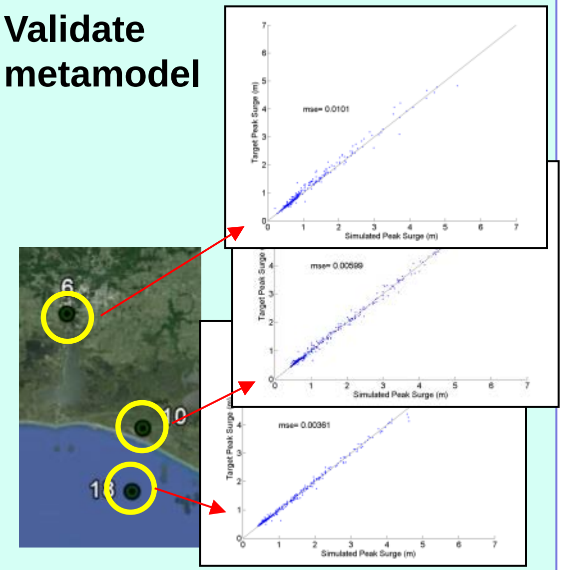
CHS Regional storm modeling

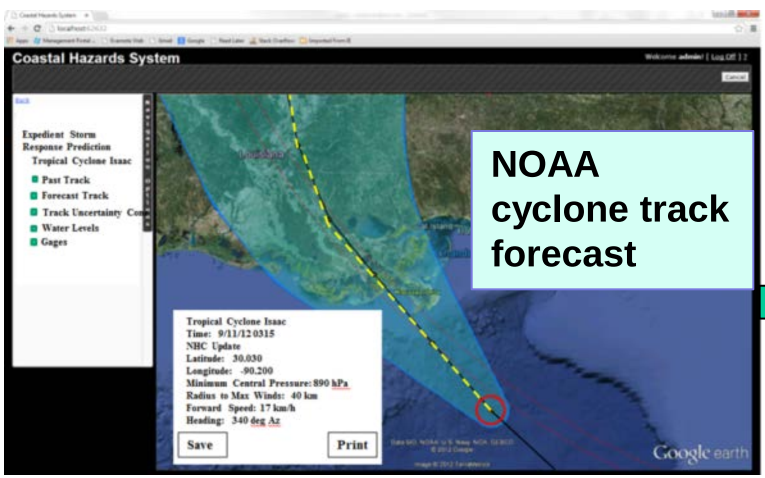


Train metamodel
- Neural Network
- GPE

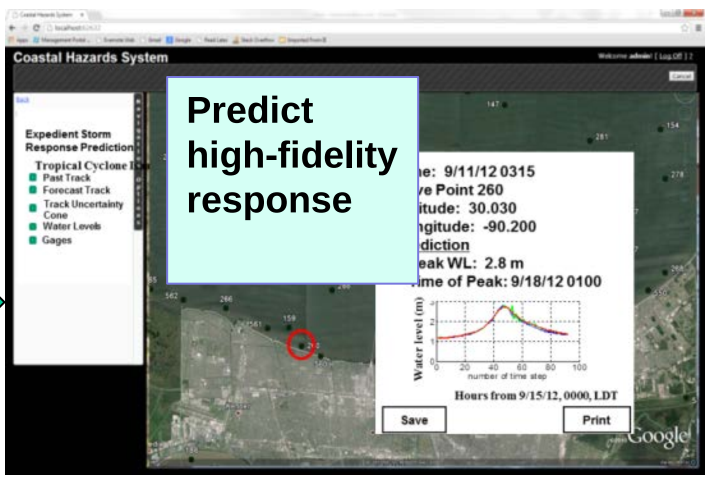


Validate metamodel





NOAA cyclone track forecast



Predict high-fidelity response

Data Preparation

- **Parameterize Forcing**, input vector **x**
  - Land fall location (lat, lon)
  - Angle of storm approach
  - Minimum central pressure
  - Average forward speed
  - Radius of maximum winds
- Response: Peak and time series of storm **surge**, **wave height**, **wave period,** wave direction, wind speed, wind direction, currents
- **Time series**: 46.5 hrs, 30 min time step, 21.5 hrs before landfall to 24 hrs after
- Augment data with dry node information
- Output vector **y**
- Perform PCA to obtain latent space **z**, retain 99.9% of variance

Surrogate Modeling

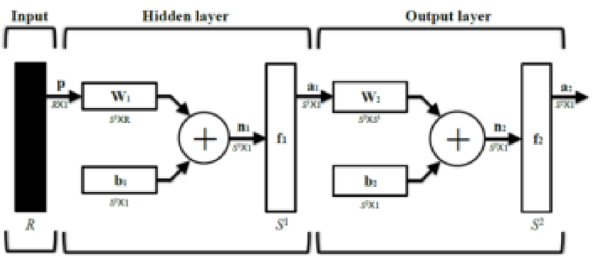
Machine learning modeling techniques are basically weighted interpolation assigning a decreasing weight with increasing separation distance.

