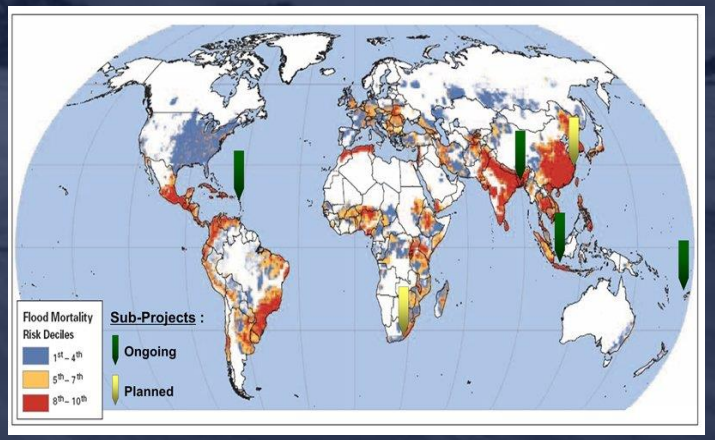
Update on International Storm Surge Activities at RSMC Miami

Brian Zachry and Jamie Rhome

WMO RA-IV RSMC/CIFDP-C System Developer

WMO CIFDP-C

- Coastal Inundation Forecasting Demonstration Project (CIFDP) initiated by Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM)
- At the 5th meeting of the CIFDP Program Steering Group (May 2014, Geneva), the previous Sub-Project for Dominican Republic (CIFDP-DR) was re-scoped for a Caribbean/regional approach and denoted CIFDP-C
- CIFDP-C will be initially demonstrated and tested for the Dominican Republic and Haiti
- Develop SLOSH products for planning, preparedness, and forecasting
- RSMC Miami will provide the leading technical contribution, in collaboration with the PSG and other partners
- Fully funded by USAID (1.2 Million U.S. Dollars)



WMO CIFDP-C Participants

RSMC Miami

Jamie Rhome CIFDP-C System Developer

Brian Zachry CIFDP-C Project Manager

Ethan Gibney CIFDP-C Grid Builder

NWS Environmental Modeling Center

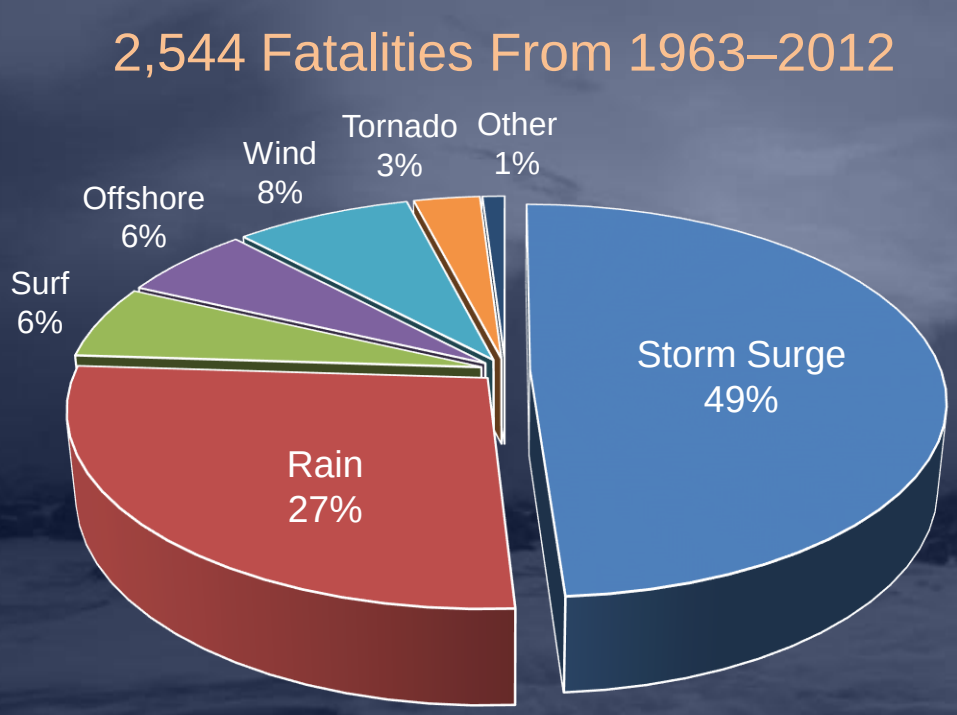
Andre Van der Westhuysen and Dongming Yang

CIFDP-C Modelers

Florida International University

Keqi Zhang CIFDP-C DEM and Grid Builder

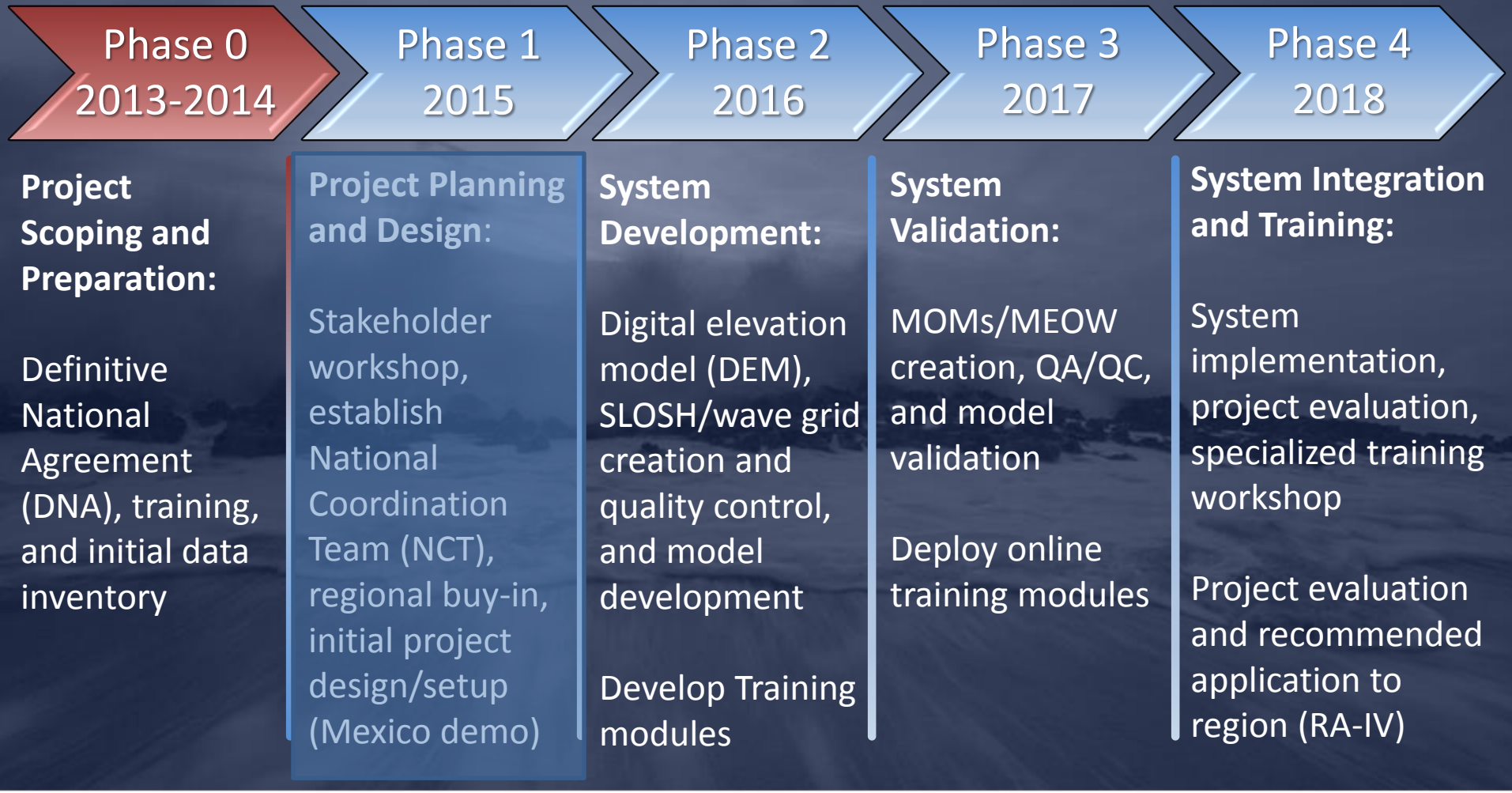
Why the Need for a Demonstration Project



- Almost 50% the deaths are due to storm surge
- Over 80% of deaths are due to water
- Wind causes less than 10% of deaths

Edward N. Rappaport, 2014: Fatalities in the United States from Atlantic Tropical Cyclones: New Data and Interpretation. Bull. Amer. Meteor. Soc., 95, 341–346.

CIFDP-C Demonstration Project Plan



Specialized Storm Surge Training

- First-ever international storm surge modeling workshop held at NHC/FIU in January 2015, funded by the WMO
- Students consisted of various Nations from the WMO RA-IV region plus participants from the Philippines (PAGASA) and JMA
- Specialized training focused on setting up, running, and analyzing SLOSH model results and required data sets necessary for properly setting up and validating a storm surge modeling system
- NHC gathered feedback from workshop participants to lay foundation for CIFDP-C system design and implementation in member Nations

CIFDP-C Project Kickoff and NCT Meeting in Dominican Republic

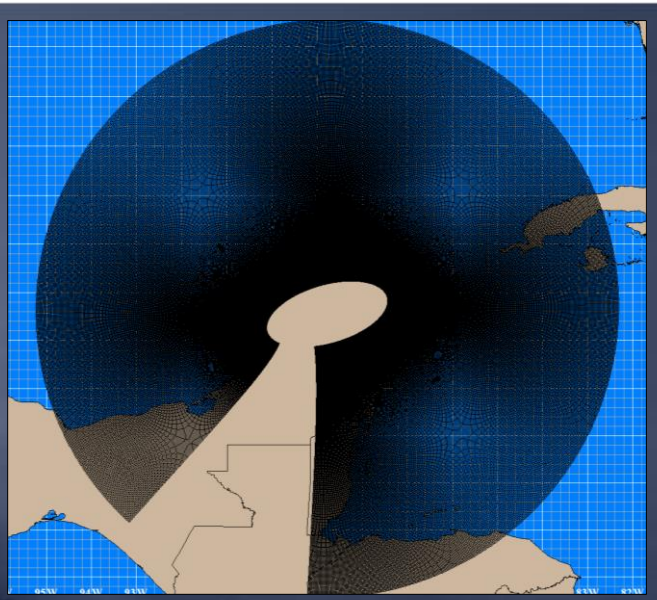
Hispaniola Demonstration Project Phases

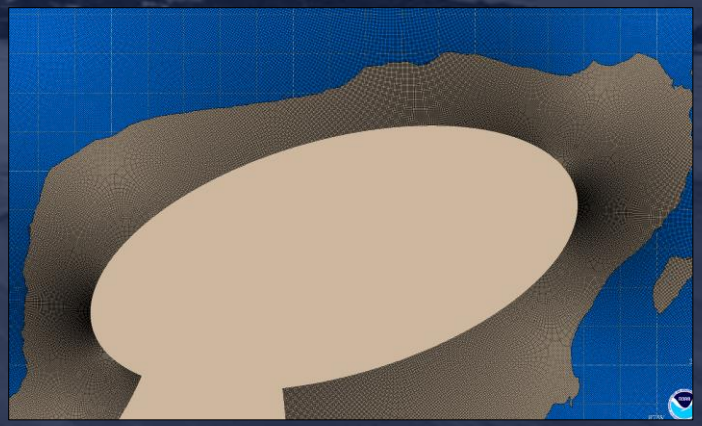
Phase 0 2013-2014	Phase 1 2015	Phase 2 2016	Phase 3 2017	Phase 4 2018
Project Scoping and Preparation: Definitive National Agreement (DNA), training, and initial data inventory	**Project Planning and Design:** Stakeholder workshop, establish National Coordination Team (NCT), regional buy-in, initial project design/setup (Mexico demo)	**System Development:** Digital elevation model (DEM), SLOSH/wave grid creation and quality control, and model development Develop Training modules	**System Validation:** MOMs/MEOW creation, QA/QC, and model validation Deploy online training modules	**System Integration and Training:** System implementation, project evaluation, specialized training workshop Project evaluation and recommended application to region (RA-IV)

MEXICO DEMONSTRATION PROJECT

Mexico Storm Surge Demonstration Project

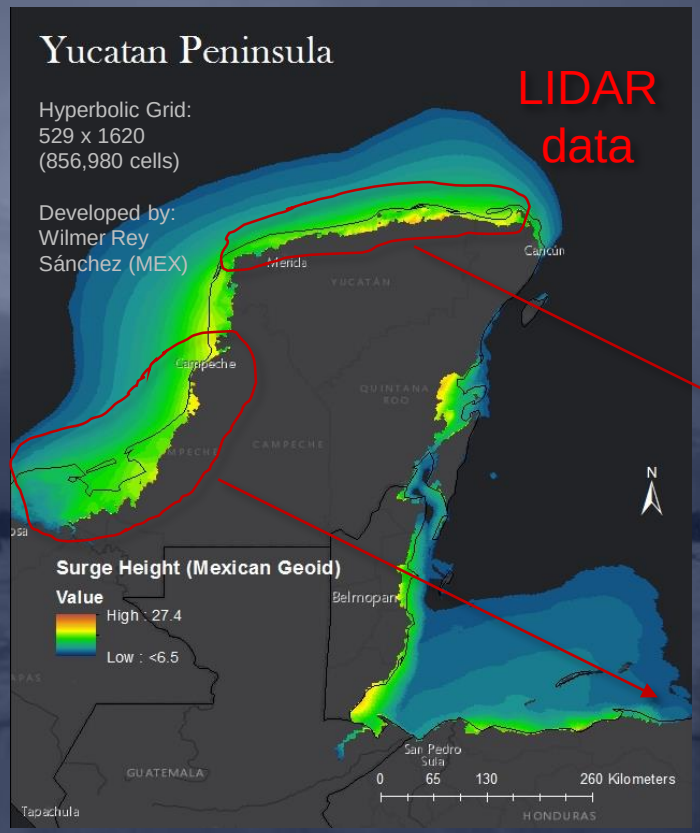
- Collaboration between RSMC-Miami, Florida International University, and the Coastal Processes and Engineering Laboratory of the Sisal Academic Unit of the Engineering Institute of the UNAM
- Explore the feasibility of using SLOSH within WMO RA-IV:
  - Initial scoping project in the Yucatan Peninsula due to data availability
- Establish a technical foundation for the CIFDP-C
- Establish a framework for sharing storm surge modeling expertise and data between RSMC Miami and RA-IV member nations

