Fast Forecast Tool for Hurricane Wave, Surge, and Run-up Inundation in Hawaii

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Motivation

- **Island communities are vulnerable to tropical storms**
  - Nowhere to evacuate
  - Infrastructure within hazard zone
- **Islands Task Force Report (2001)**
  - Mainland modeling technology largely unsuitable for islands
- **Unique/Important Island Features & Physics**
  - Steep slopes
  - Reef roughness
  - Reef flat dynamics (ponding, wave reformation)
  - Importance of waves
  - Growth of infragravity waves

SWIMS Fast Forecasting Approach

- **Pre-run storms with high-fidelity models**
  - ADCIRC
  - unSWAN
  - BOUSS-1D
- **Create database of response**
- **Develop surrogate model to forecast inundation**
  - Deterministic
  - Probabilistic
- **Hawaii Hurricane Evacuation Study**
  - Interface FFT w/Mass Managers System (MMS)
- **Team**
  - ERDC, University of Notre Dame, University of Hawaii, and Honolulu District

Conclusions

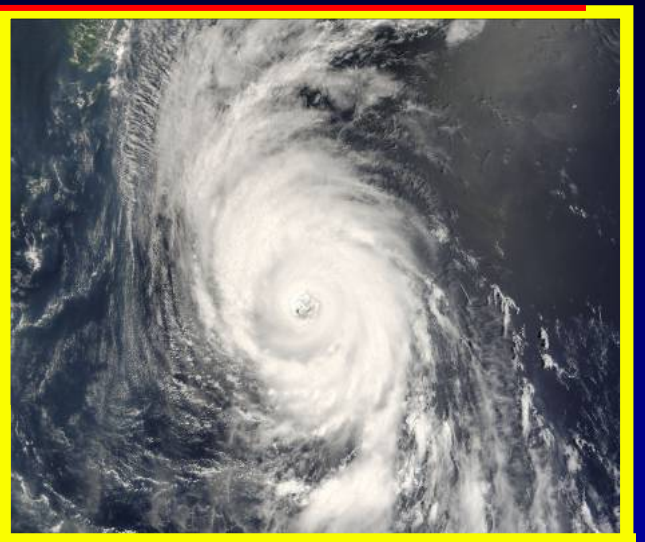
- High-fidelity, high-resolution models have been used to simulation hundreds of hurricanes
- Database of simulation results can be used to generate deterministic or probabilistic estimates for planning and operations
- Fast Forecasting Tool provides framework for dynamic and fast evaluation of waves, surge, run-up and inundation
- Results available in seconds to minutes rather than hours or days

EQUATIONS

$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot \left[\left(\vec{c}_g + \vec{U} \right) N \right] + \frac{\partial c_\theta N}{\partial \theta} + \frac{\partial c_\sigma N}{\partial \sigma} = \frac{S_{tot}}{\sigma}$$

$$\frac{\partial^2 \zeta}{\partial t^2} + \tau_0 \frac{\partial \zeta}{\partial t} + \frac{\partial \tilde{J}_x}{\partial x} + \frac{\partial \tilde{J}_y}{\partial y} - UH \frac{\partial \tau_0}{\partial x} - VH \frac{\partial \tau_0}{\partial y} = 0$$

Pacific Islands Land-Ocean Typhoon Experiment (PILOT)
Surge & Wave Island Modeling Studies (SWIMS)



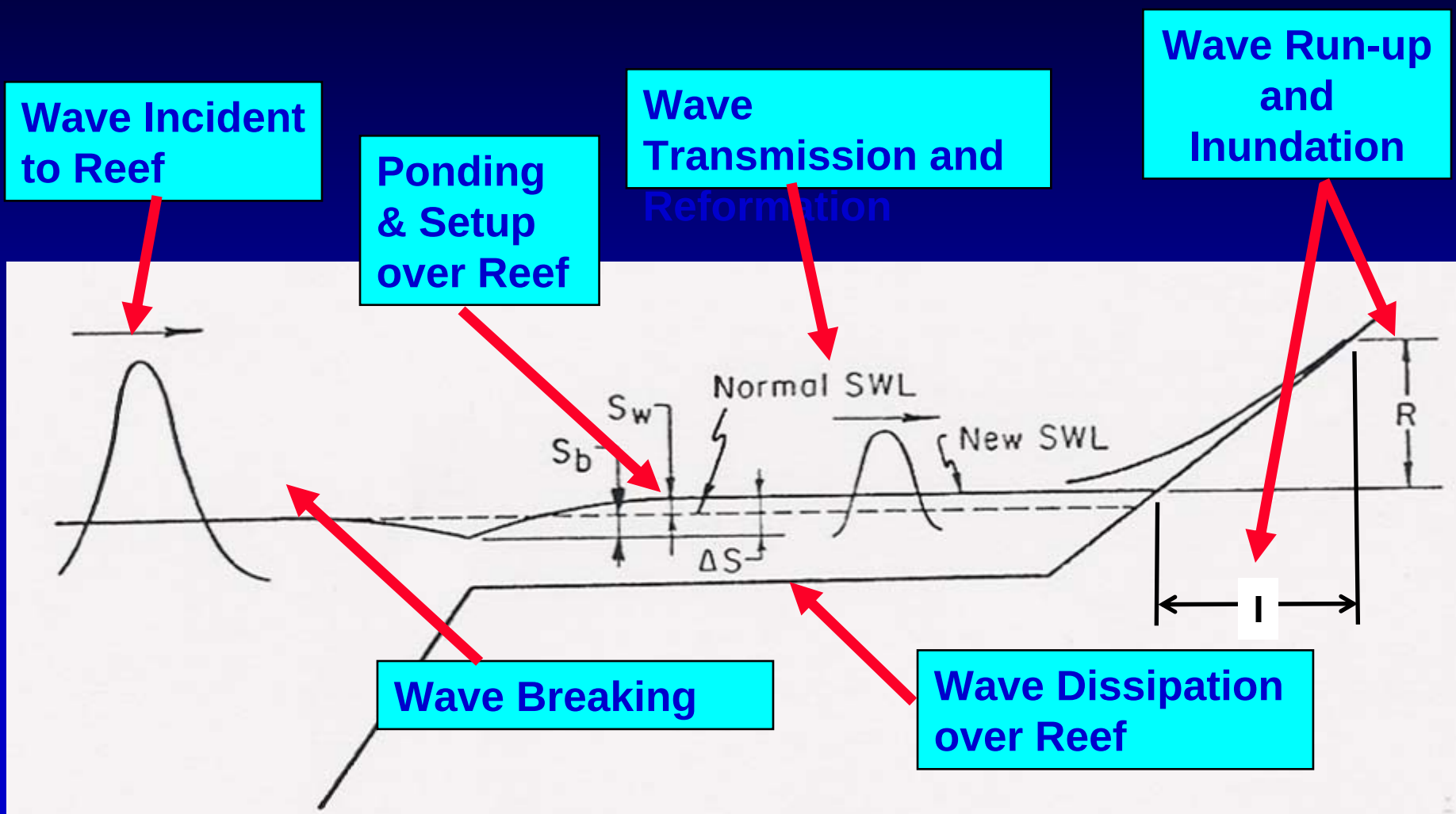
Objectives:

- **Collect coastal processes data under typhoon and high-wave conditions in island environments**
- **Improve model physics and tool for island application for emergency management and design**

Products

- Field data sets:
  - **Guam**
  - **Saipan**
  - **Oahu, Hawaii**
  - **St. Croix, VI**
- Laboratory Data Sets (2D/3D)
- Model Improvements
- Fast Forecasting Tool

Reef Processes



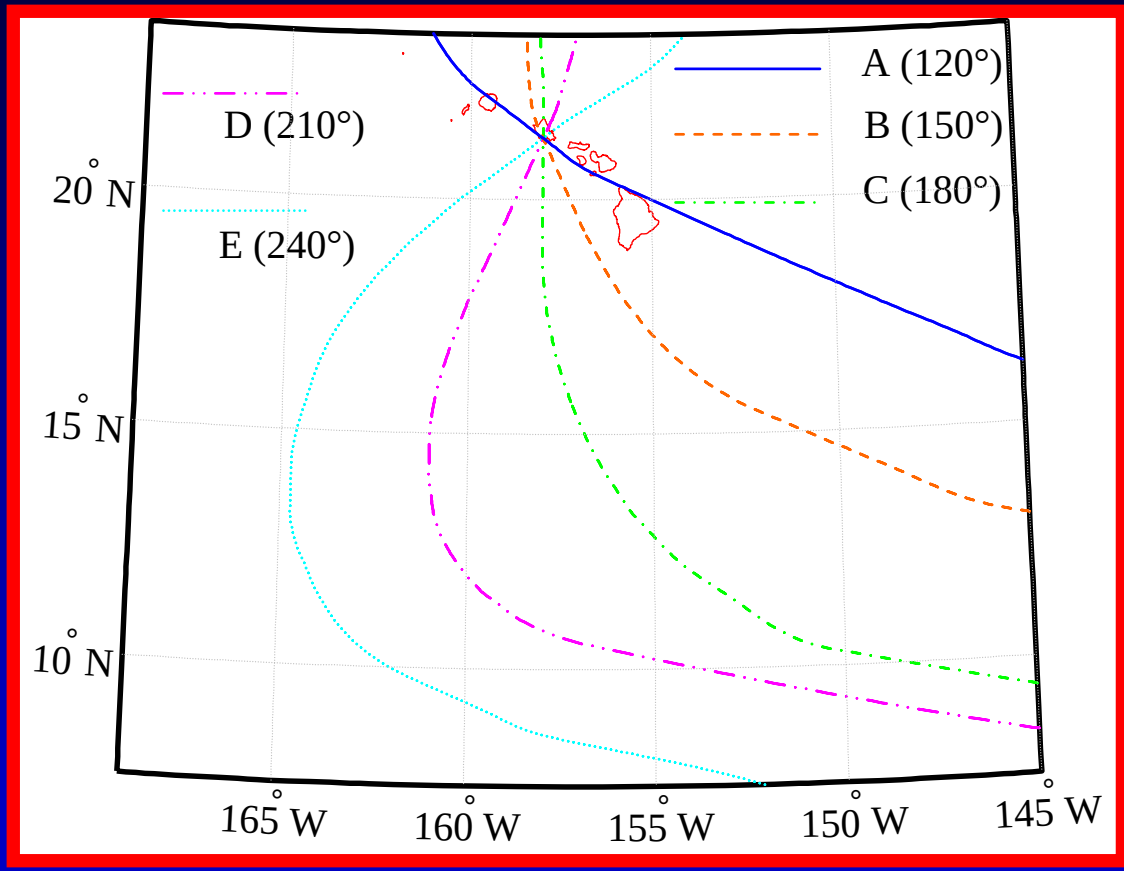
Storm Selection

- **Category 4 Storm on Oahu**
  - Severe damage to air & sea ports
  - Island-wide power and communications outages (1 month or longer)
  - 80% of homes destroyed
  - 650,000 people seeking shelter
- **Since 1950:**
  - Nina (1957)
  - Dot (1959)
  - Iwa (1982)
  - Estelle (1986)
  - Iniki (1992)