Kriging Model

- Jia and Taflanidis (2013) and Kim et al. (2014)
- Given latent space **z …**
- Kriging to obtain predictions and statistics of prediction error

ANN Model

- Kim et al. (2014)
- Multilayer feed forward network
- Levenberg-Marquardt algorithm (LMA) for surface fitting
- 16 - 25 neurons
- Training: 70% of storms
- Validation: 15% of storms
- Testing: 15% of storms
- Performance: correlation coeff > 0.95

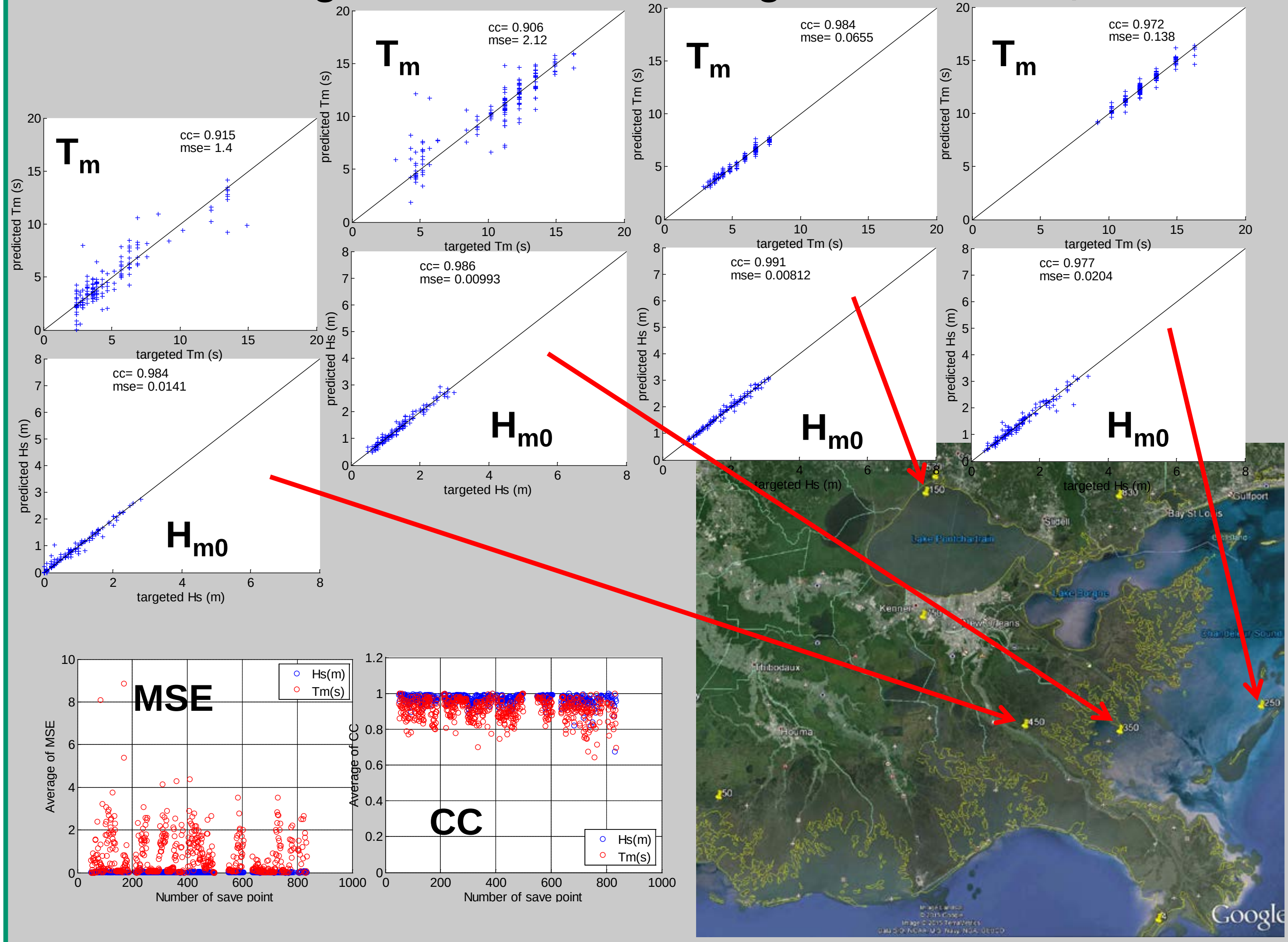


Jia, G., and Taflanidis, A. A. (2013). "Kriging metamodeling for approximation of high-dimensional wave and surge responses in real-time storm/hurricane risk assessment." ***Computer Methods in Applied Mechanics and Engineering***

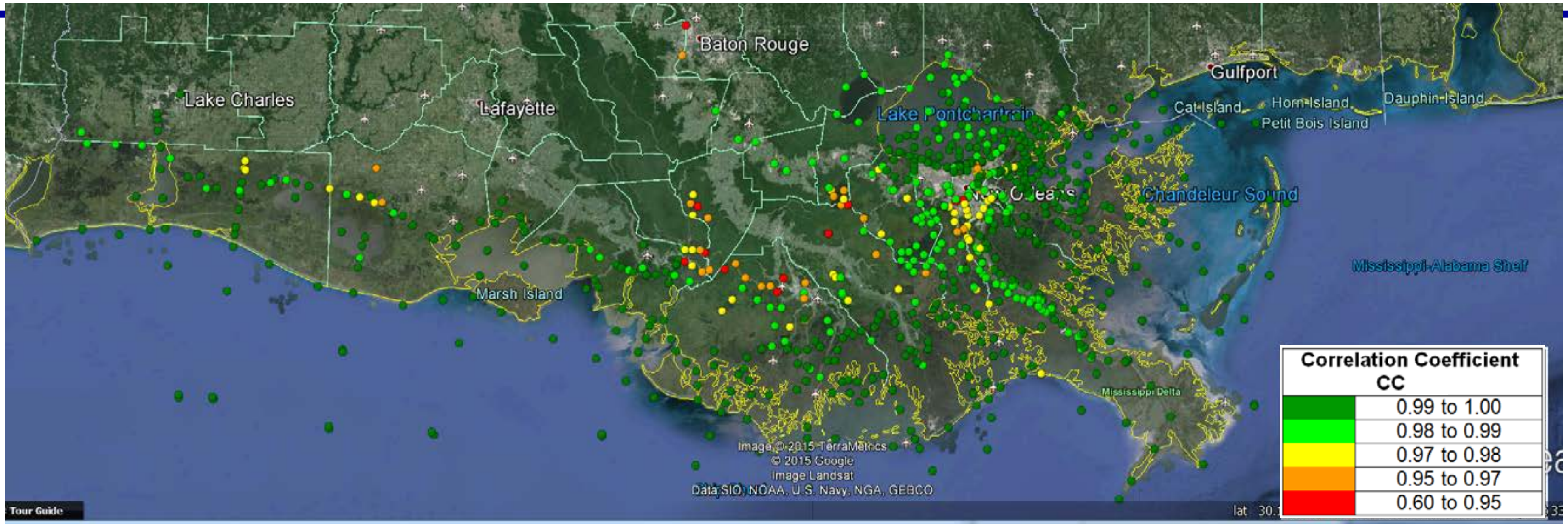
Seung-Woo Kim et al. 2014. A time-dependent surrogate model for storm surge prediction based on an artificial neural network using high-fidelity synthetic hurricane modeling. ***Natural Hazards*****, Springer.**