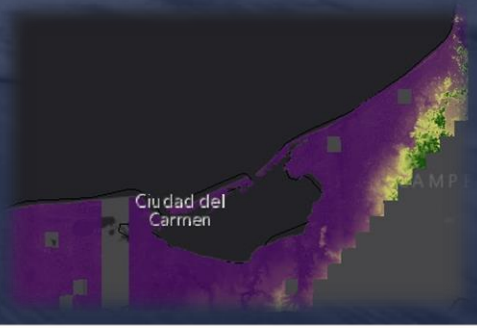


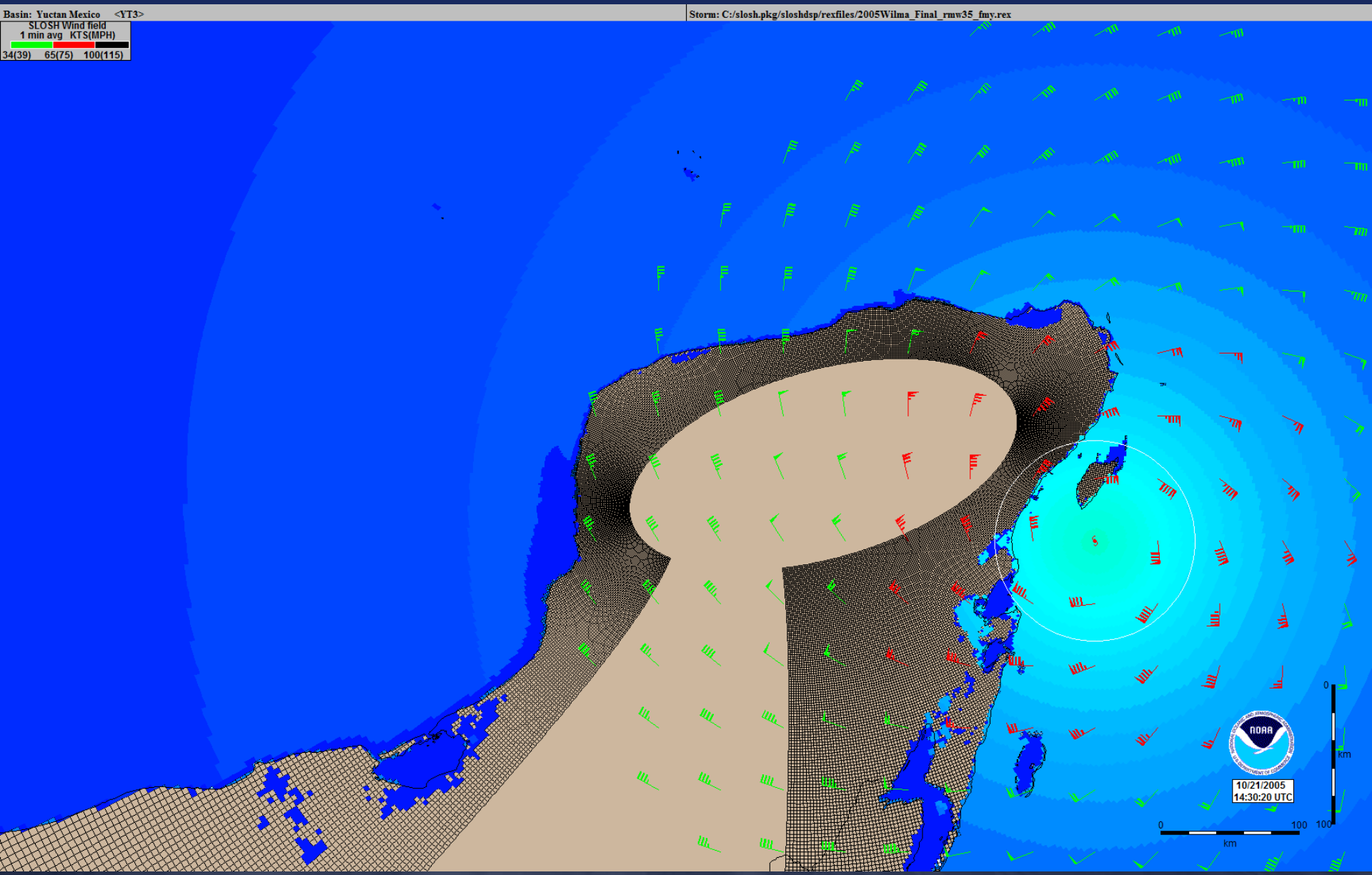


SLOSH Basin for Yucatan Peninsula

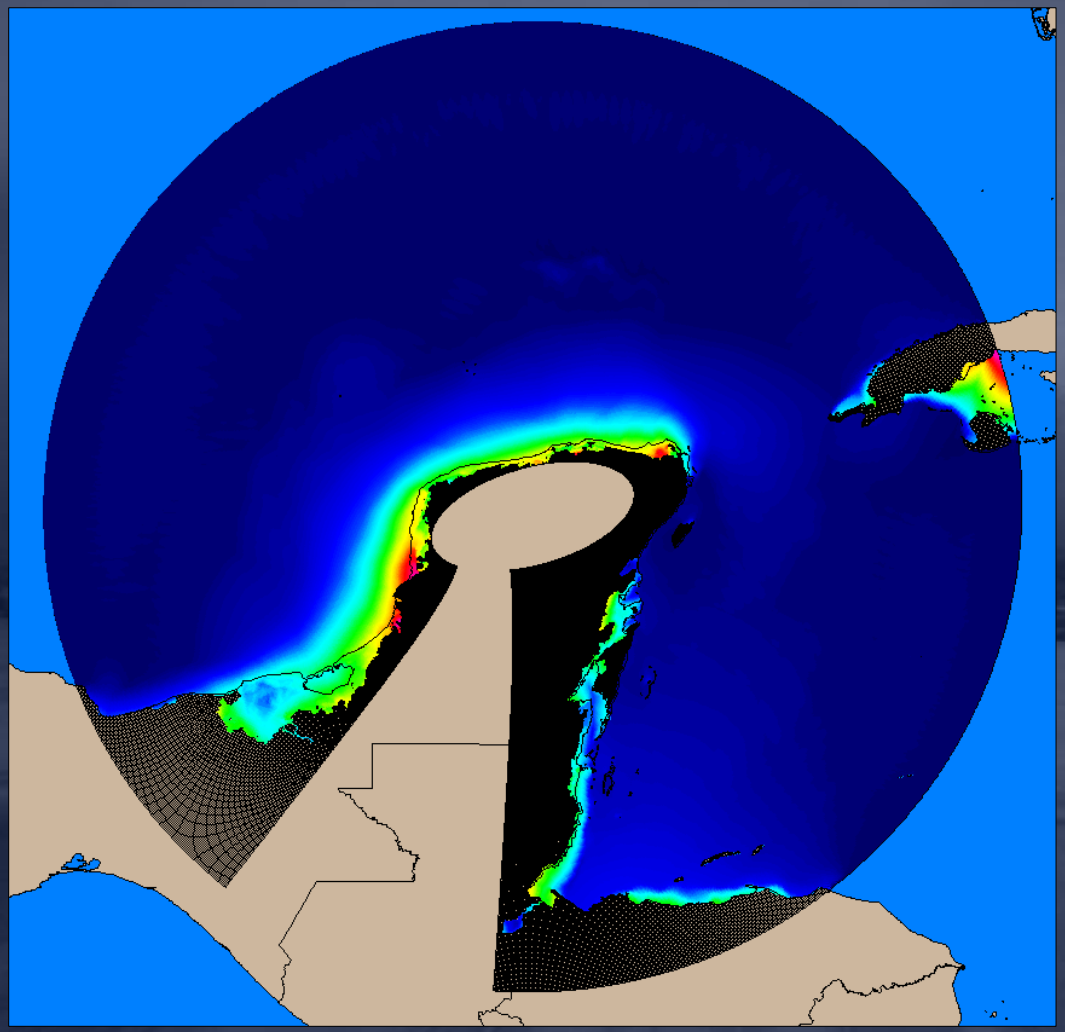
- First ever SLOSH basin for the Yucatan Peninsula
- Working to understand IT requirements and data necessary to develop SLOSH within Mexico
- LIDAR data supplemented with ETOPO1 (1.8 km) global relief model for topography and bathymetry data

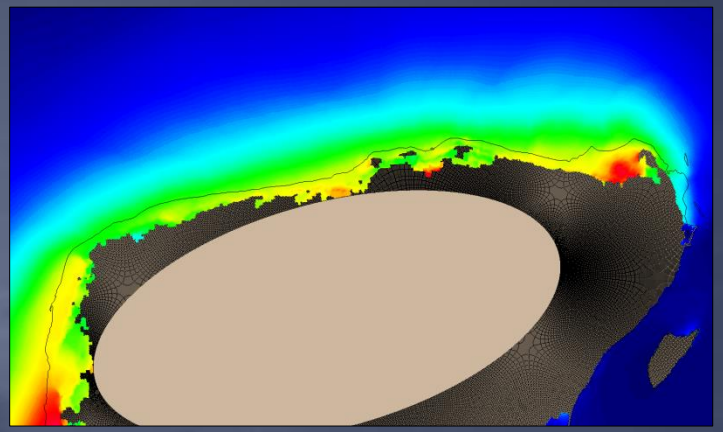


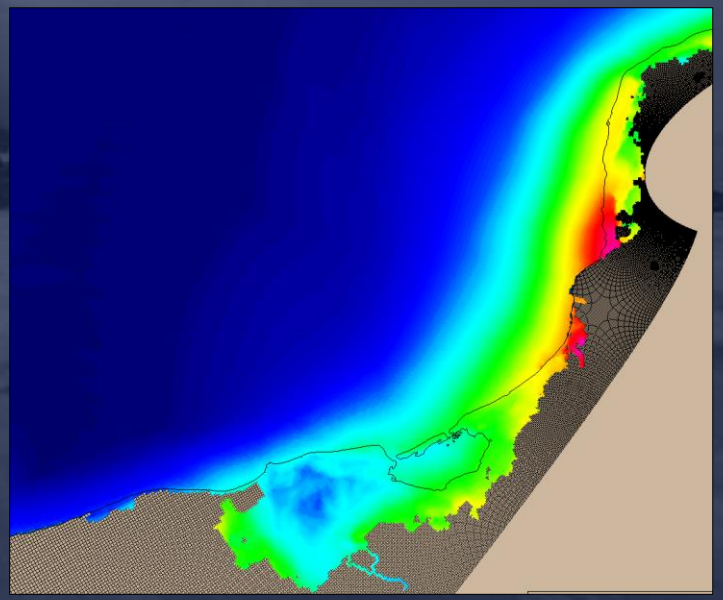



Basin: Yuctan Mexico <YT3>
Storm: C:/slosh.pkg/sloshdsp/rexfiles/2005Wilma_Final_rmw35_fmy.rex
SLOSH Wind field
1 min avg KTS(MPH)
34(39) 65(75) 100(115)
NOAA
10/21/2005
14:30:20 UTC
0
100
100
km
0
km

Mexico Storm Surge Demonstration Project
Category 3 MOM (Mean Tide)