Hurricane Iniki

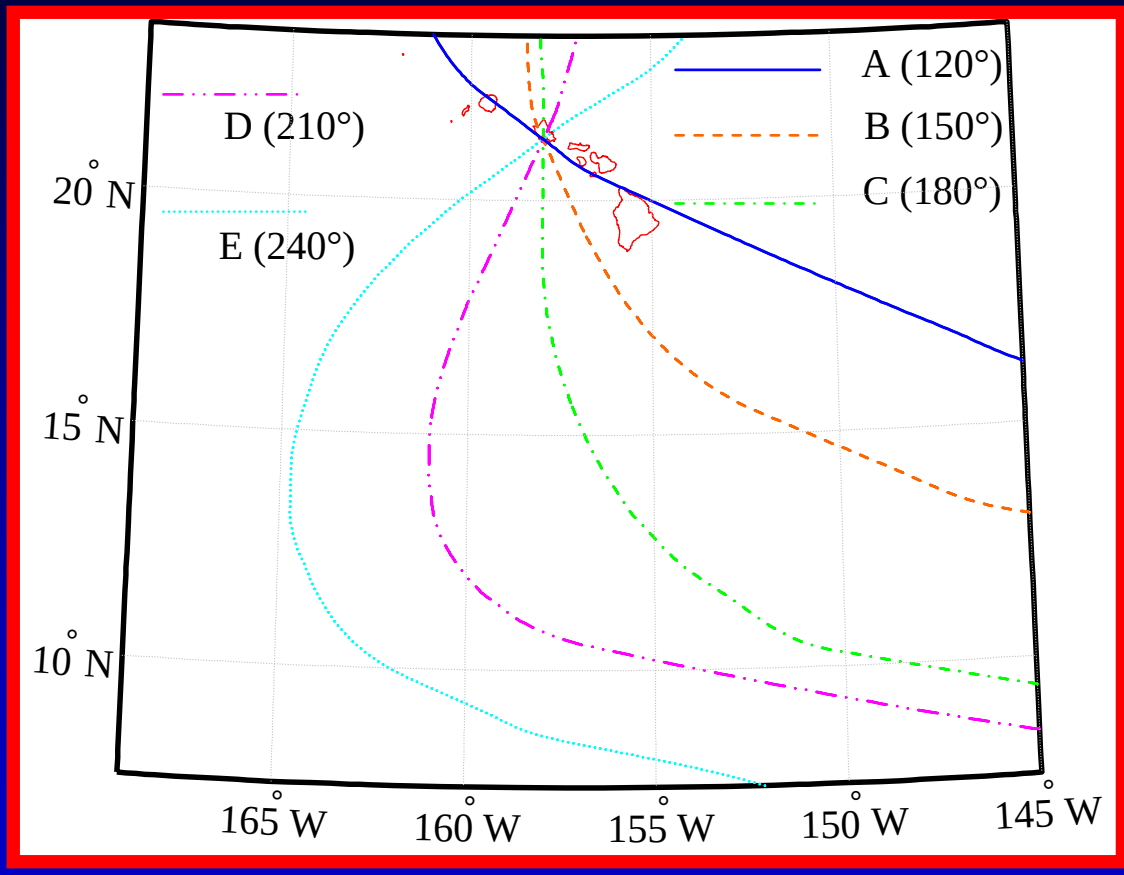
Storm Tracks

- Five base storm tracks from hurricane climatology (NWS)
- Tracks shifted to give different landfall locations
- Tracks and parameters varied to give a matrix of potential storms (bound most possible landfall scenarios)



Storm Scenarios

- **Base Tracks**
  - 120,150,180, 210 and 240 degrees
- **Central Pressure**
  - 940, 955, 970 mb
- **Radius of Max Winds**
  - 30, 45, 60 km
- **Forward Speeds**
  - 7.5, 15, 22.5 knots
- **15 Landfall Locations**
  - Oahu and Kauai
- **13 Landfall Locations**
  - Maui and Hawaii



Wave, Surge, and Run-up Inundation Database

Wave and Surge Prediction *(high-fidelity model)*

- High-resolution Grid
- SWAN+ADCIRC Wave and Circulation Models
- Validation with Tides and Hurricane Iniki Surge