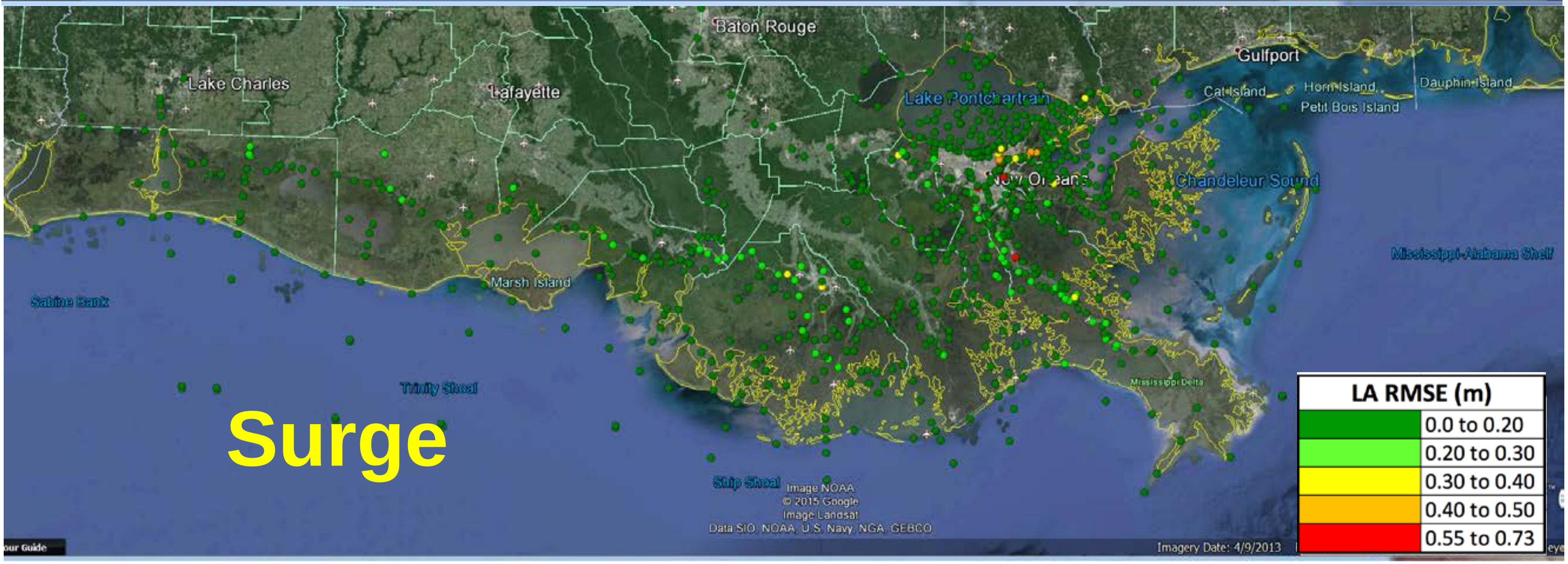
Artificial Neural Network

Wave Height and Period Training Set Validation, LA



Artificial Neural Network

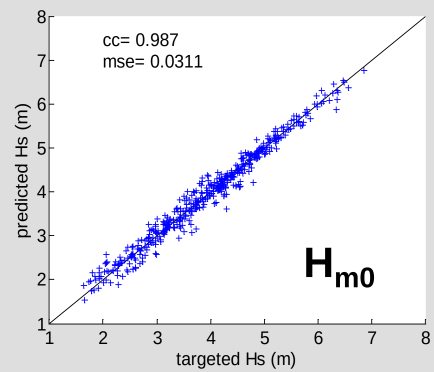


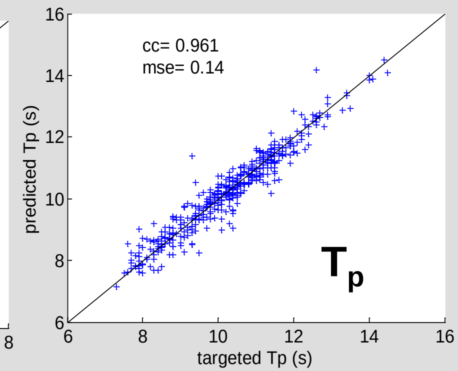


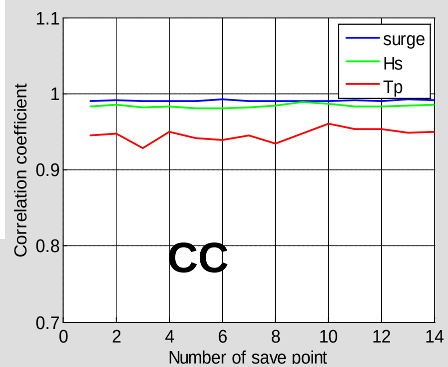
Artificial Neural Network

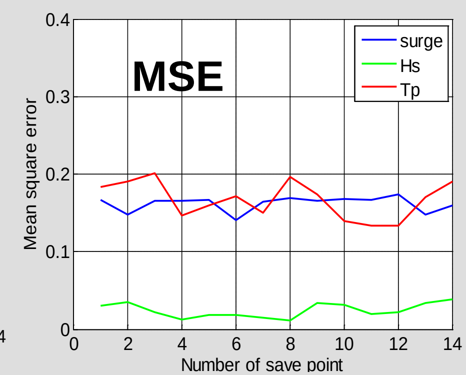
Wave Height and Period Training Set Validation