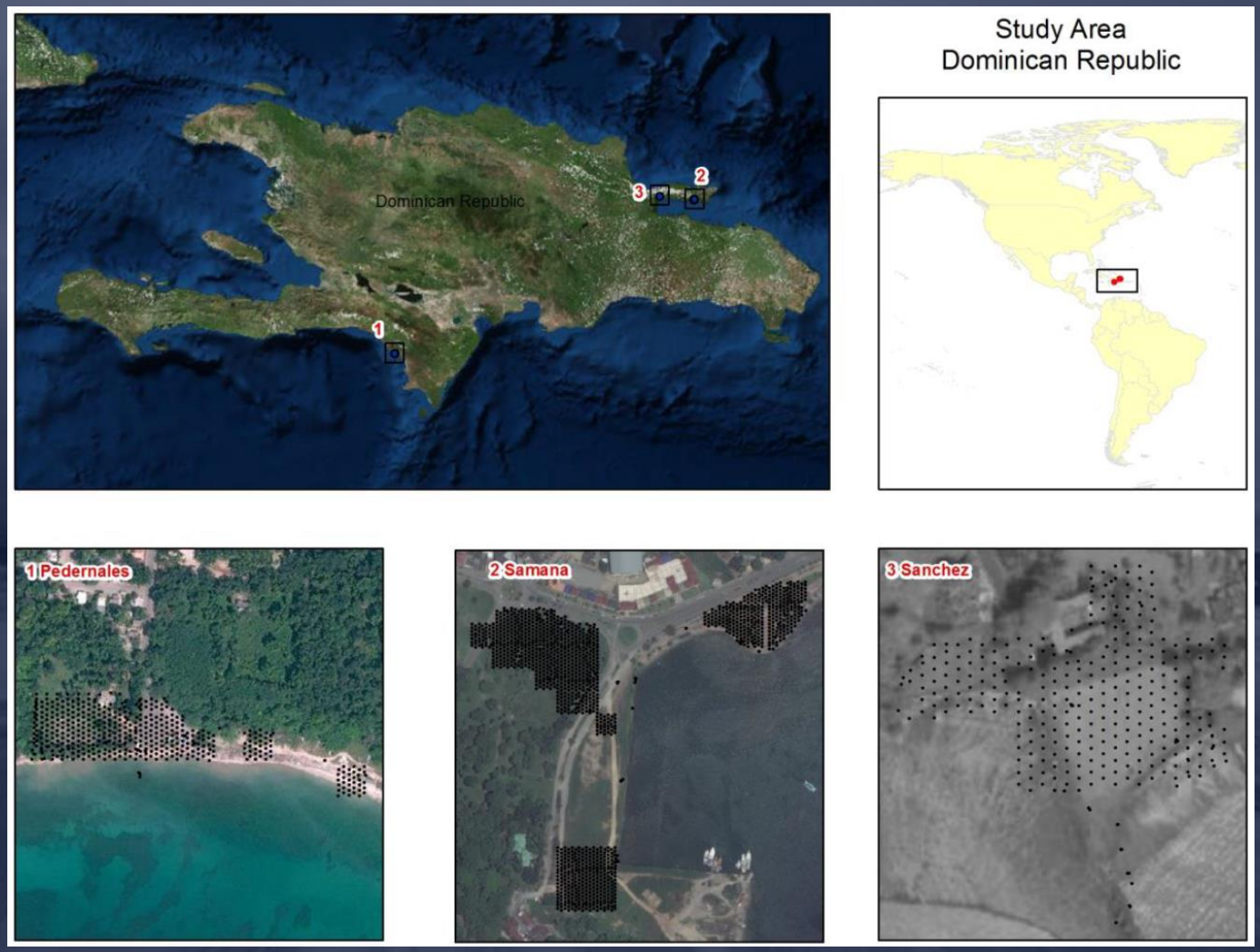




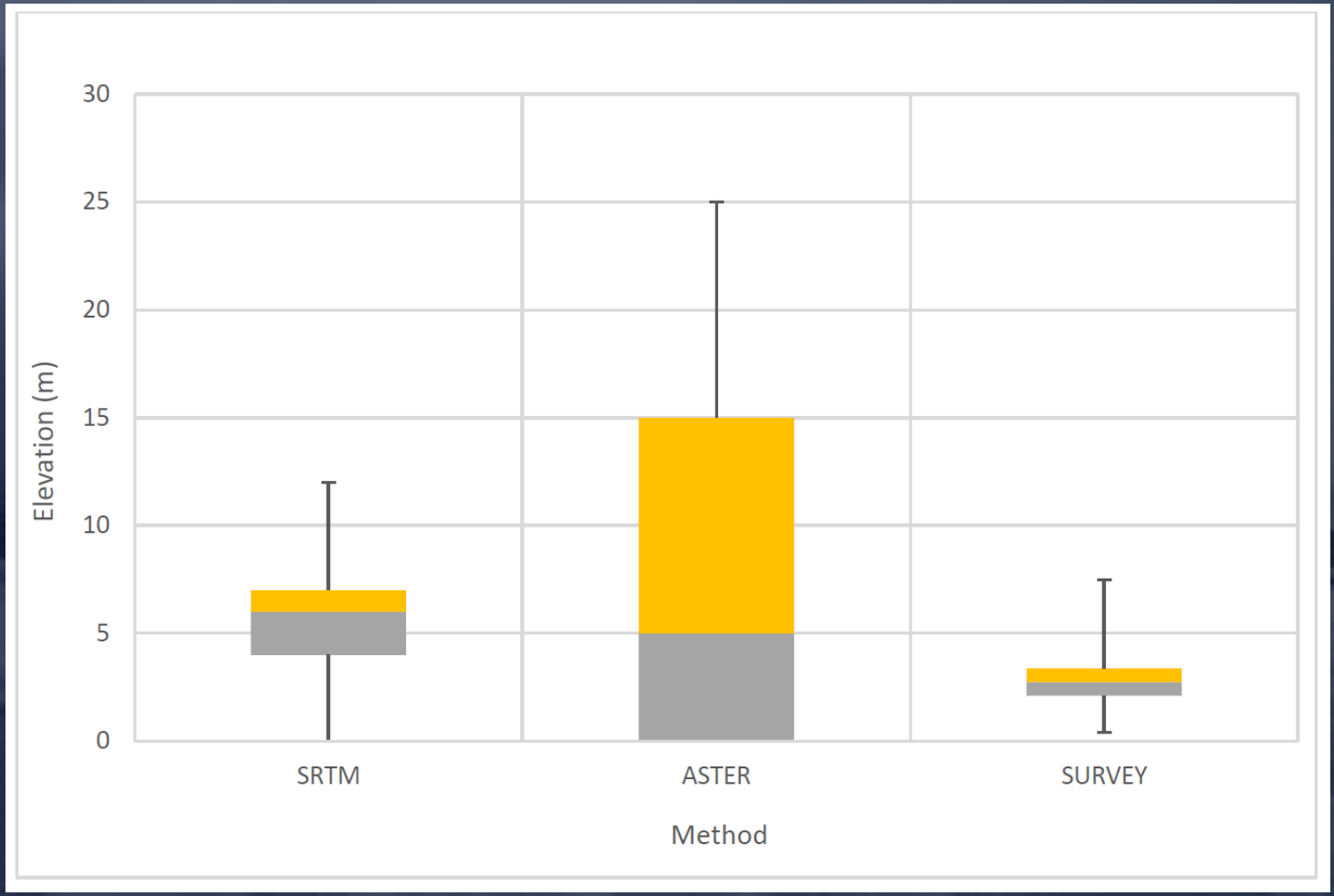


CIFDP-C DATA COLLECTION AND DATA ASSESSMENT

FIU Surveyed Areas in Dominican Republic

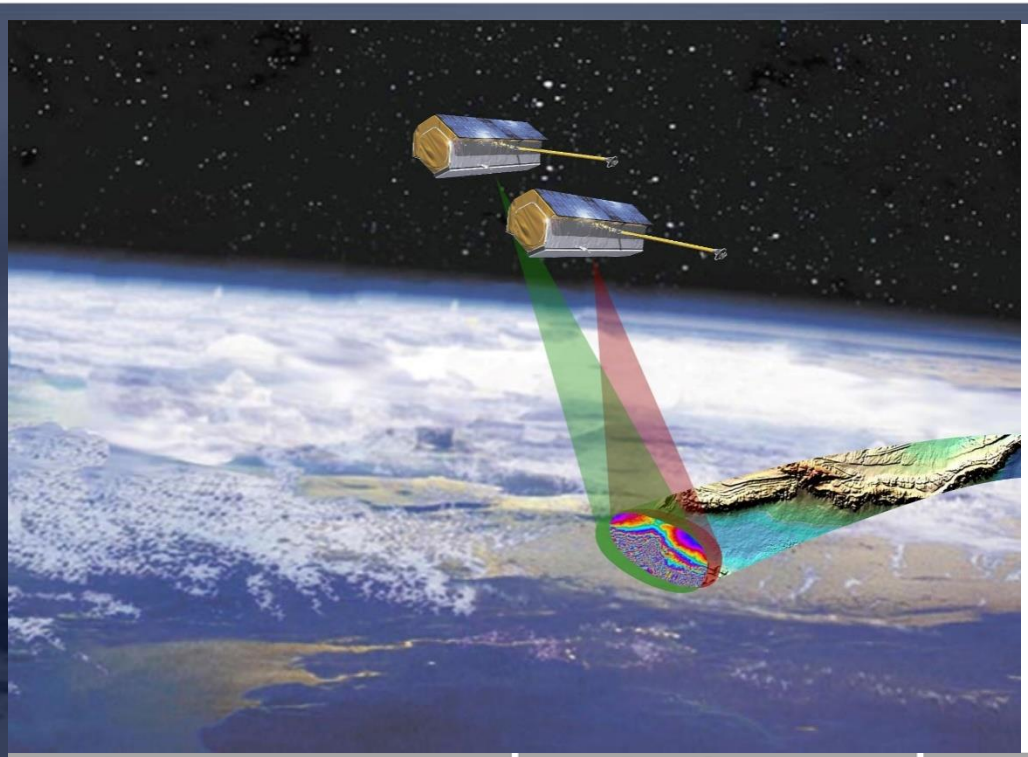


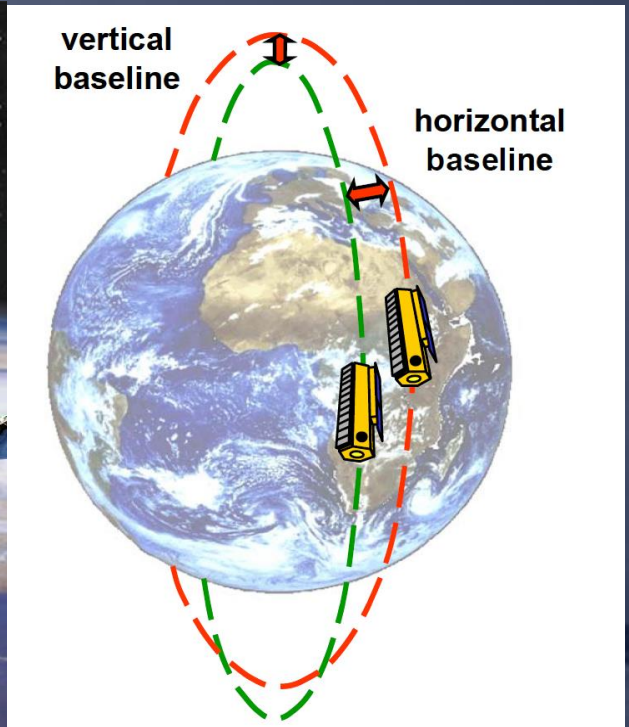
Boxplots for Grid Elevations and Survey Elevations for all Sites



Grey area represents the 25th to 50th percentiles; yellow 50th to 75th

TanDEM-X

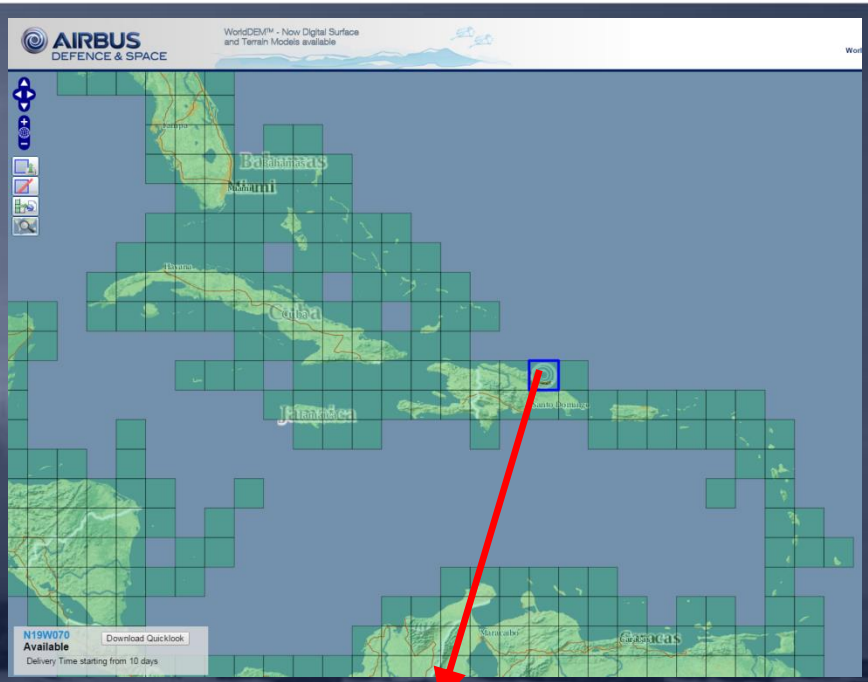




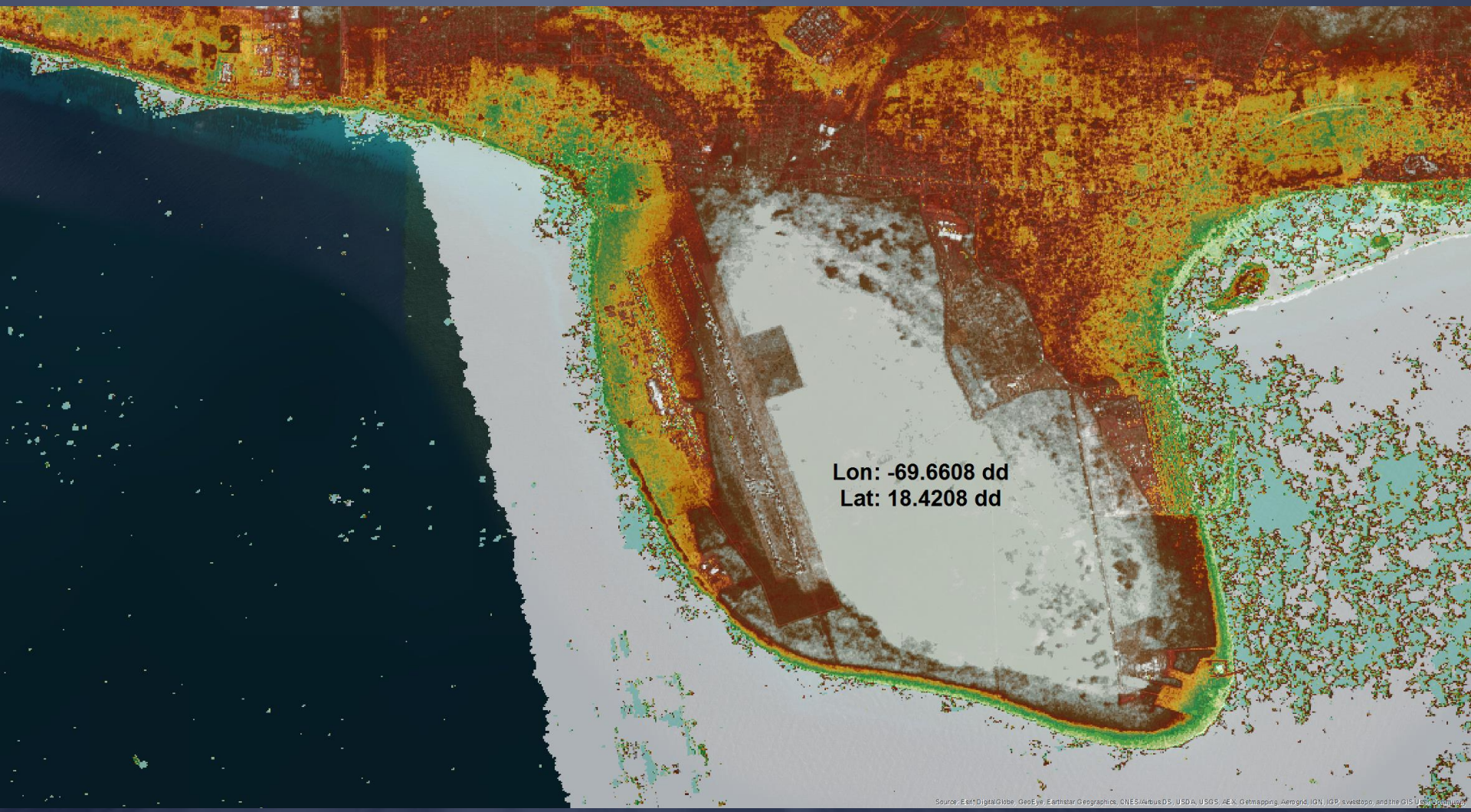
Requirements	Specification	DTED-2	TanDEM-X DEM
Relative Vertical Accuracy	90 % linear point-to-point error over a 1° by 1° cell	12 m (slope < 20 %) 15 m (slope > 20 %)	2 m (slope < 20 %) 4 m (slope > 20 %)
Absolute Vertical Accuracy	90 % linear error	18 m	10 m
Relative Horizontal Accuracy	90 % circular error	15 m	3 m
Absolute Horizontal Accuracy	90 % circular error	23 m	10 m
Spatial Resolution	Independent pixels	30 m (1 arc sec @ equator)	12 m (0,4 arc sec @ equator)

TanDEM-X Data Availability

- Availability as of March 2016
- Estimated cost: ~100K U.S. dollars for study area
- Working with NWS International Affairs and FIU to establish an agreement regarding data sharing and savings for CIFDP-C