Wave Run-up Predictions

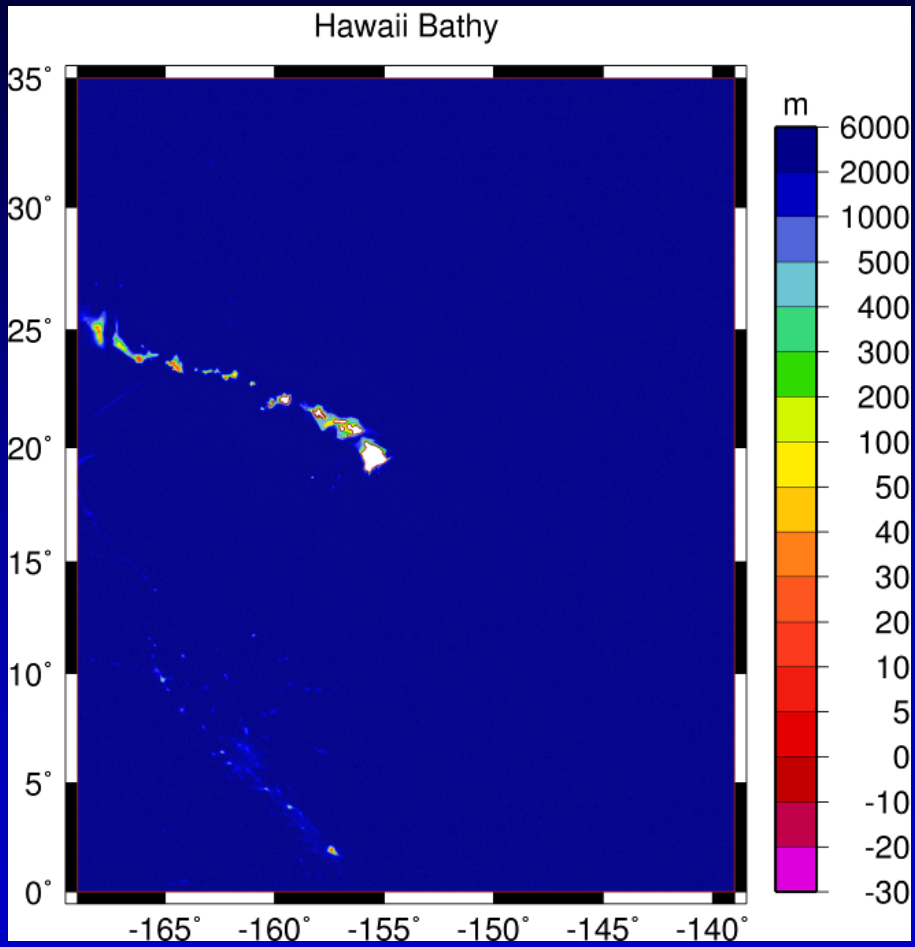
- BOUSS-1D
- Cross Shore Transects

Wave, Surge and Run-up Inundation Database and Predictions for New Scenarios

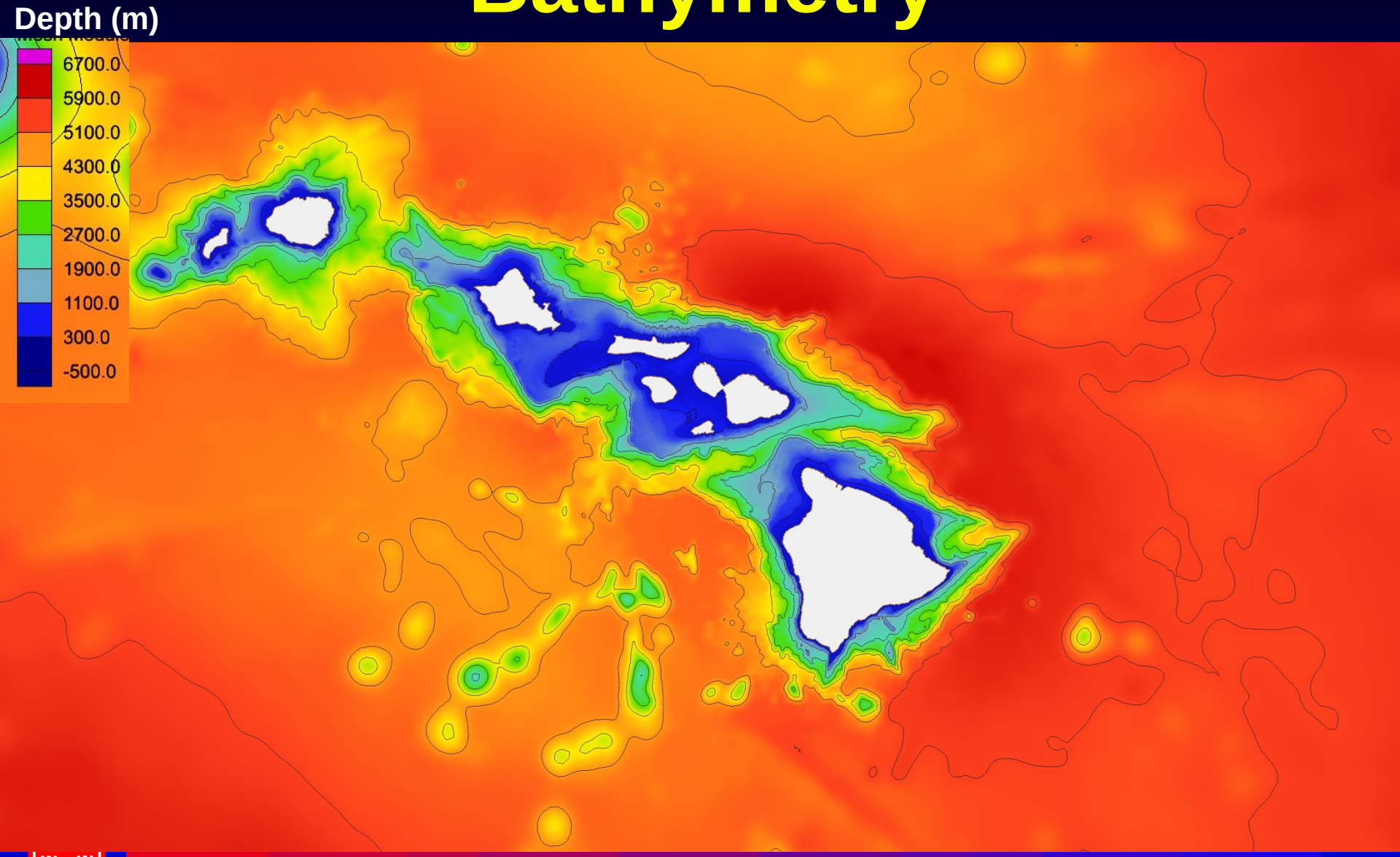
- Surrogate Modeling
- Fast Forecast Tool

Grid Domain

- Domain incorporates Hawaiian Islands and north central Pacific Ocean
- Grid resolution ranges from 5,000 m in deepwater to 30 m in the nearshore and on land
- Incorporates high resolution features (channels, coral reefs and wave breaking zones)