Freeport, TX





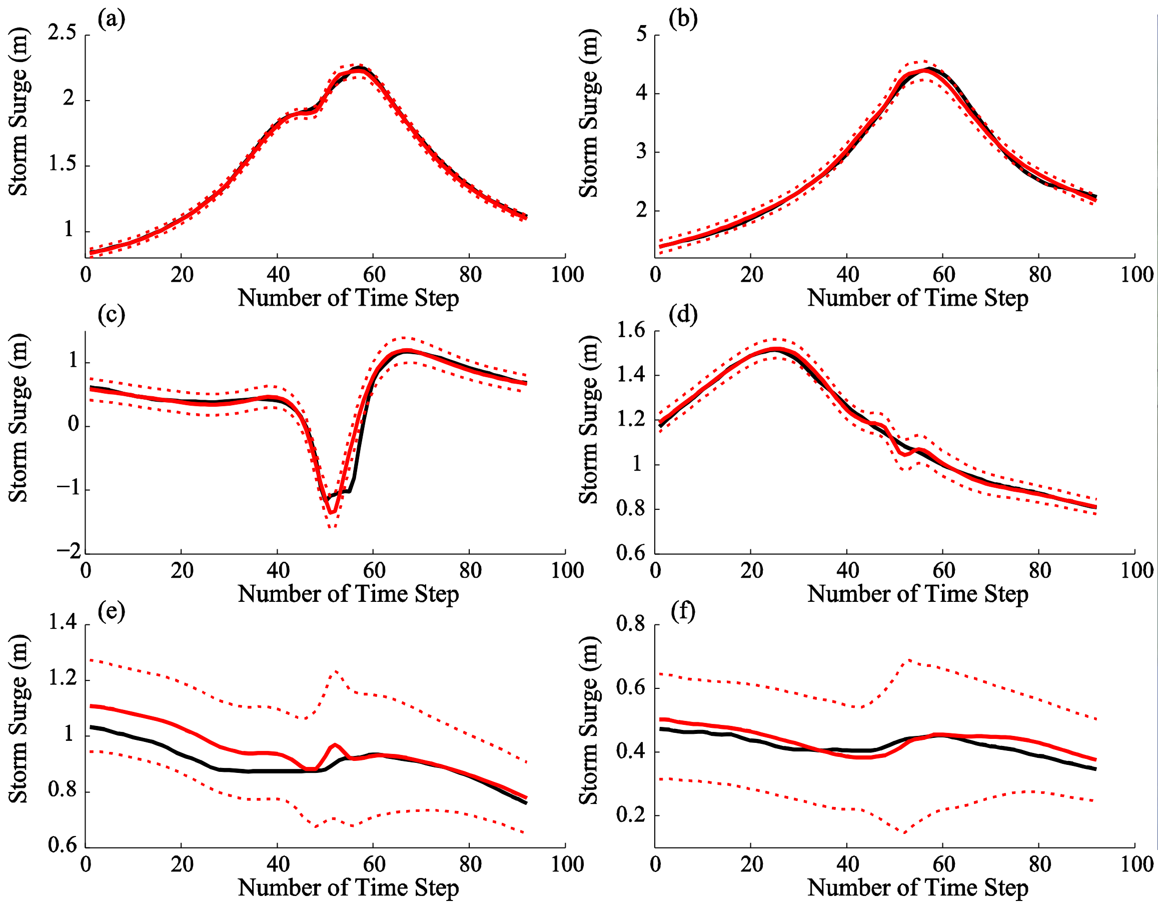




All Points

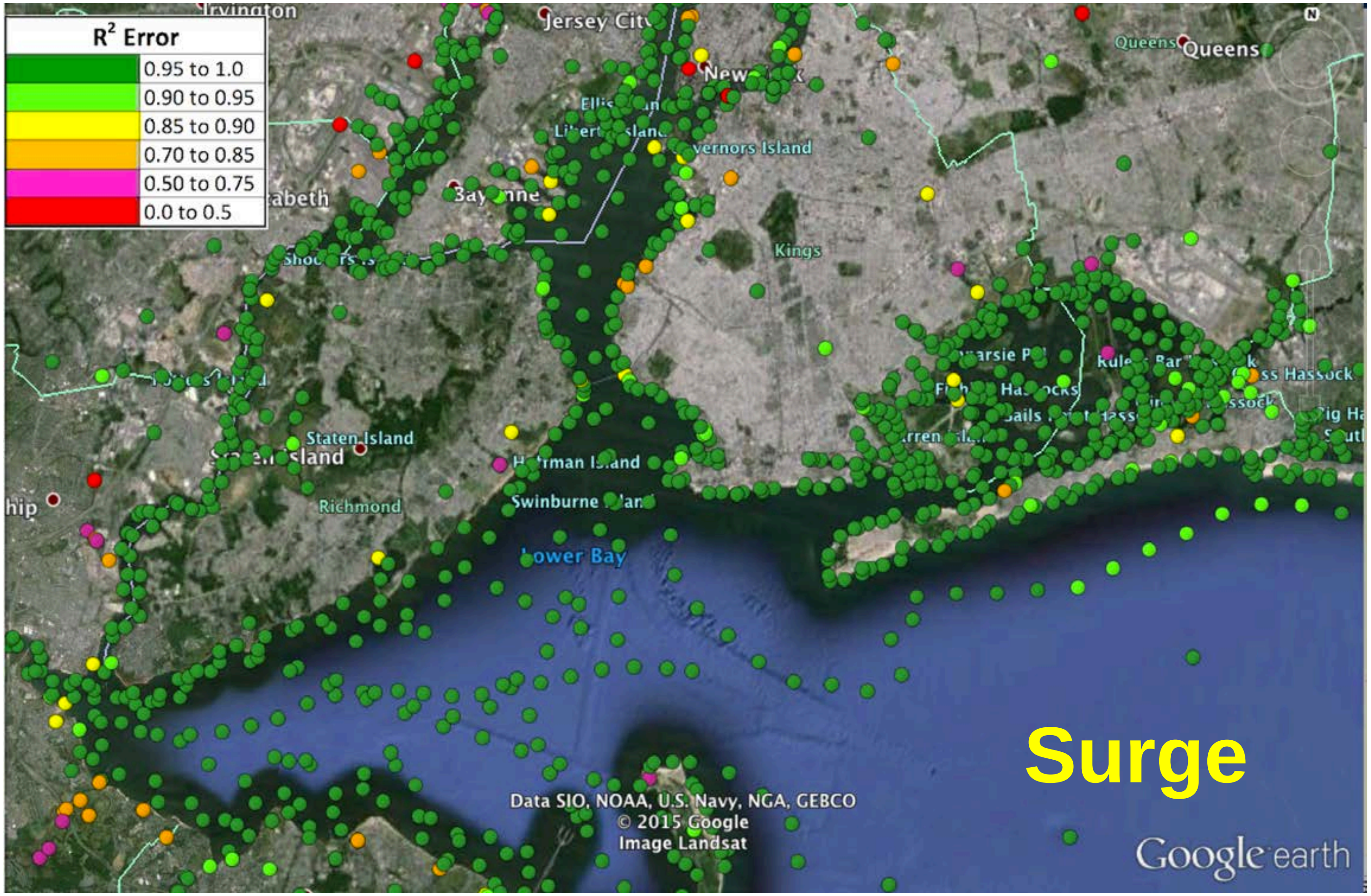
	CC	RMSE
Surge:	0.99	0.40 m
H_{m0}:	0.98	0.15 m
T_p:	0.95	0.48 s