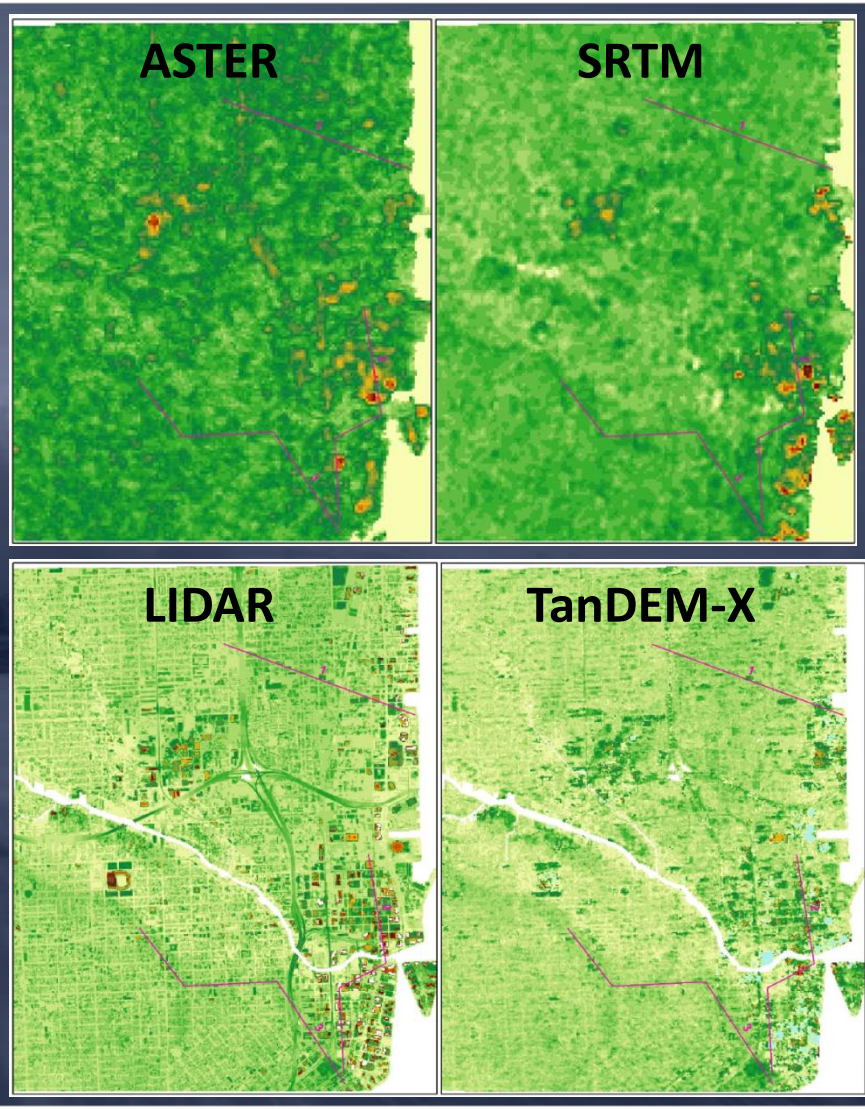


Raw TanDEM-X: Santo Domingo Airport

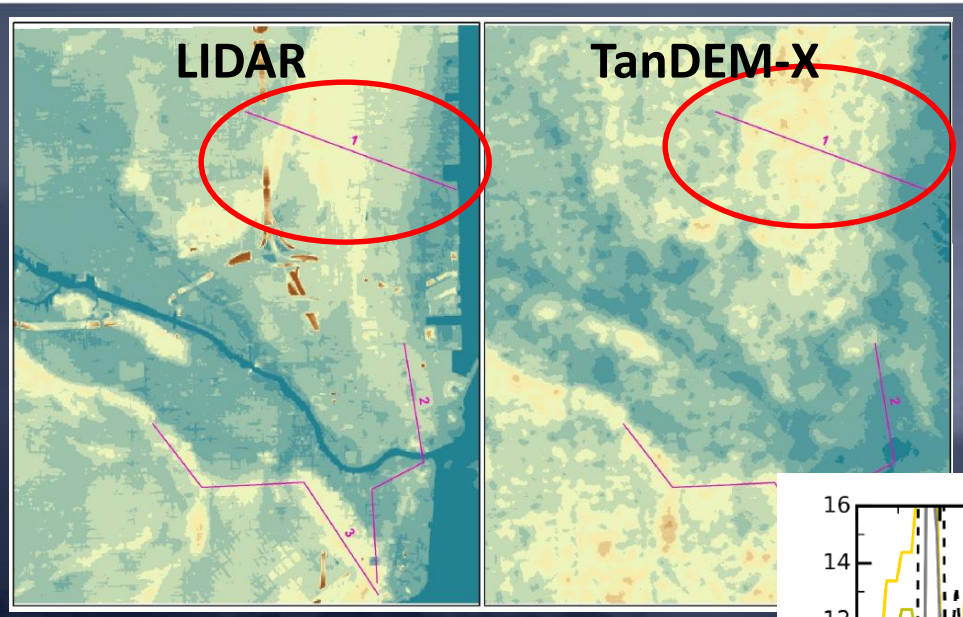


Topography Data Comparison: Miami, FL

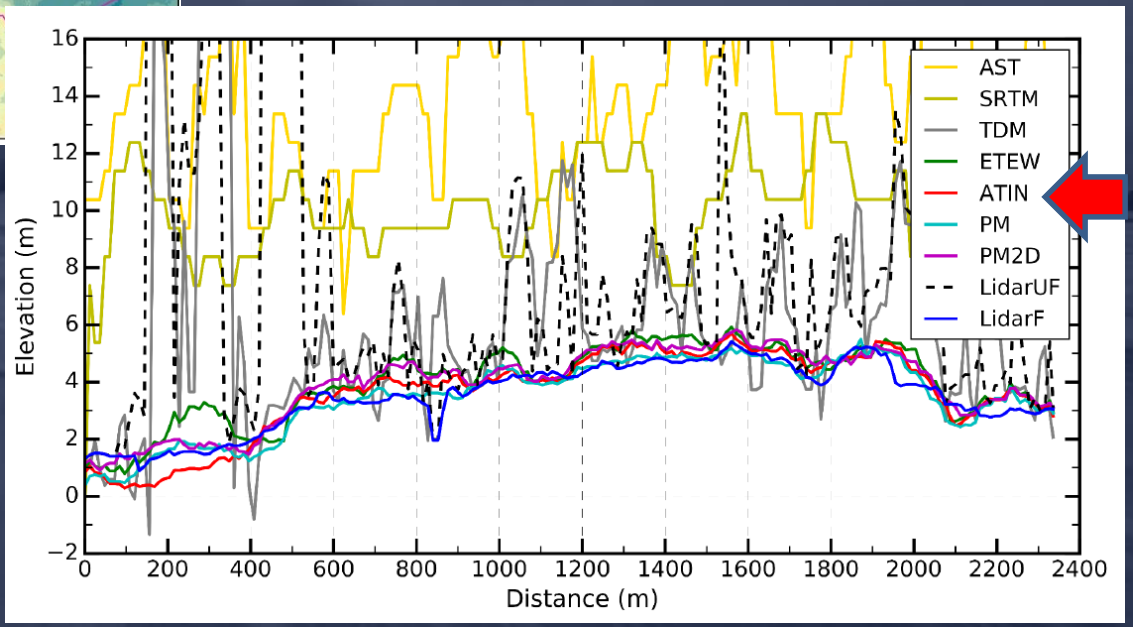
Downtown Miami, FL



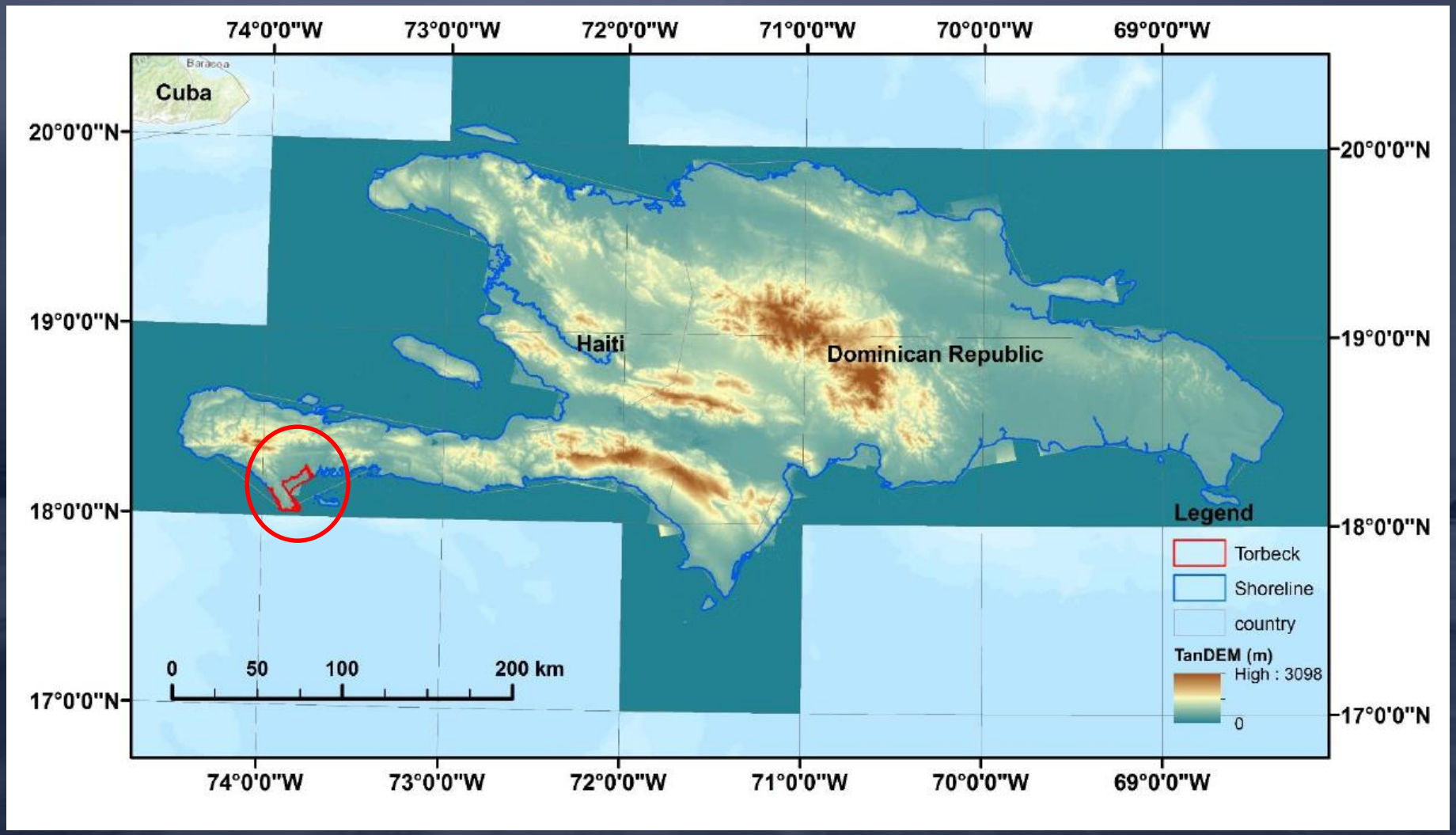
Topography Data Comparison: Miami, FL



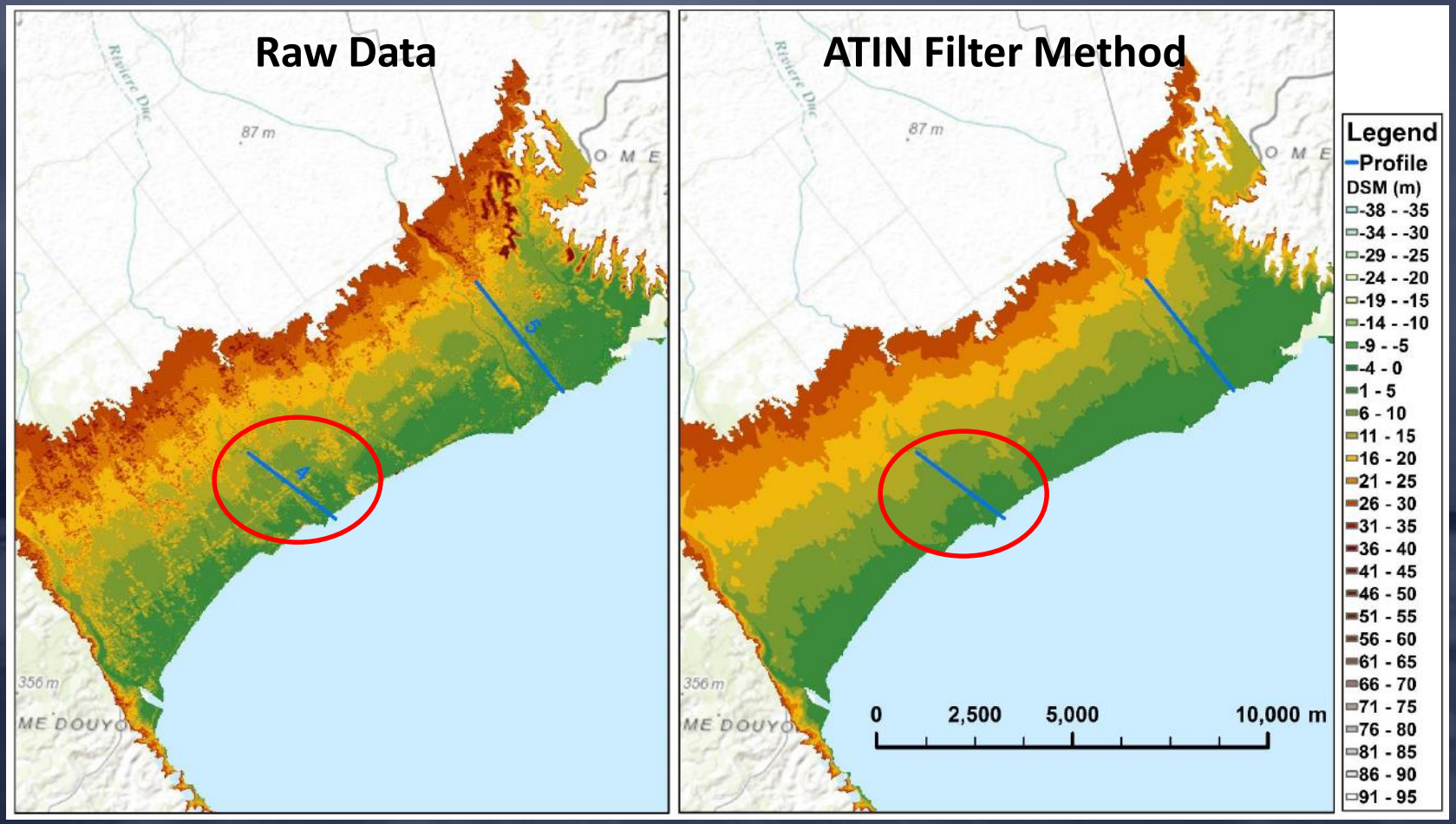
Filtering Methods to create DTM



TanDEM-X Data for Hispaniola

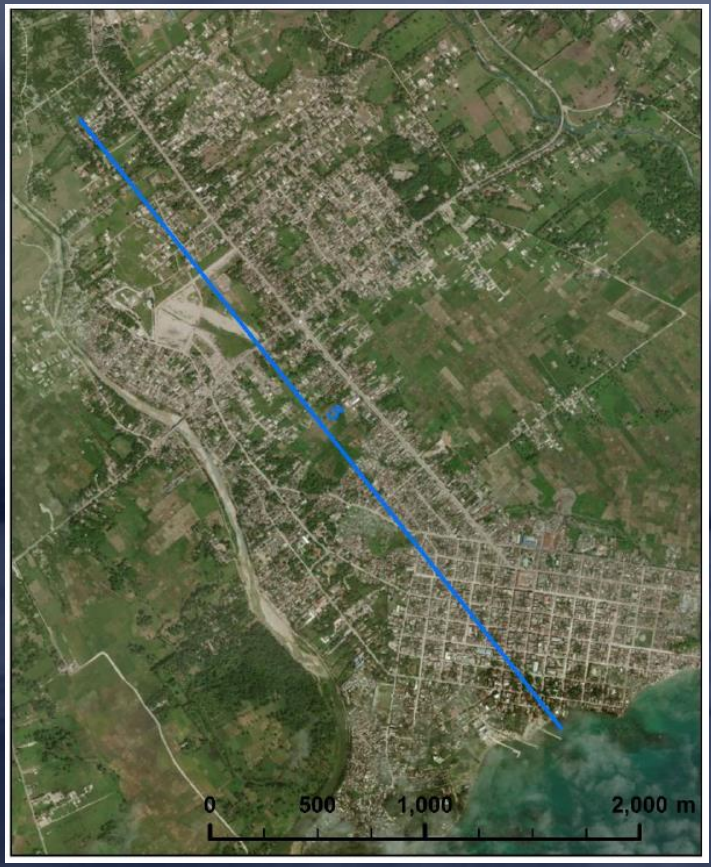


DTM Creation: Torbeck, Haiti

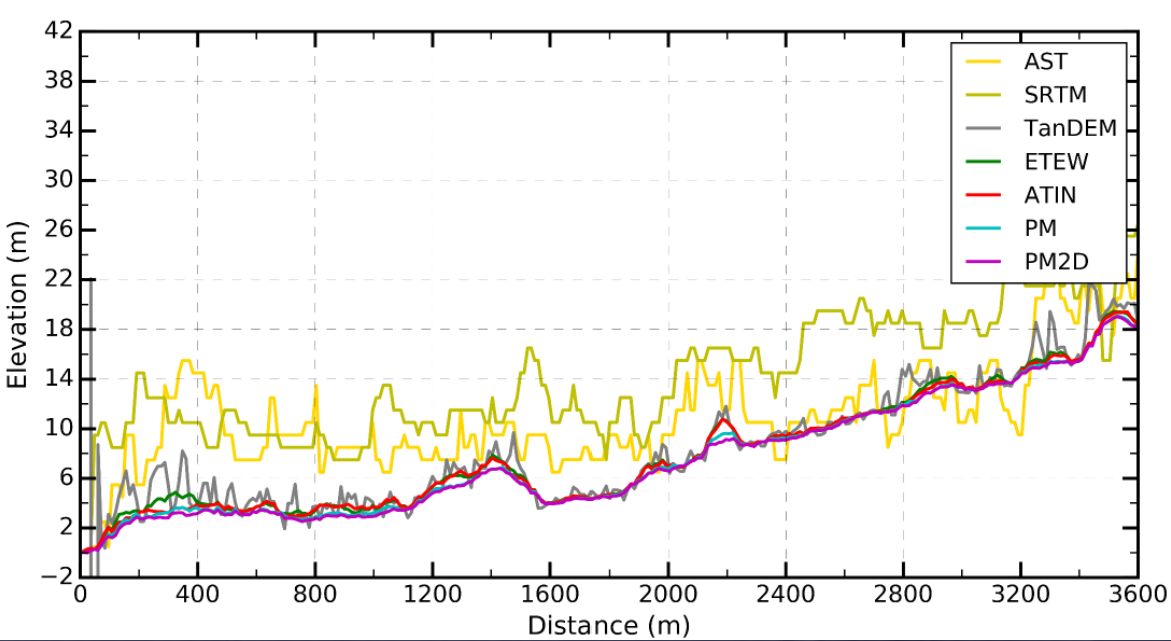


DTM Comparison: Torbeck, Haiti

Profile Location



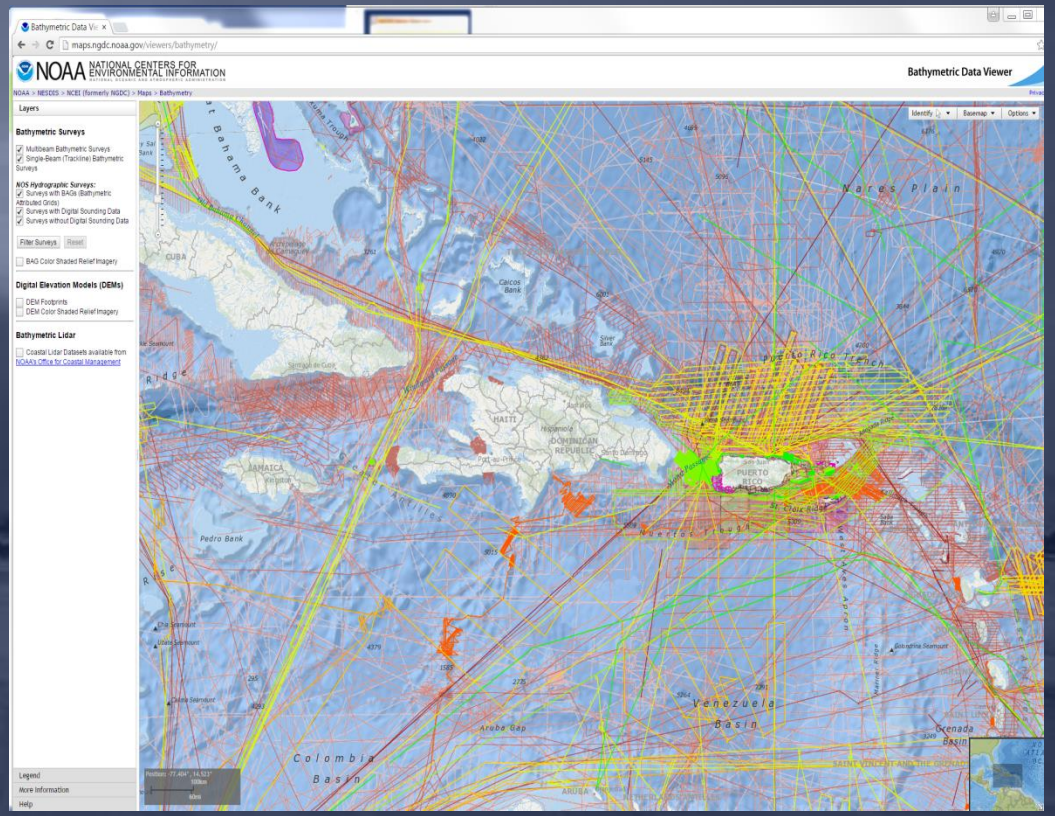
DTM Comparison: ASTER, SRTM, TanDEM-X



Bathymetric Data

- NOAA single and multi-beam sounding surveys
- NOAA Tsunami program
- CIFDP-C NCT data collection
- IOC bathymetry

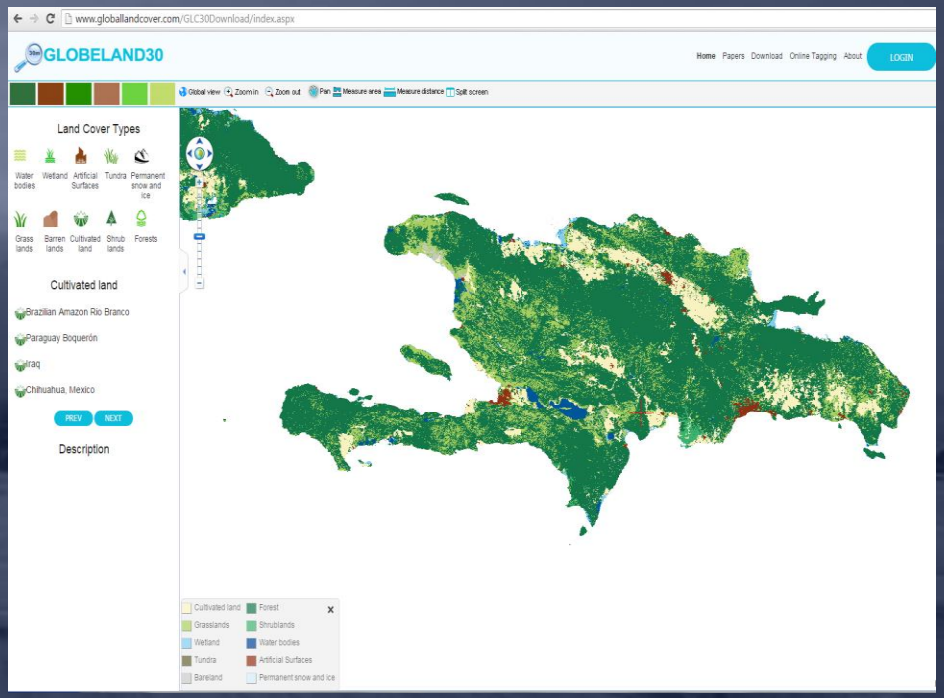
- Already incorporated into model grids



Supplemental Information

NOAA Global Shoreline

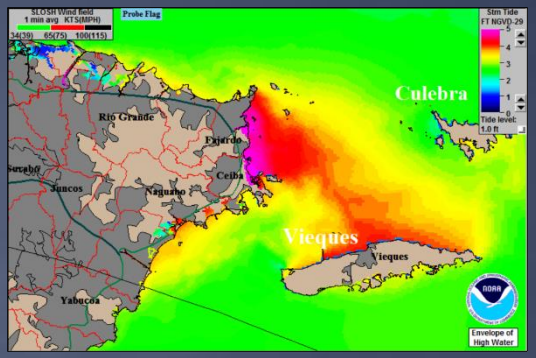
Global 30m Land Cover from China

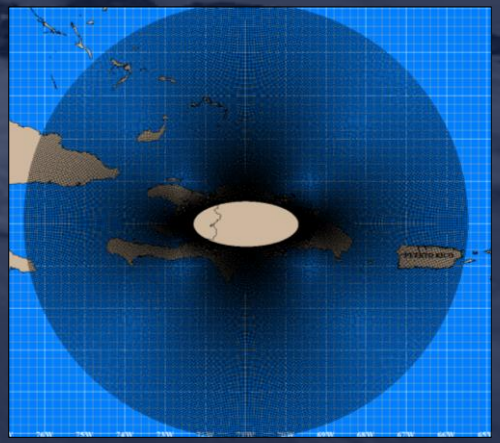


CIFDP-C SYSTEM DEVELOPMENT

CIFDP-C System Development

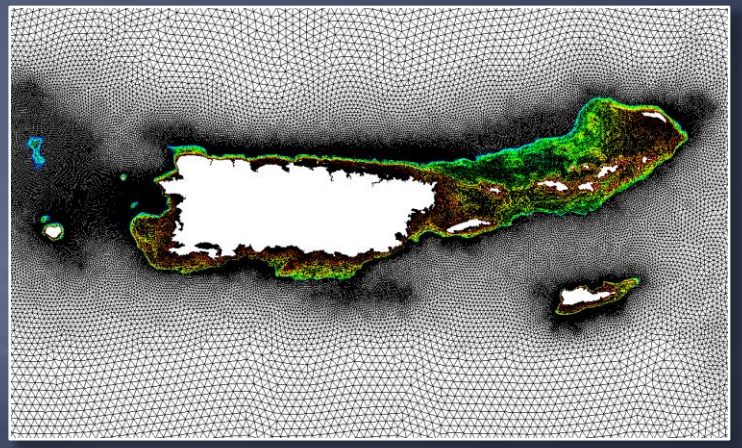
- Implement a coupled storm surge and wave modeling system
  - SLOSH hydrodynamic model
  - Wave model recommended by IOOS modeling testbed
- Develop products for planning, preparedness, and forecasting
  - SLOSH MOMs and MEOWs