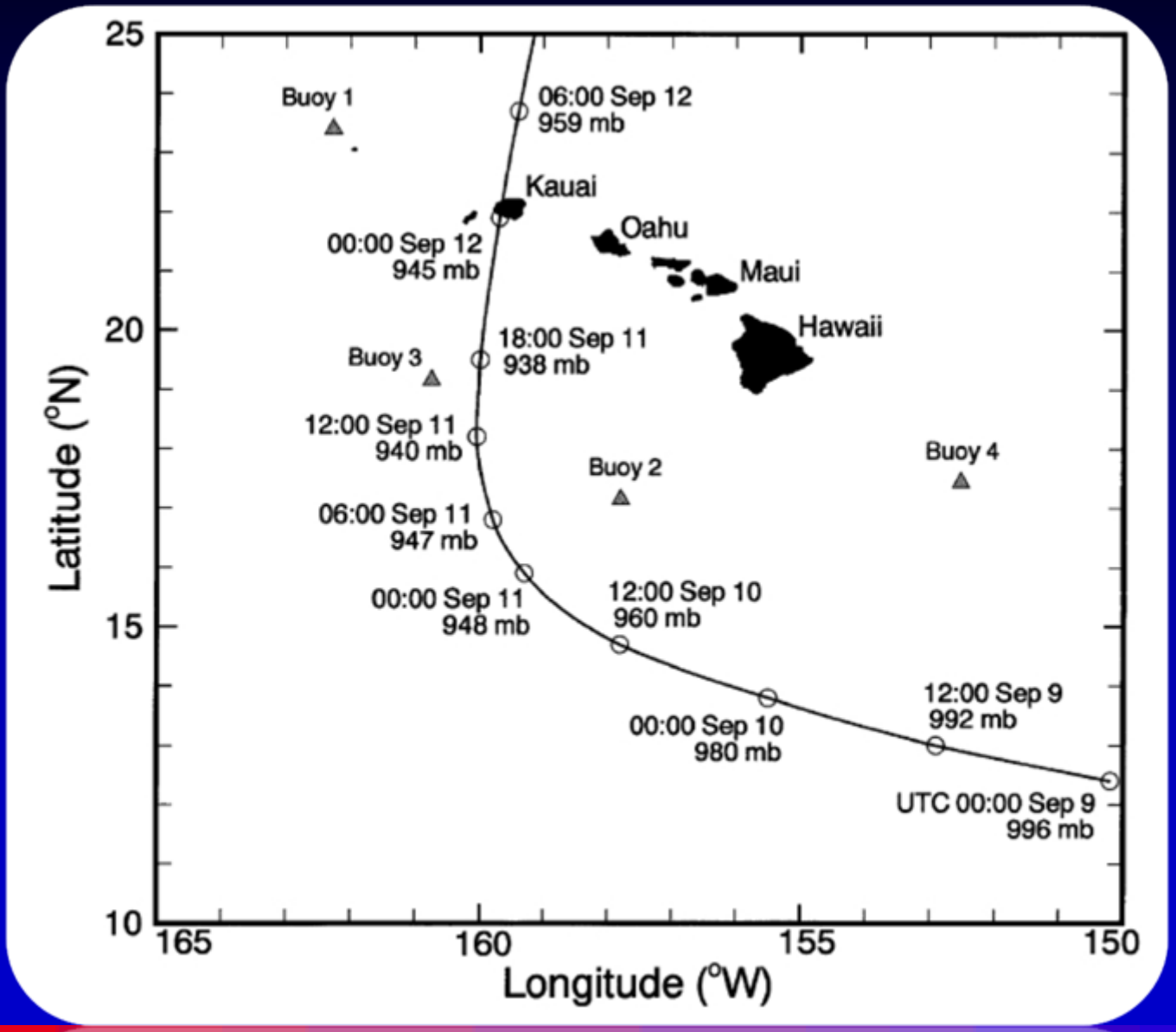
Bathymetry


Depth (m)
6700.0
5900.0
5100.0
4300.0
3500.0
2700.0
1900.0
1100.0
300.0
-500.0

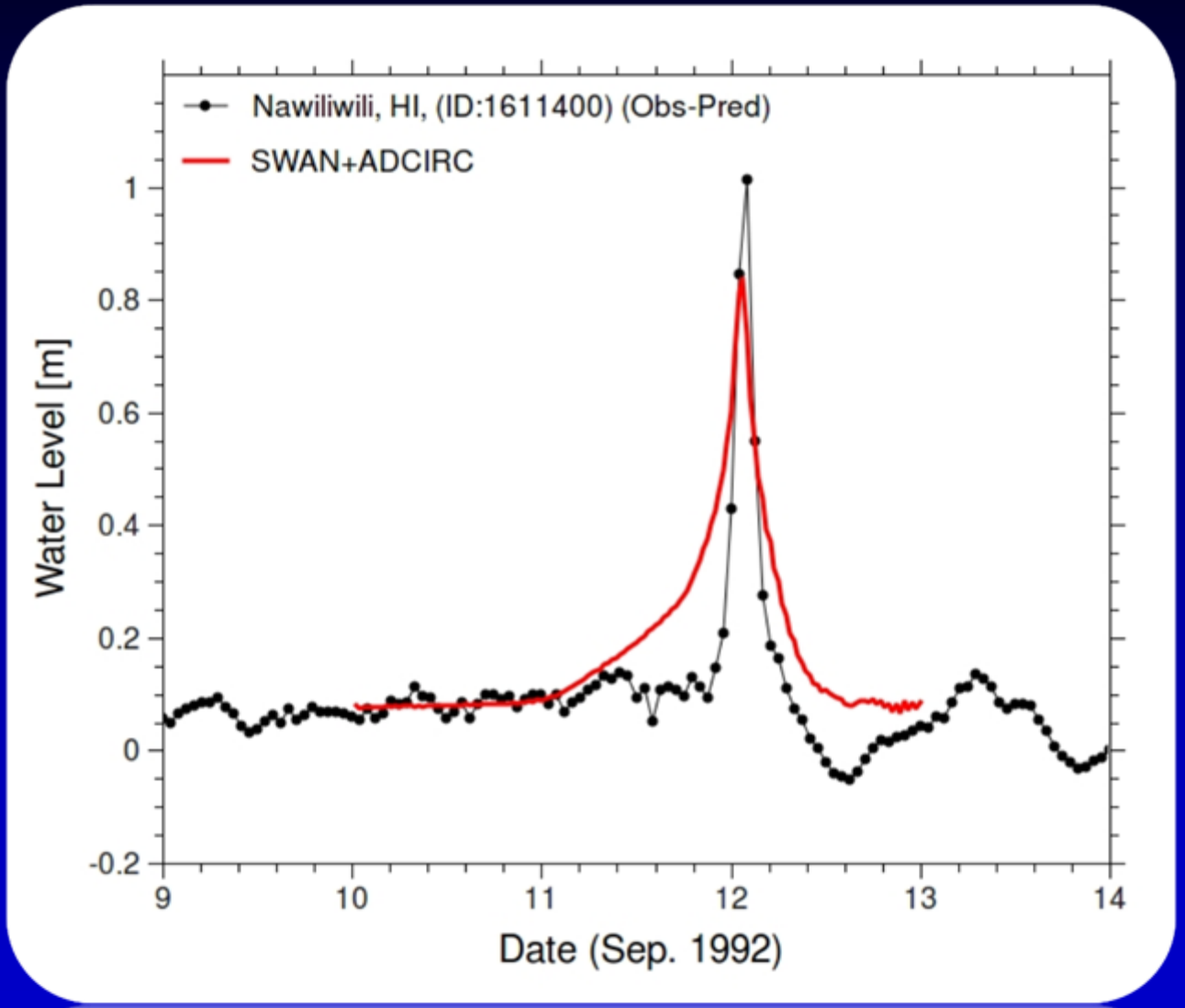
SWAN+ADCIRC Model – Coupled Waves and Currents on Unstructured Grids

- ADCIRC solves for water surface elevations and currents in two dimensions
- SWAN solves the wave action density and is a phase-averaged wave model with wave energy represented by a spectrum
- ADCIRC passes water elevation and currents to SWAN
- SWAN passes wave radiation stresses to ADCIRC
- Models run in parallel on the same grid