Kriging



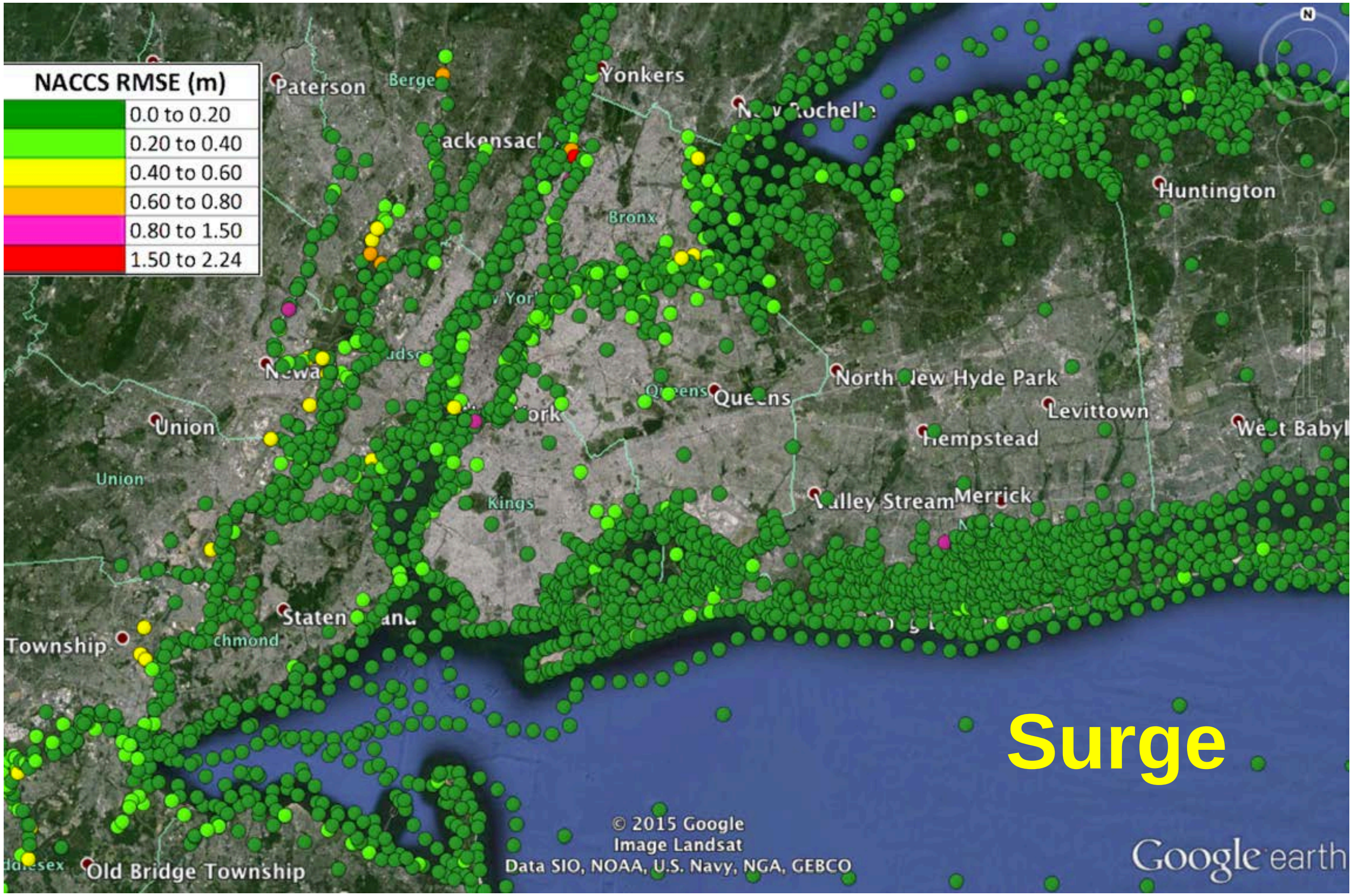
Kriging

NACCS Surge Training Set Validation – Coefficient of Determination
18977 points overall mean R^2 = 0.95