  - Same display system as employed by RSMC-Miami (SLOSH Display Program)
- Provide specialized training programs on how to use the storm surge products for planning and preparedness

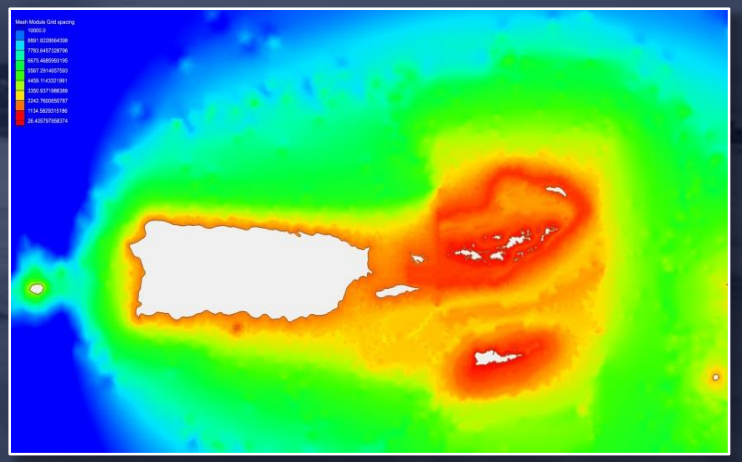




Leveraging U.S. Modeling Testbed for Puerto Rico and the Virgin Islands

- Evaluate wave/surge operational modeling/forecasting in steep-sloped regions such as the Caribbean
- Features regional-scale and nearshore-scale field cases using SWAN wave model
- Broad participation from academic and operational communities with a wide range of surge and wave models
- Conclude with recommendations for operational environment and facilitate the transition to NOAA's National Hurricane Center





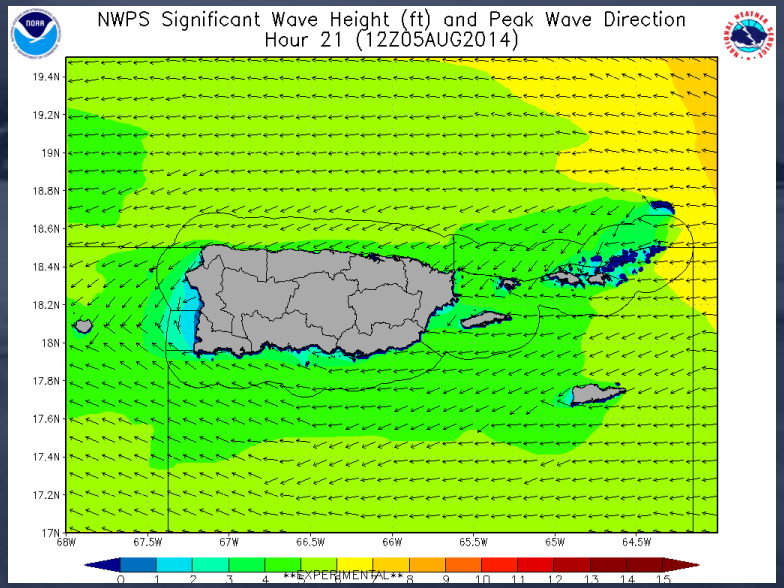
2nd Generation Wave Model for SLOSH

- Initial model development and evaluation of a 2nd generation wave model to couple with SLOSH
- Selected the Great Lakes Wave Model and began adding wave physics parameterizations
- Model uses simplified physics, but is cheaper computationally than SWAN or WW3
- More suitable to couple with SLOSH than SWAN

$$\frac{\partial \vec{M}}{\partial t} + \vec{v} \cdot \nabla_{x,y} \vec{M} = \vec{\tau}_w$$

$$\vec{\tau}_w = 0.028 \rho_a D_f \left| \vec{U} - 0.83 C_p \right| \left(\vec{U} - 0.83 C_p \right)$$

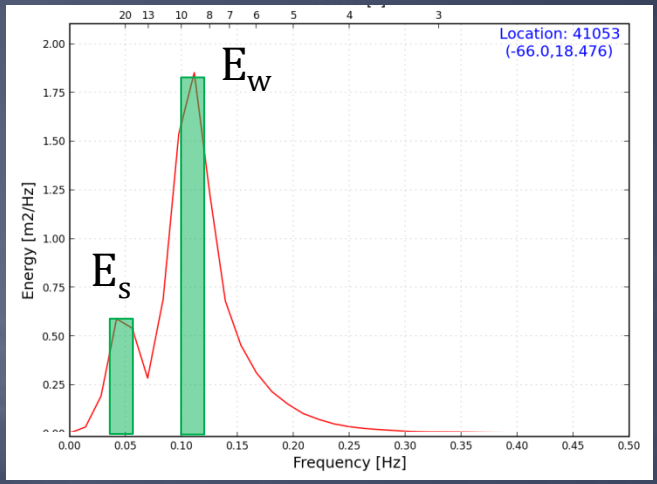
$$\sigma^2 = 6.23 \times 10^{-6} \left(\frac{f_p U}{g} \right)^{-10/3} \frac{U^4}{g^2}$$