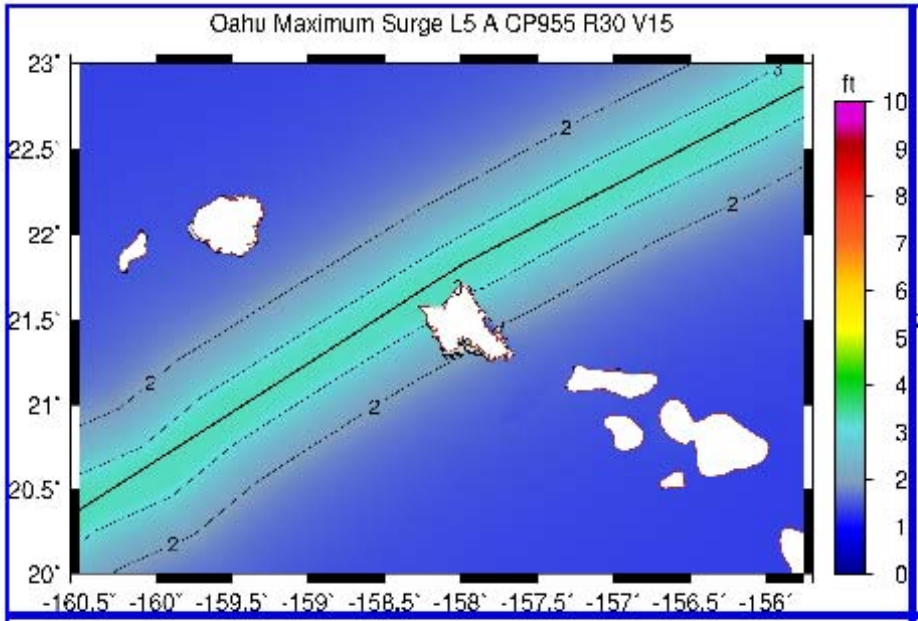
Hurricane Iniki (1992)