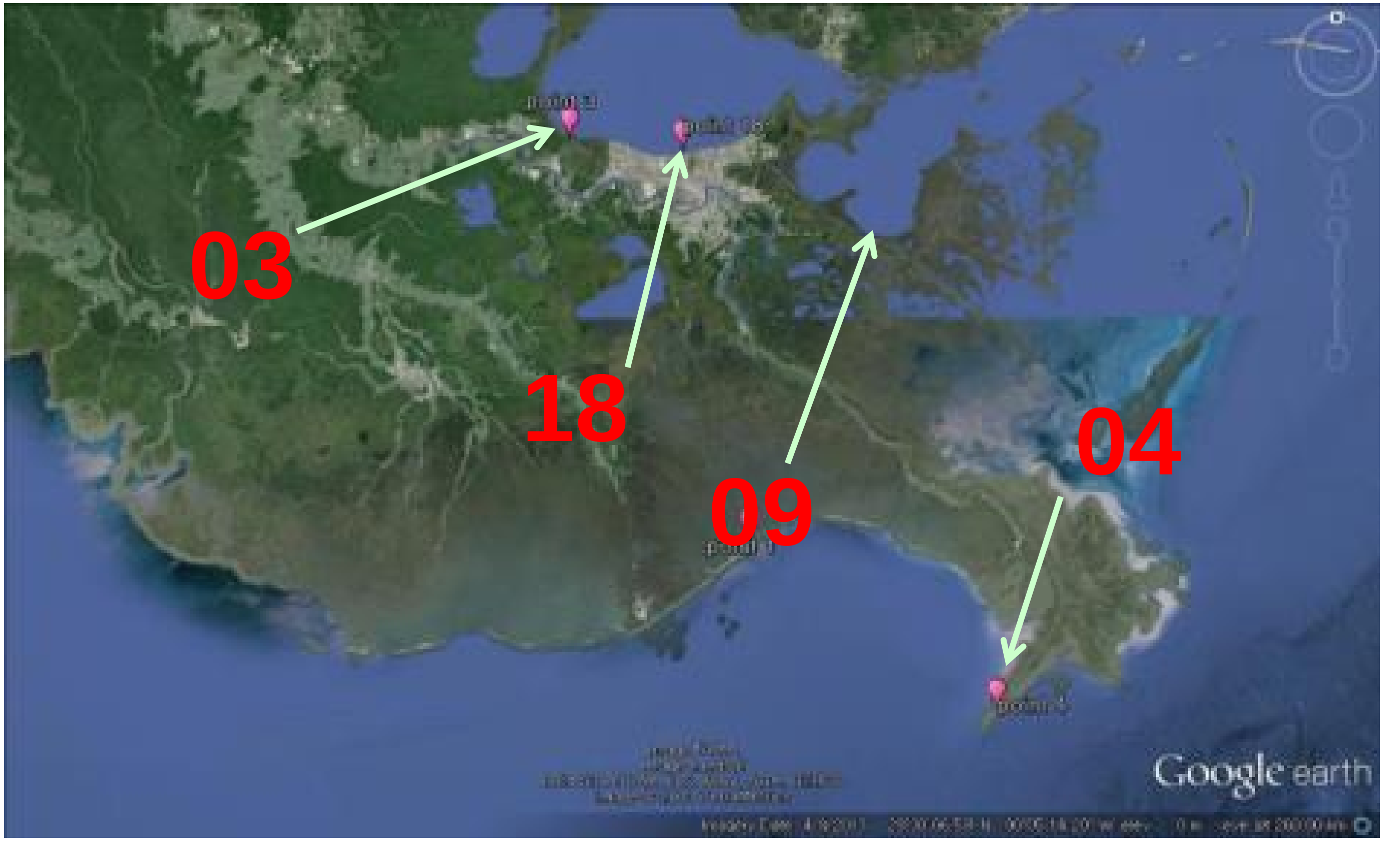
Kriging

NACCS Surge Training Set Validation – Correlation Coefficient
18977 points overall mean RMSE = 0.11 m