Wave Model Discretization

Wind Sea: $$\frac{\partial E_W}{\partial t} + \frac{\partial C_g \cdot E_W}{\partial x} = S_{wind} + S_{diss}$$

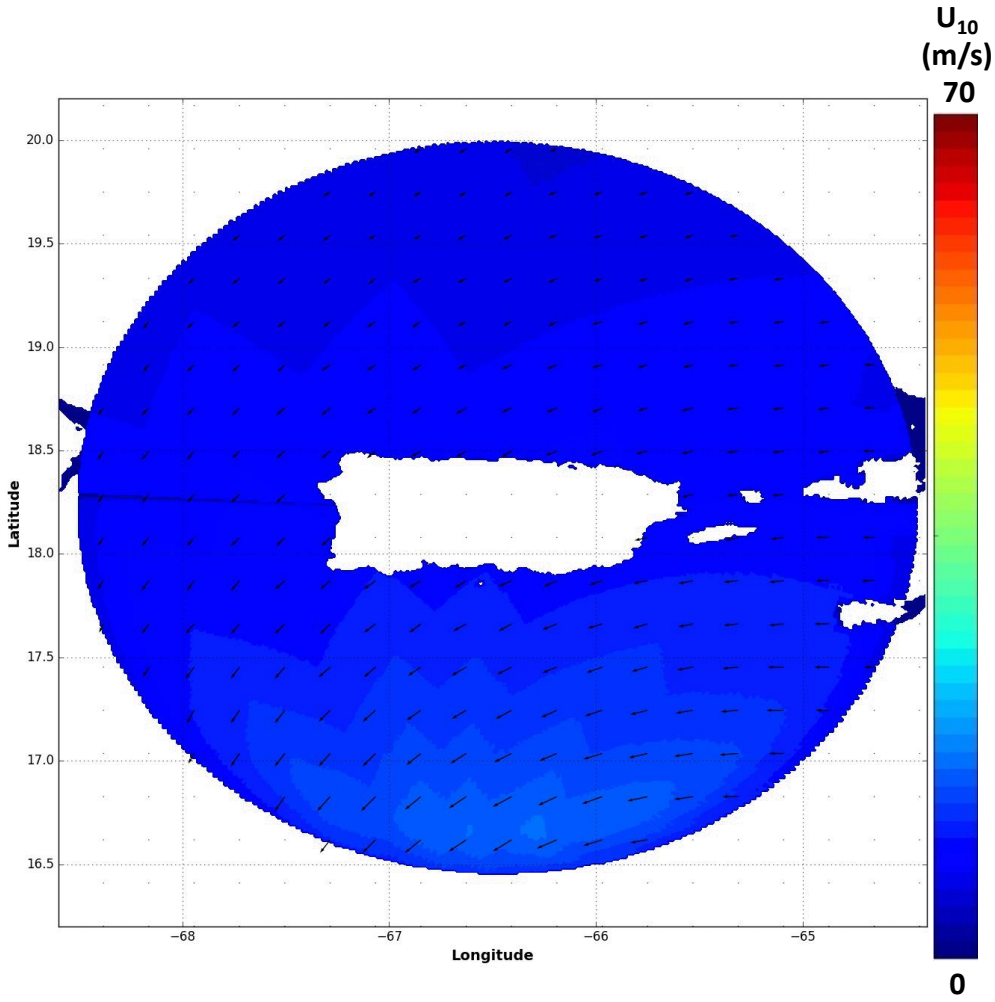
Swell: $$\frac{\partial E_s}{\partial t} + \frac{\partial C_g \cdot E_s}{\partial x} = S_{diss}$$



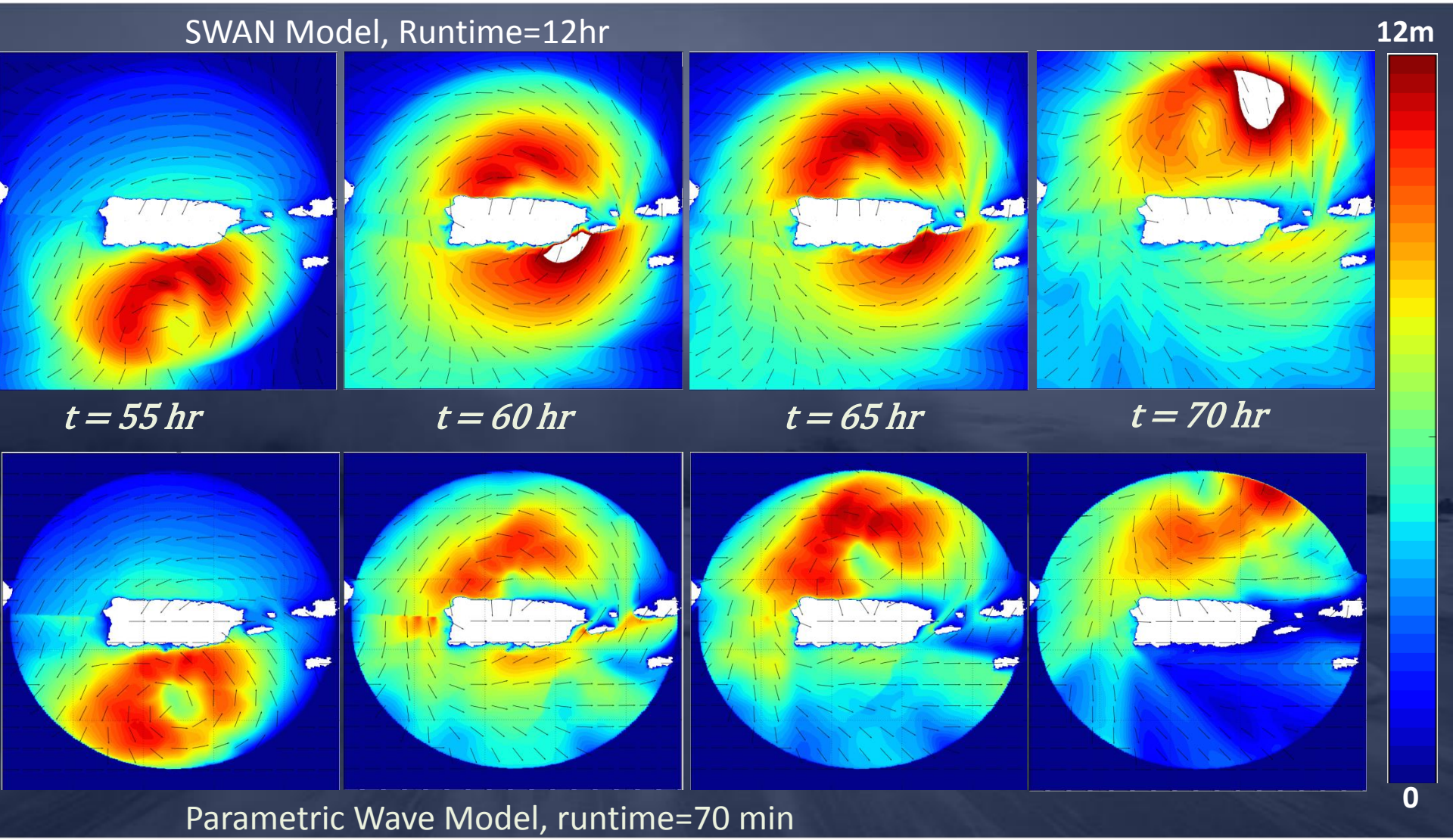
- Wind seas (E_w): grows when angle between wave direction and wind direction is < 90°, and wind velocity is larger than phase velocity
- Swell transition: associated wind sea wave energy now propagates without further generation and is treated as swell energy (E_s)
- Swell frequency: equals corresponding wind sea frequency at the point when the wave growth ends
- Total variance: adding E_w and E_s for each wave direction and integrating through all directions

Parametric Wave Model Test Case

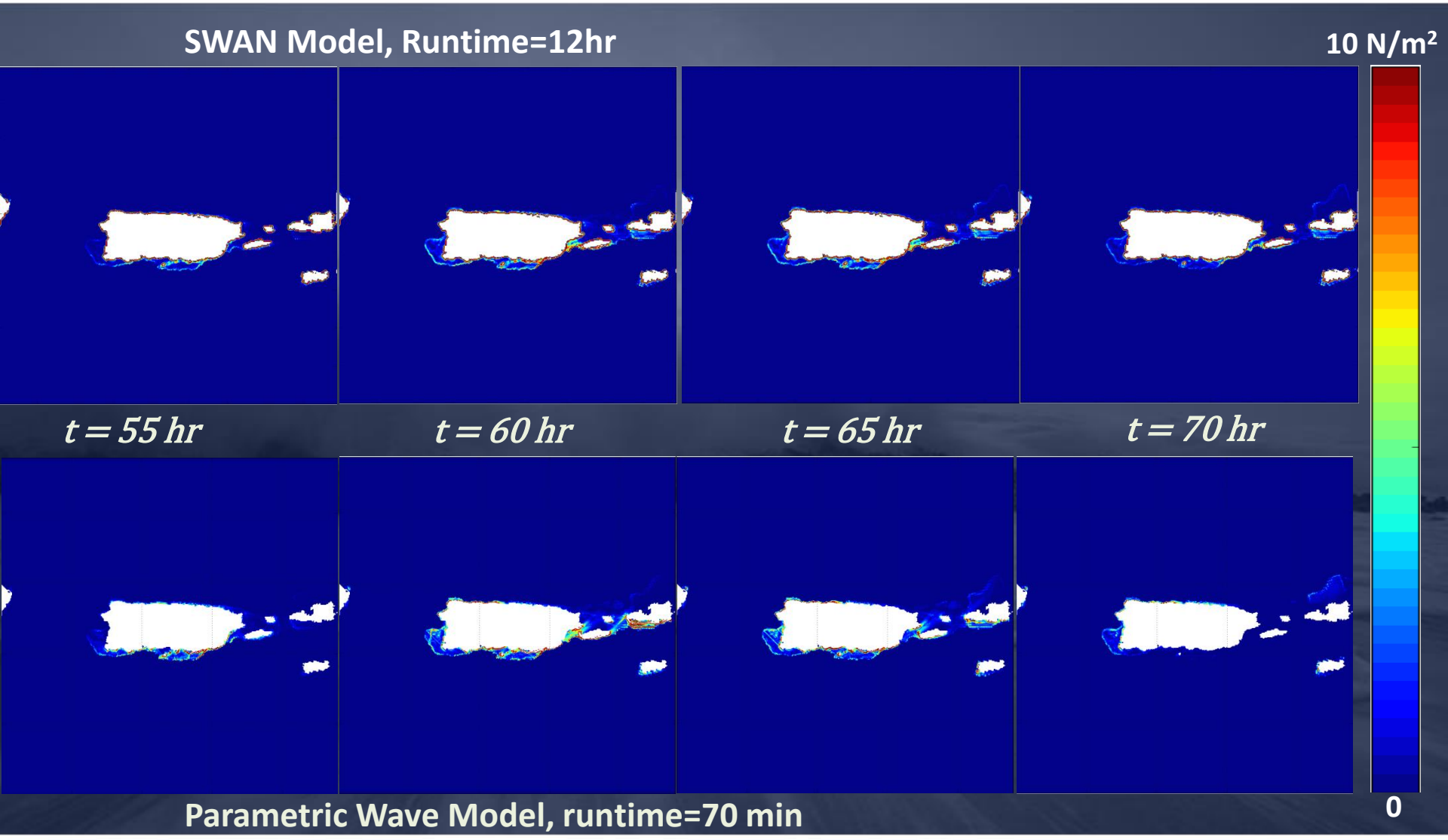
- Hypothetical Category 5 Hurricane
- Storm center crosses Puerto Rico from the South to the North
- Maximum wind speed around 65 m/s