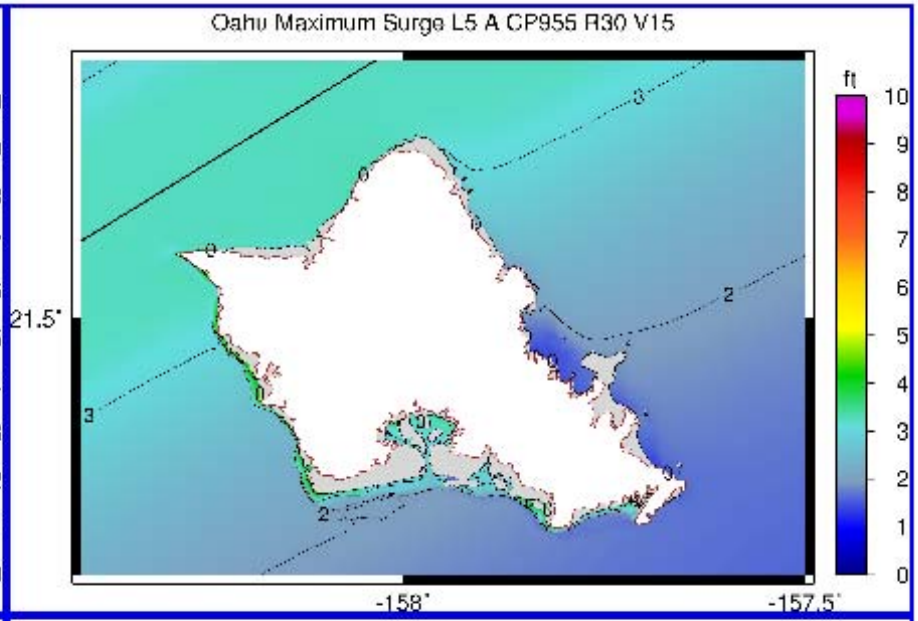


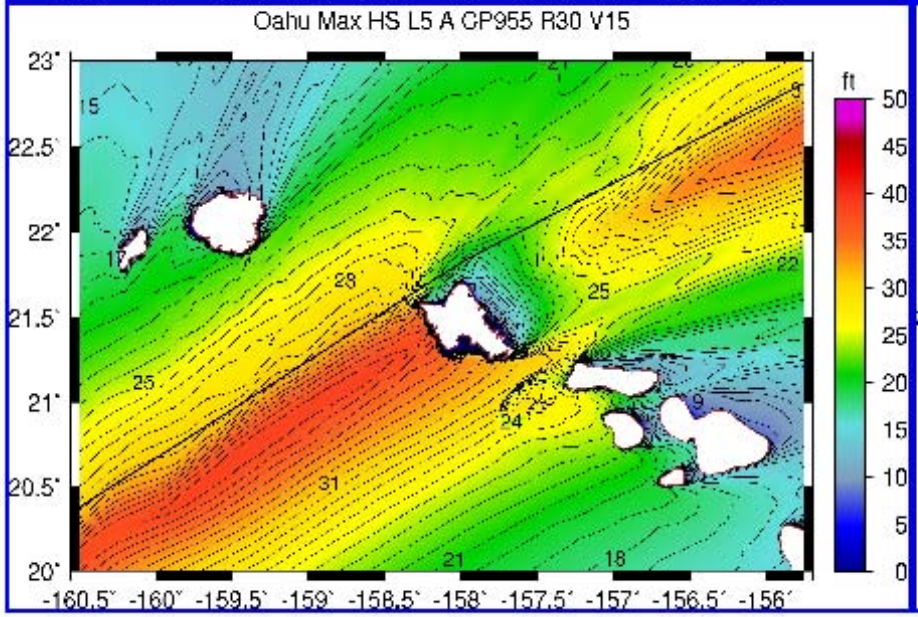
Hurricane Iniki Water Levels

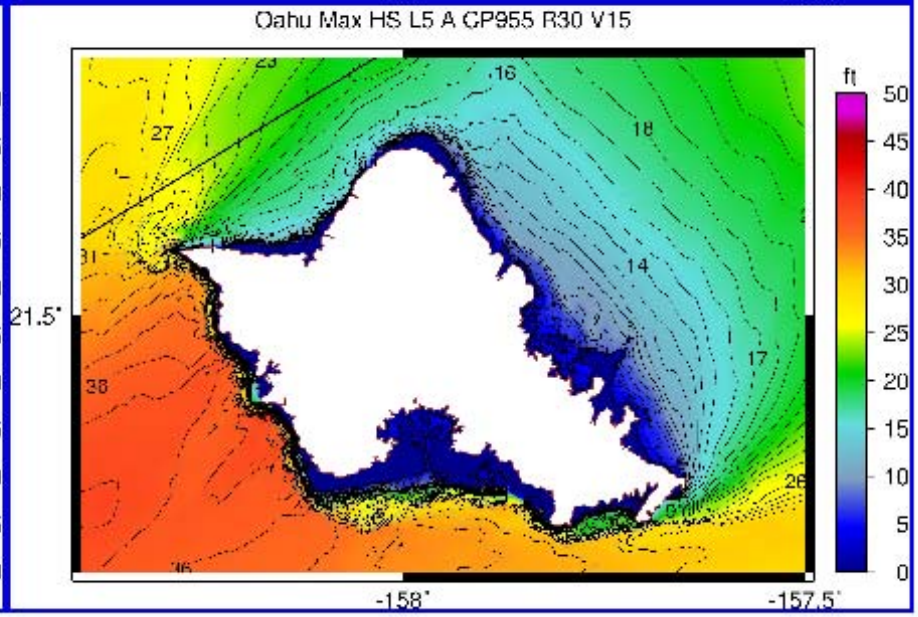


Storm Atlas


Oahu Maximum Surge L5 A CP955 R30 V15
ft
23°
22.5°
22°
21.5°
21°
20.5°
20°
-160.5° -160° -159.5° -159° -158.5° -158° -157.5° -157° -156.5° -156°


Oahu Maximum Surge L5 A CP955 R30 V15
ft
21.5°
-158°
-157.5°


Oahu Max HS L5 A CP955 R30 V15
ft
23°
22.5°
22°
21.5°
21°
20.5°
20°
-160.5° -160° -159.5° -159° -158.5° -158° -157.5° -157° -156.5° -156°

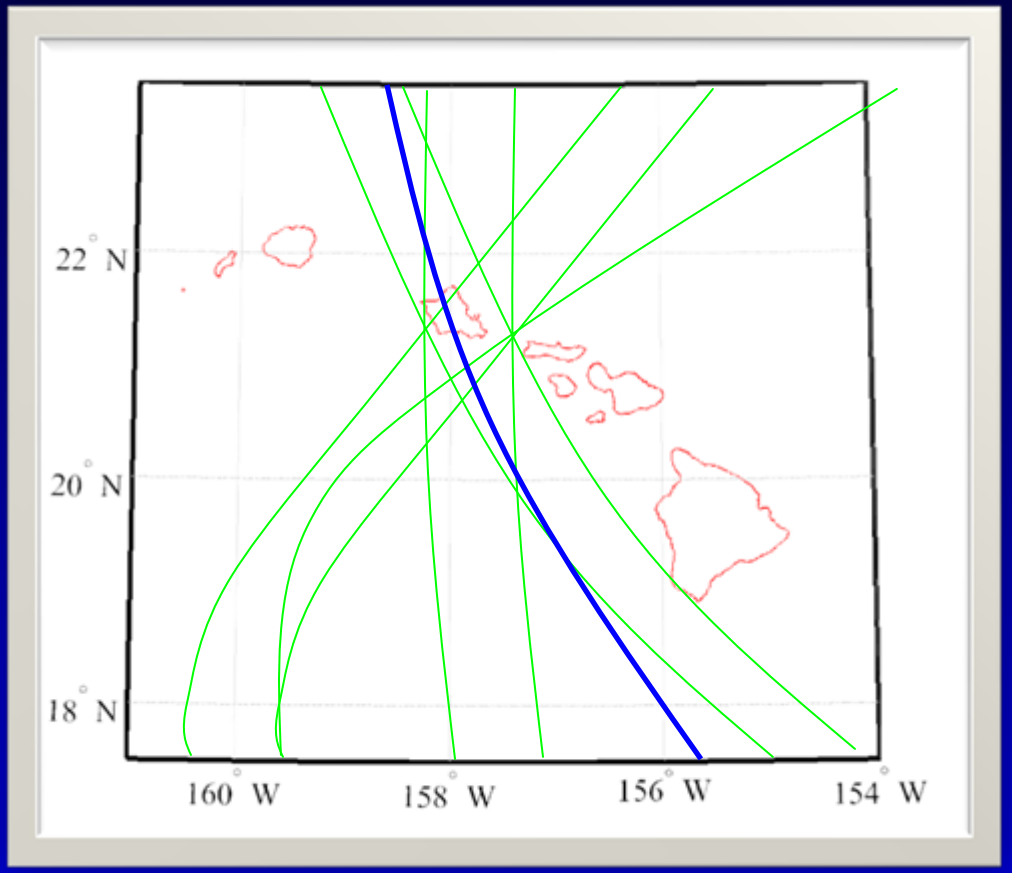

Oahu Max HS L5 A CP955 R30 V15
ft
21.5°
-158°
-157.5°

Wave Run-up Analyses

- SWAN+ADCIRC gives wave heights and still water levels nearshore
- Wave Run-up (intermittent wave inundation at the shore) can be dominant in some storms
  - Hundreds of meters inland, several meters more elevation than still water level
  - Large During Hurricane Iniki (6-8m)

Prediction of Output for New Scenario

- Pre-run and store **suite of** basis hurricane scenarios **that cover expected range of future events**
- **Based on basis scenarios predict the output for any** new **hurricane scenario (i.e., create a surrogate model)**



Graphical User Interface

Instructions

Output for hurricane has been created. Figures may be now generated. Need to select each time one type of output and for which type of analysis to generate the figures

Figures created in seperate window(s); may now select different output or analysis to generate figures for or change input

Input (Characteristics of hurricane track)

Landfall Latitude	21.30	degrees
Landfall Longitude	-158.20	degrees
Track Angle	200.00	degrees
Central Pressure	950.00	mbar
Forward Speed	12.00	knots
Radius of Maximum Winds	50.00	km
Time to Landfall	40.00	hours