Surrogate Modeling

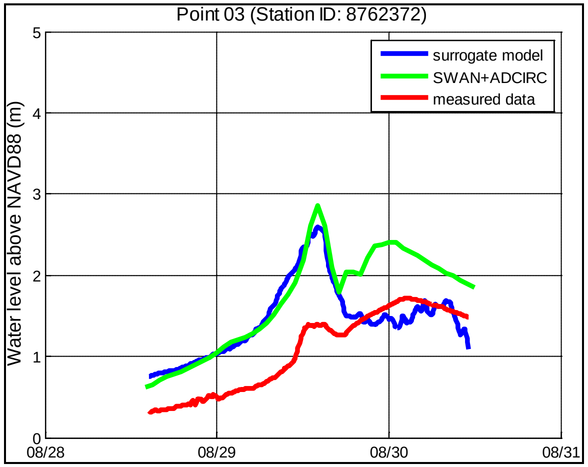
Model Validation



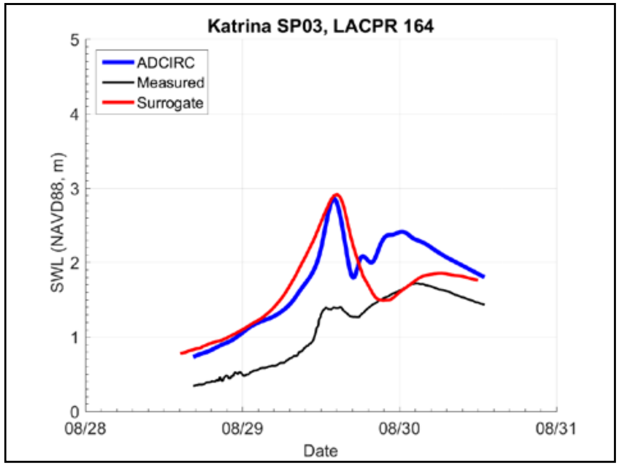
Hurricane Katrina Surge

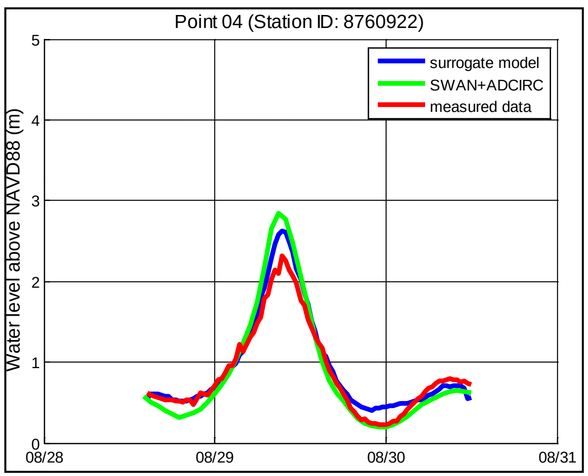
Artificial Neural Network

Kriging



Save Point 3





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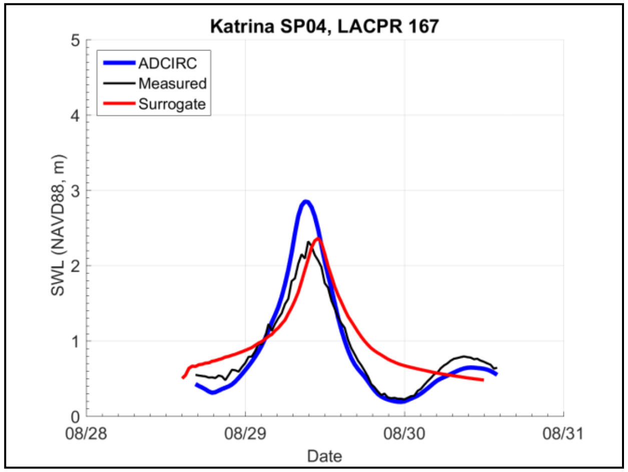
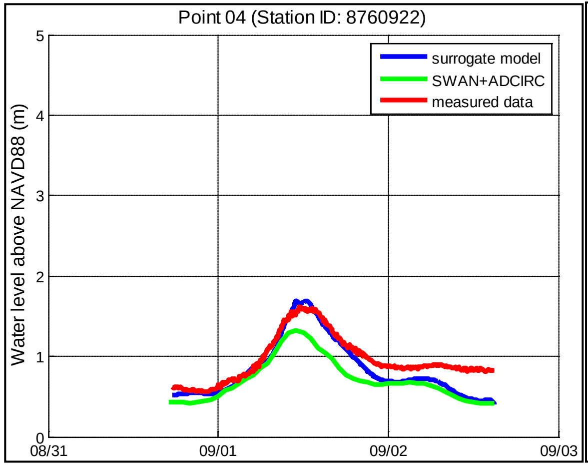
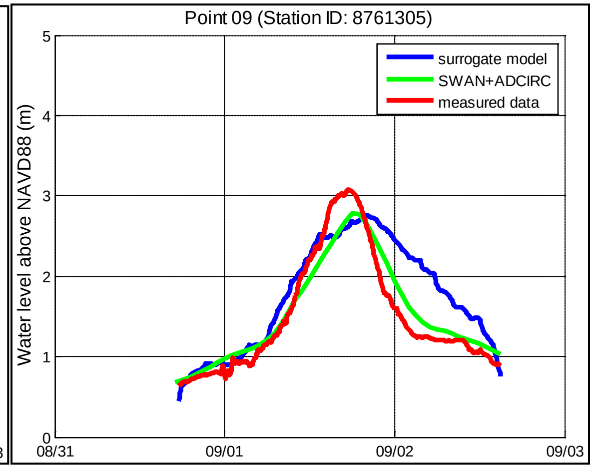