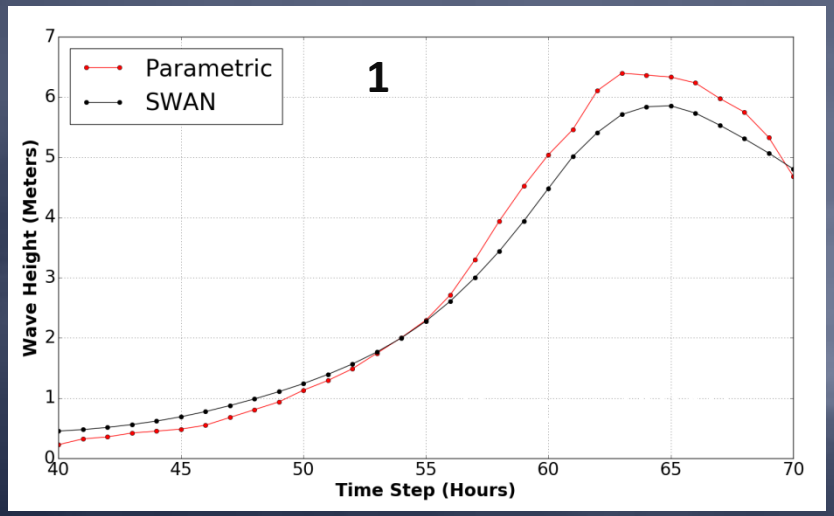
Wave Height Comparison

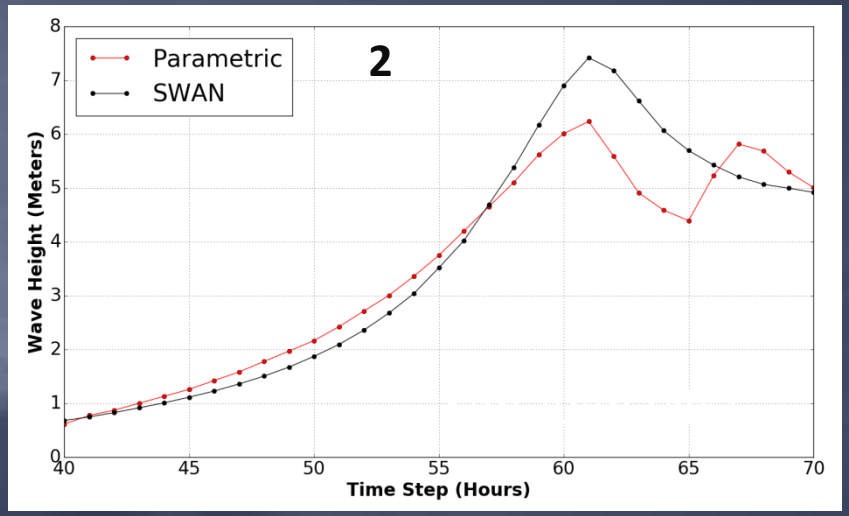


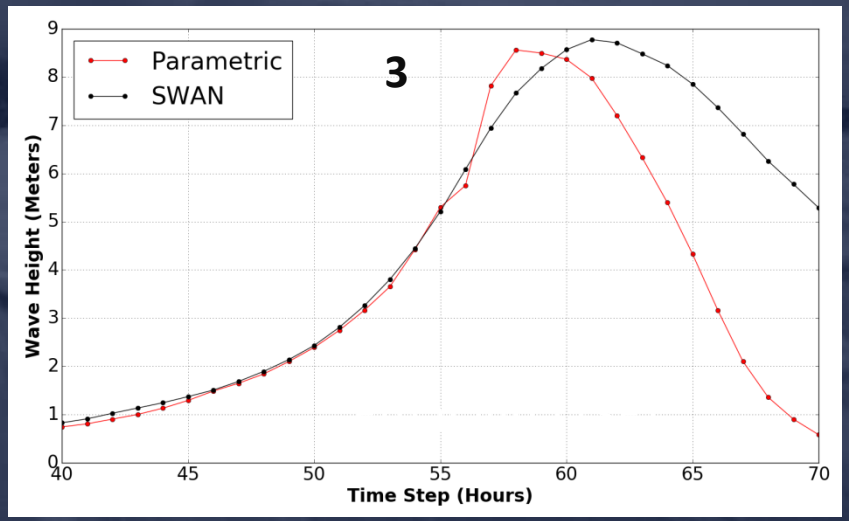
Wave Radiation Stress Comparison



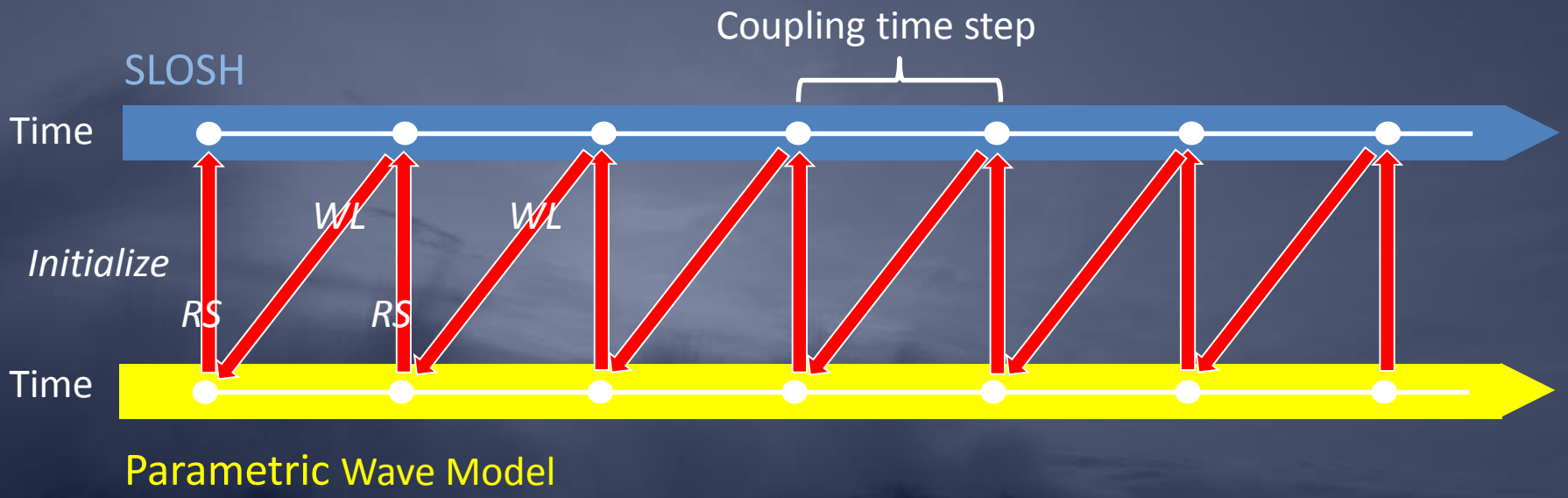
Wave Height Comparison







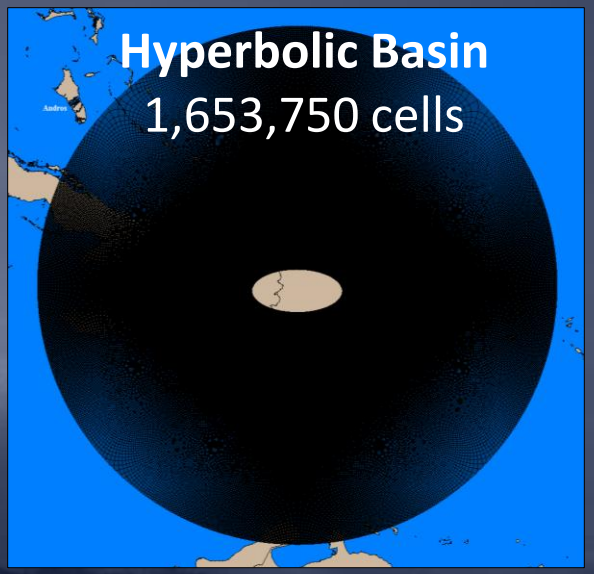
Wave Model Coupling to SLOSH

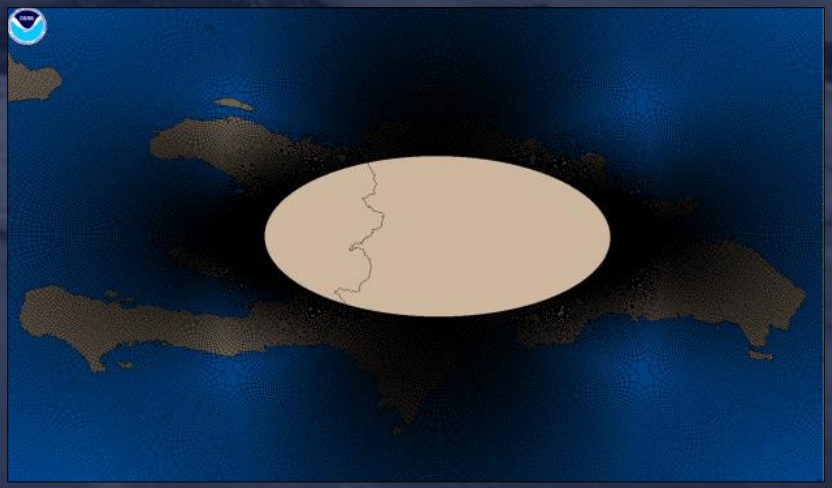


- SLOSH is driver, with parametric wave model as a subroutine
- Compiled into single, efficient executable
- To be used for computation of MEOW surge/inundation envelopes

SLOSH Grid Development

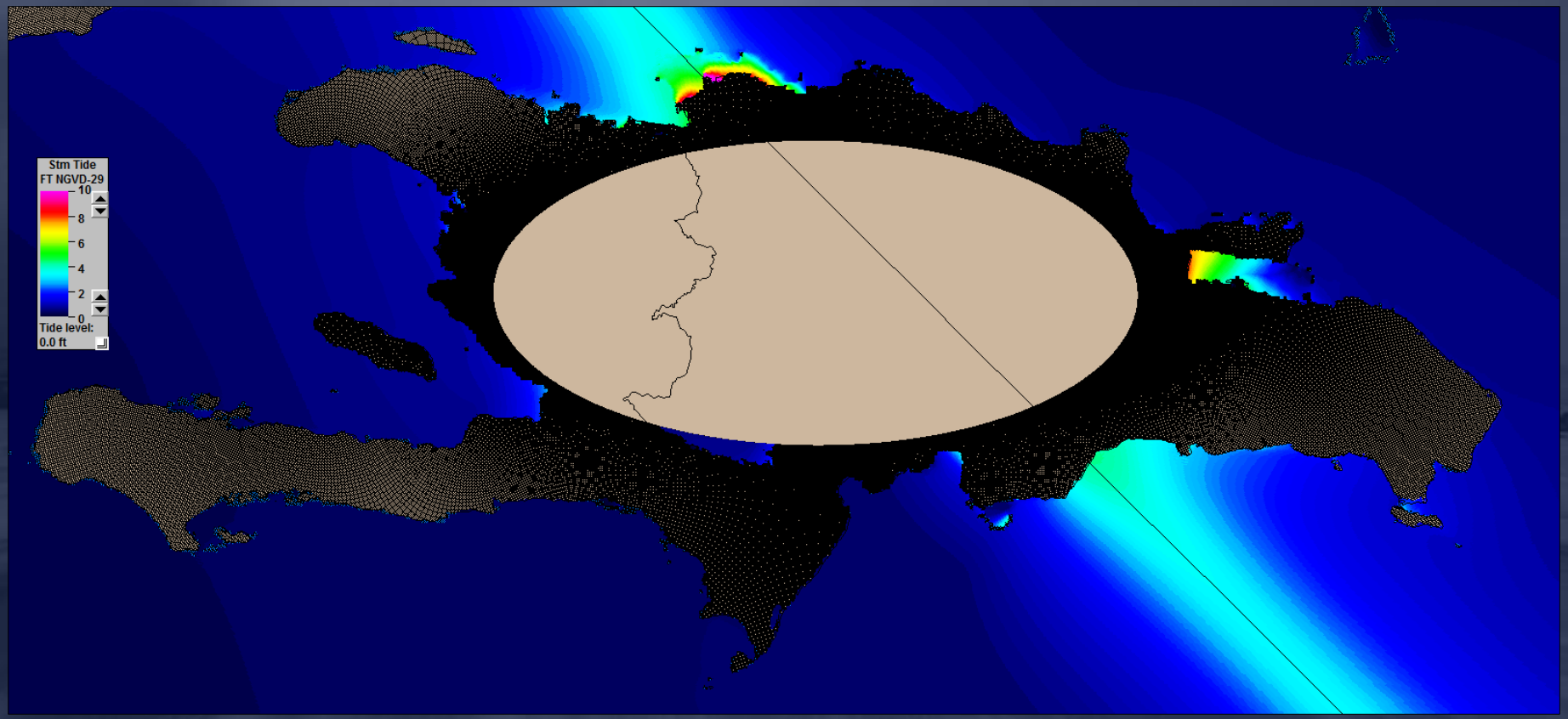
- Tested different SLOSH basin configurations for optimal grid resolutions in main areas of interest
- Developed an initial SLOSH basin for testing and evaluation of run times and stability analysis
- Evaluated current data requirements, data availability, and data gaps



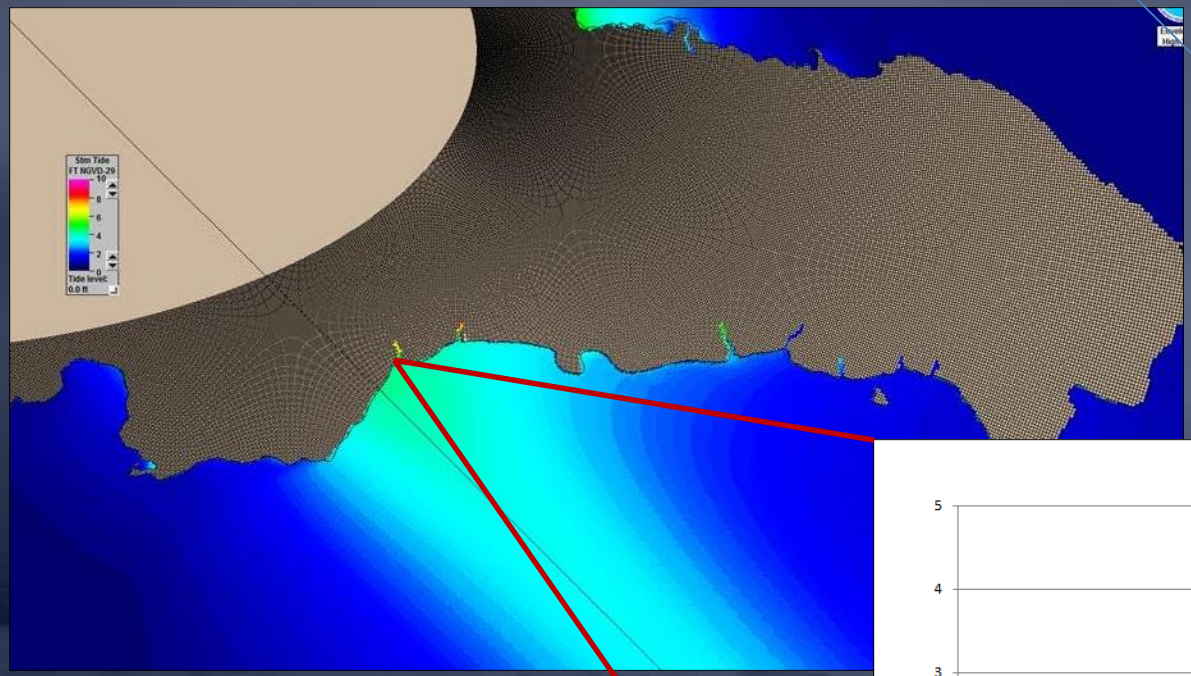


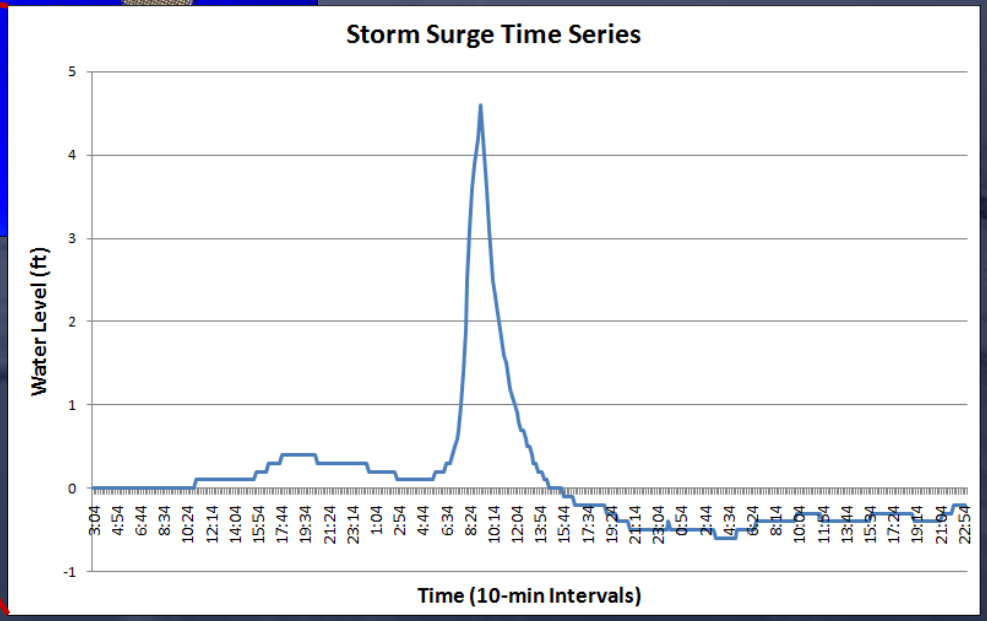
SLOSH Model Results

SLOSH Category 5 Hurricane Moving NW at 20 mph



River Coupling Methodology: Ozama River



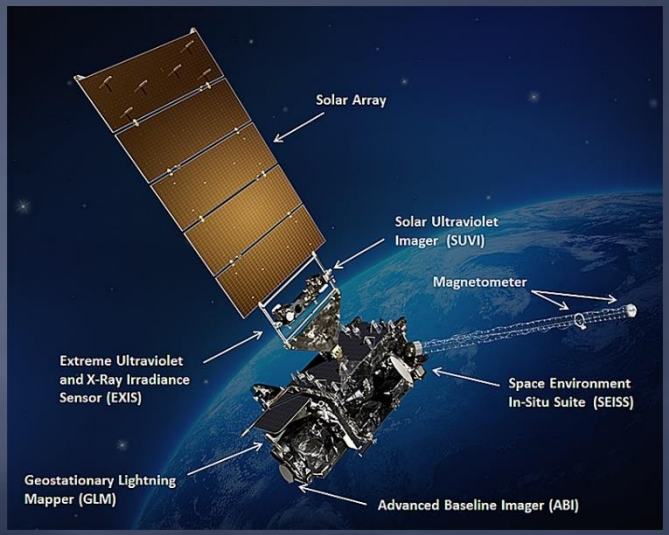


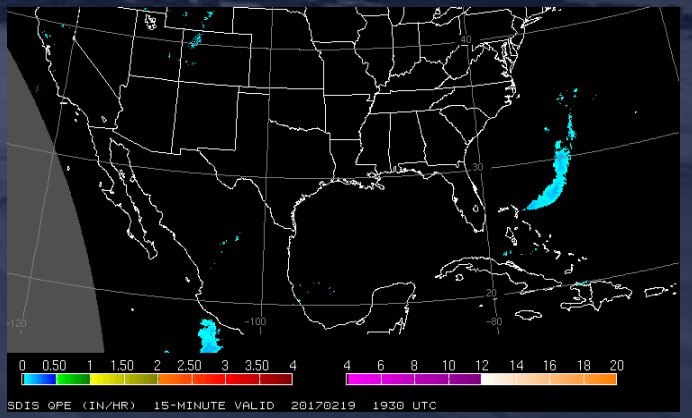
Accurate and Timely QPE for CIFDP-C?