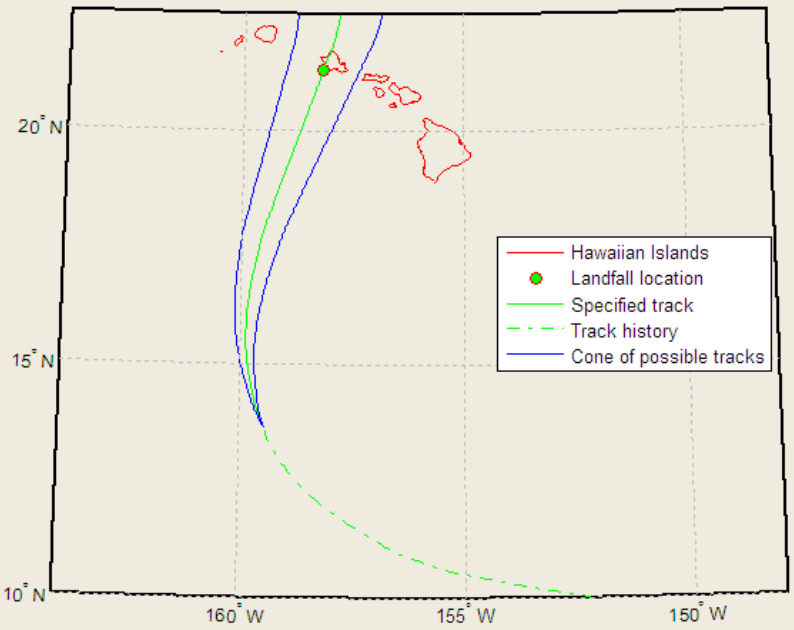
Calculate output

Type of output to calculate
- (•) Runup
- ( ) Still water level
- (•) Significant wave height

Type of analysis to perform
- (•) Exact track
- (•) Cone of possible tracks

Calculate Output

Hawaii map



hurricane track and cone of tracks shown

Select different limits for map

	Latitude	Longitude
min	10.00	-164
max	22.50	-148

Plot cone of potential hurricane tracks

US Army Corps of Engineers®

Generate figures for calculated output

Type of output to create figure for
- ( ) Runup
- ( ) Still water level
- (•) Significant wave height

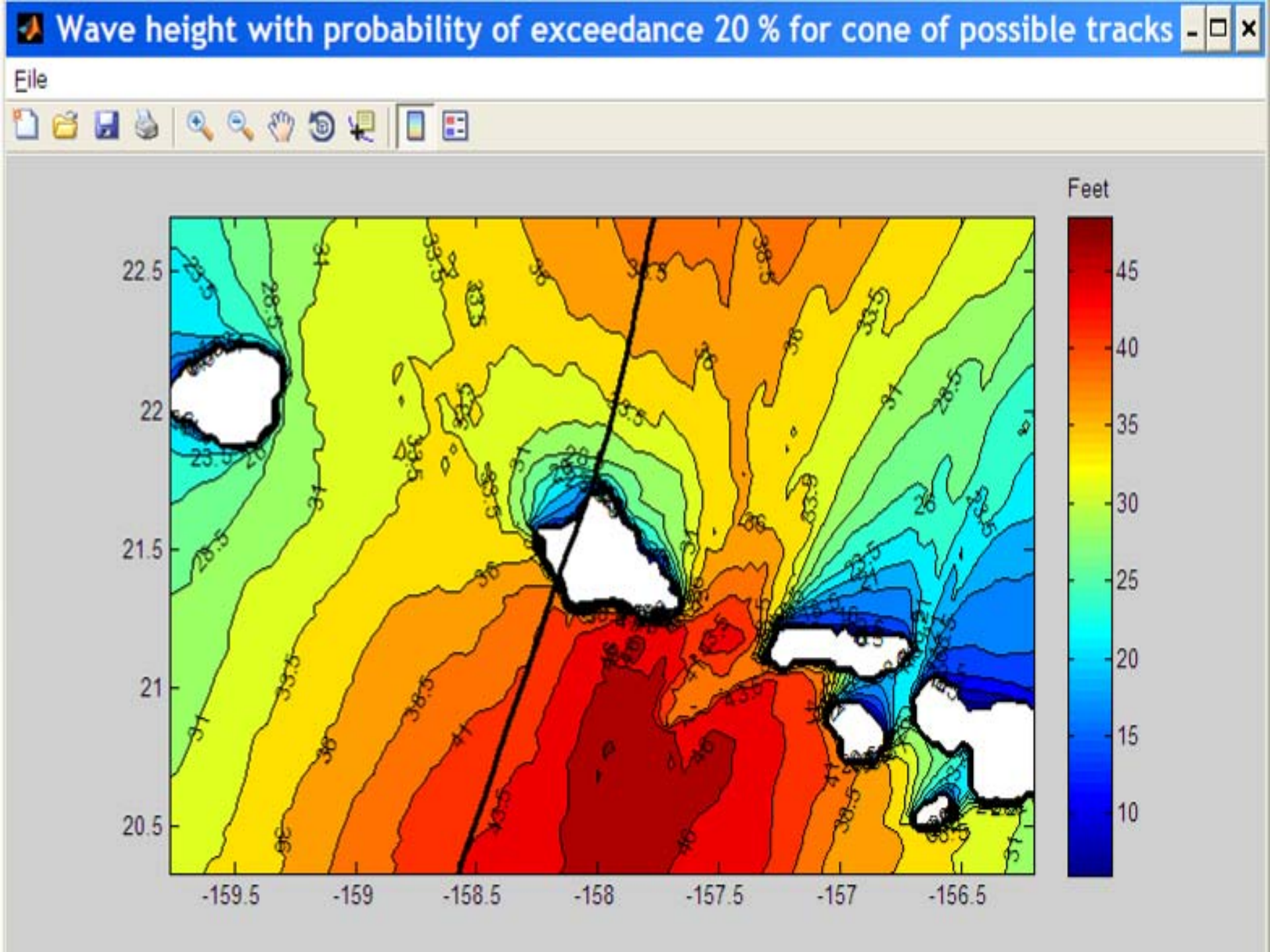
Generate figure

Type of analysis to create figure for
- ( ) Exact track (deterministic)
- ( ) Average output over all potential tracks
- (•) Output with probability of exceedance (%) 20
- ( ) Probability that output exceeds (feet) 0

Shapefiles

If for wave runup or still water shapefiles should be also generated press button and also select file name

name


Wave height with probability of exceedance 20 % for cone of possible tracks
File
Feet
45
40
35
30
25
20
15
10
22.5
22
21.5
21
20.5
-159.5
-159
-158.5
-158
-157.5
-157
-156.5

Run-up and Still Water

Conclusions

- High-fidelity, high-resolution models have been used to simulation hundreds of hurricanes
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QUESTIONS