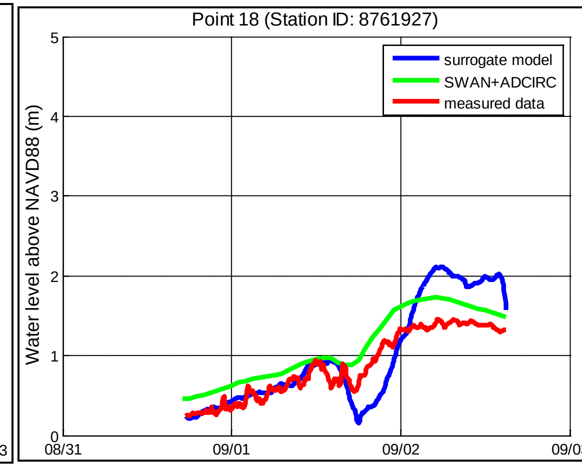
835 points run in 0.018 sec

Hurricane Gustav Surge

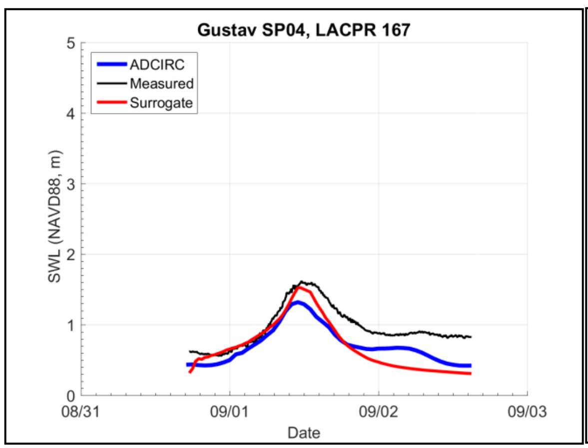
Artificial Neural Network

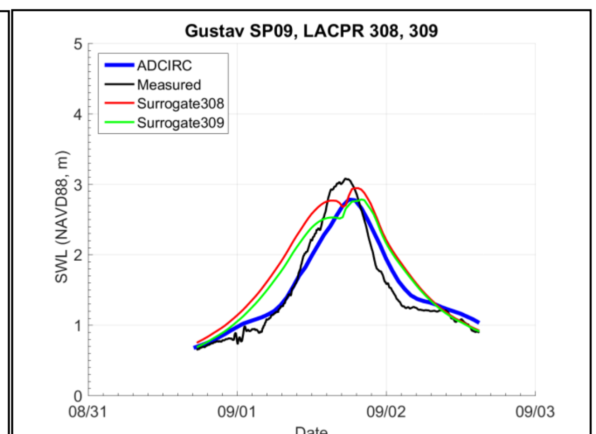


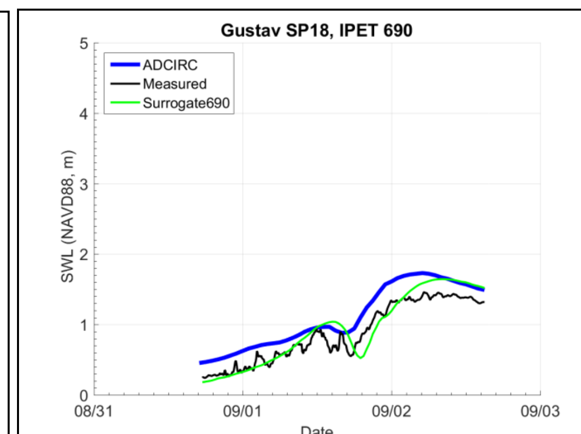




Save Point 4 **Save Point 9** **Save Point 18**







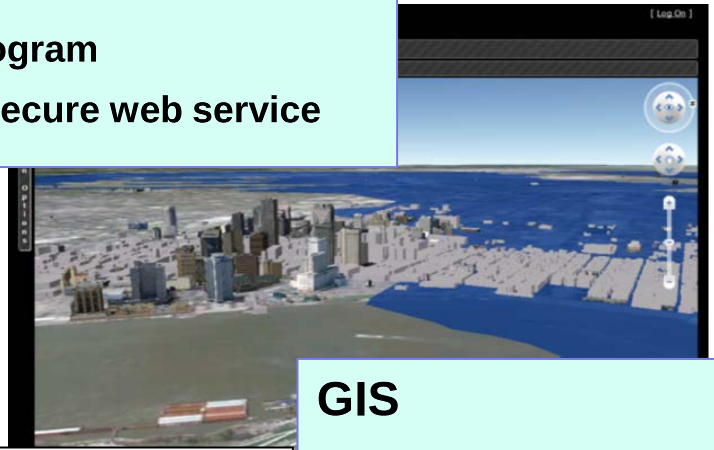
Kriging

Surrogate Modeling

Deployment

USACE Distribution

1. CHS-CHRP – stand-alone program
2. GeoTIFF, SHP files through secure web service

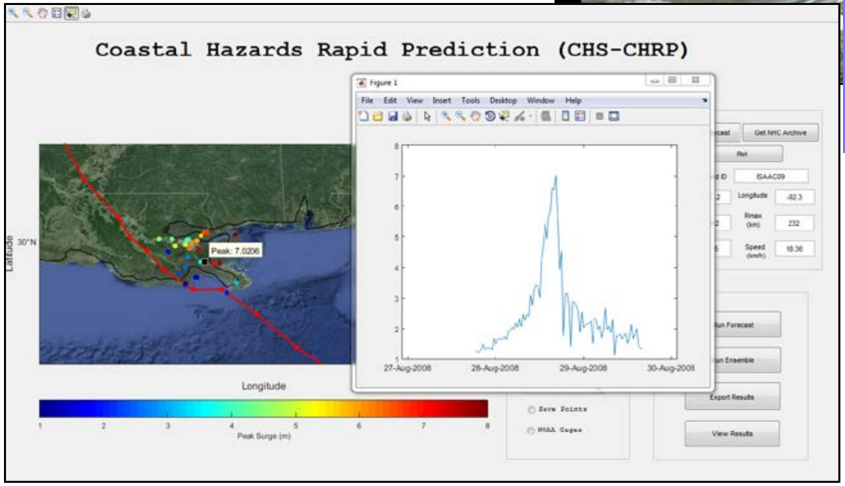


Real-Time Risk

Incorporate into, for example, HEC-FIA for rapid real-time or static hazard, vulnerability and risk assessment, FRM

GIS

Rapid high-fidelity flood prediction and visualization



Summary

- Coastal Hazards System – Regional high-fidelity efficient coastal storm data resource
- High-fidelity storm response surrogate modeling
  - Artificial Neural Network and Kriging
  - Predict surge, significant wave height, peak wave period
  - Model error is reasonably low
  - Computes regional response << 1 sec.

Thanks for listening…Questions?