- Many countries in Latin America, including DR, lack timely and accurate Quantitative Precipitation Estimates (QPE)

- While QPE products are available from GOES satellites, accuracy typically suffers in tropical environments and areas of complex terrain.
  - Dissemination is a challenge

- GOES-R will provide improved QPE
  - Baseline rainfall rate product from ABI IR brightness temperatures will be calibrated in real time against microwave-derived rain rates to enhance accuracy.

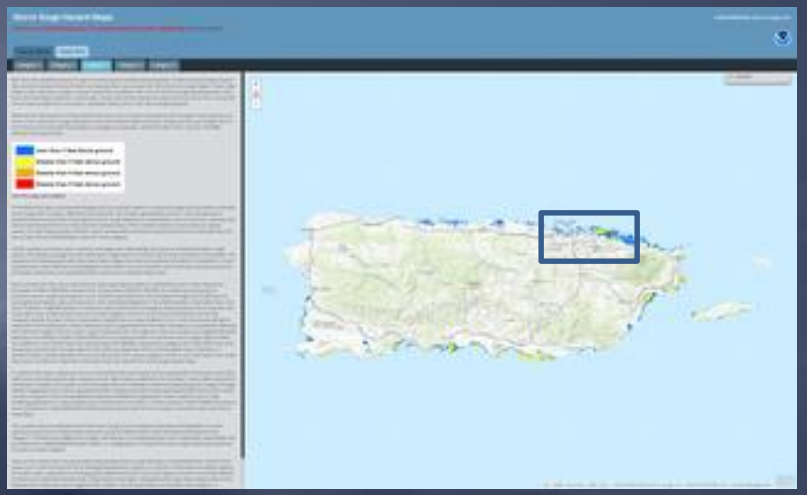


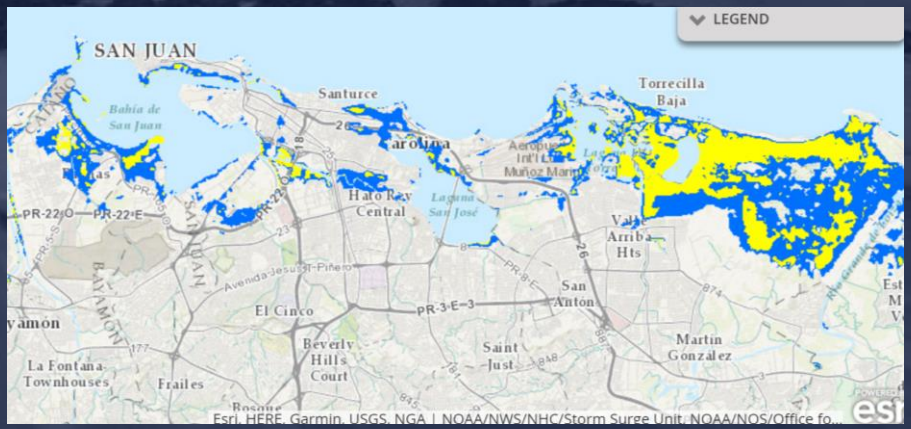


TRAINING MODULES AND OUTREACH MATERIAL

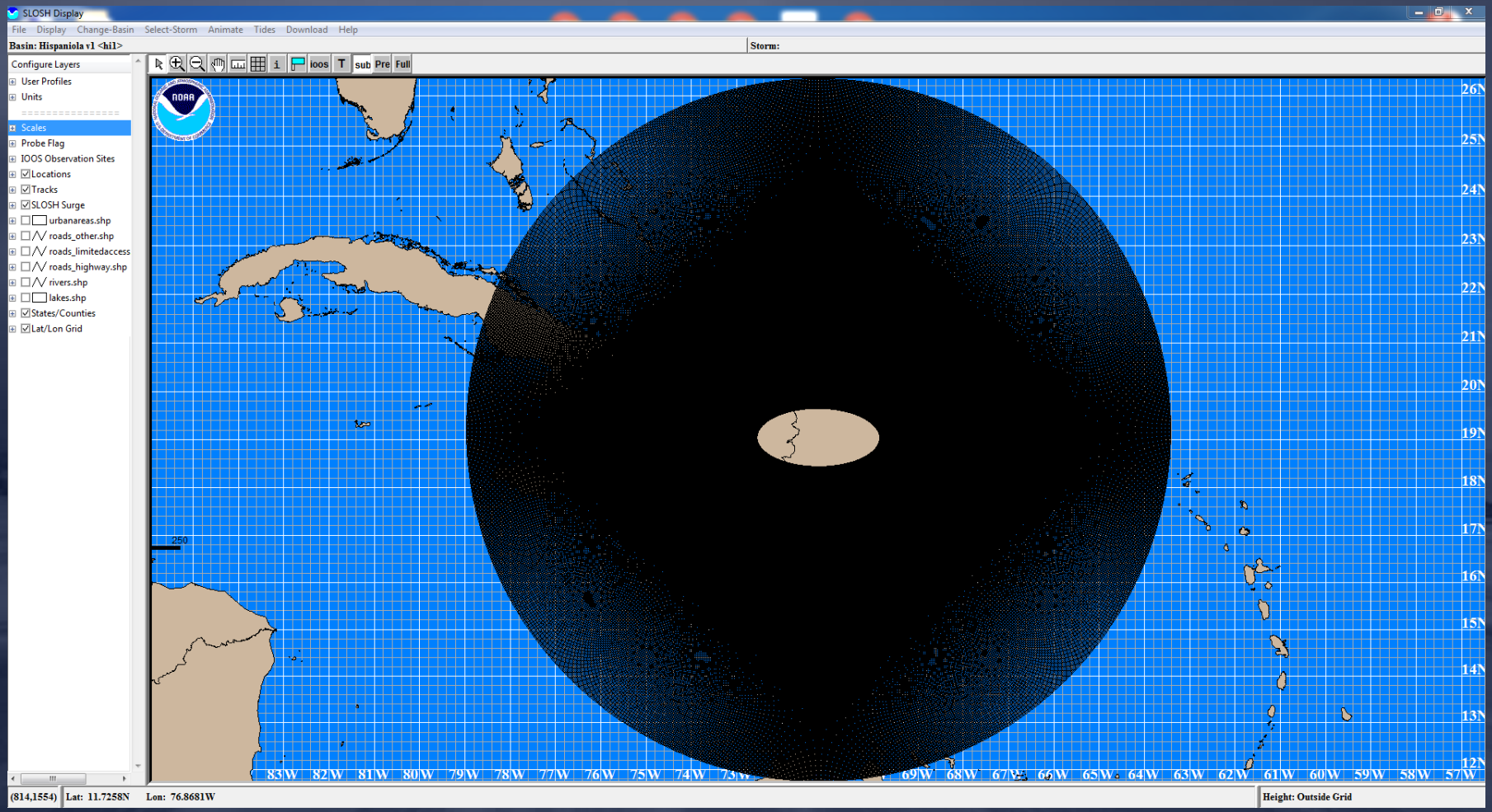
Dissemination and Data Availability

- NHC will host the CIFDP-C MOMs on an online web portal for high-resolution inundation mapping
- Provide GIS data
- Map services



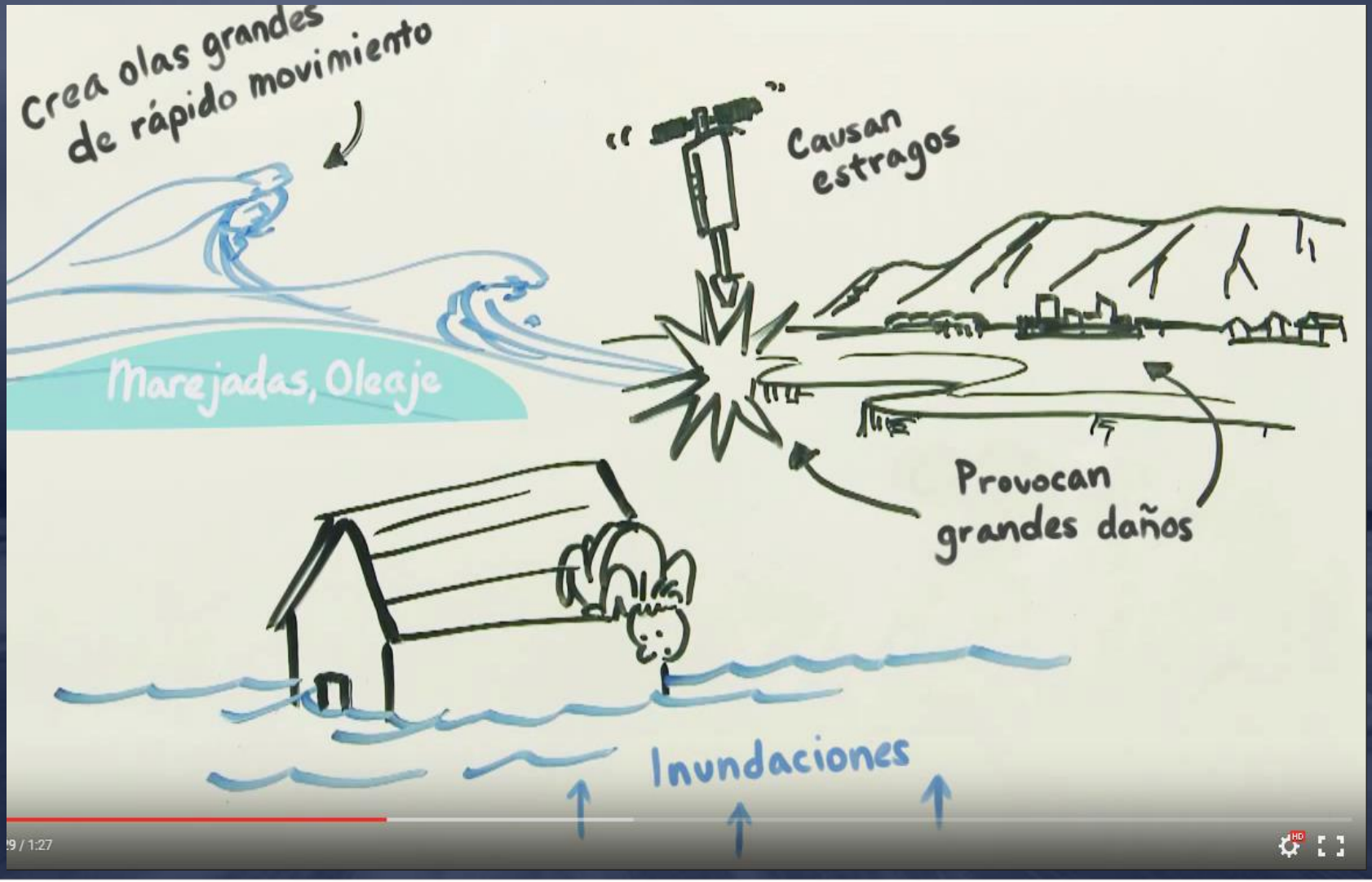


SLOSH Display Program



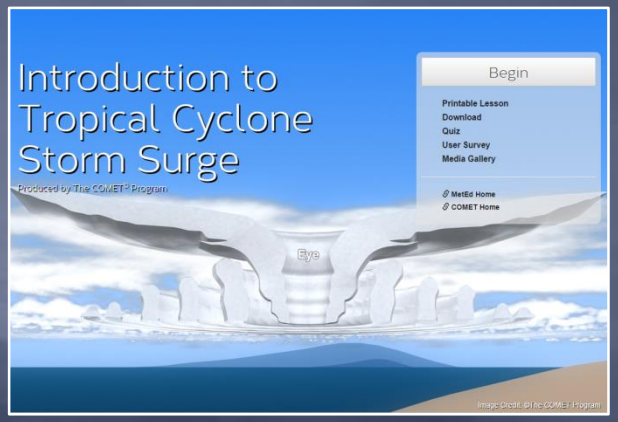
Demo

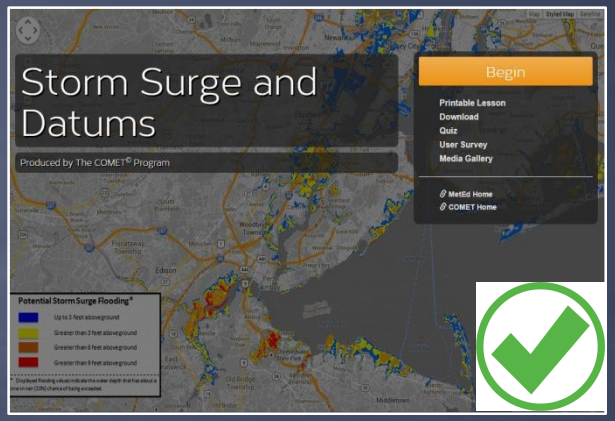
Translation of Outreach Material



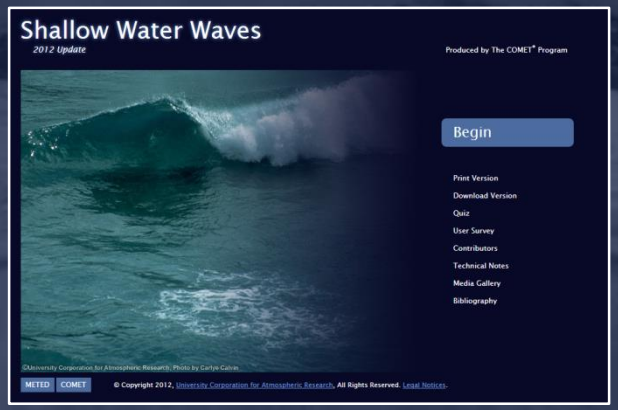
Translation of Existing COMET Modules to Spanish and French

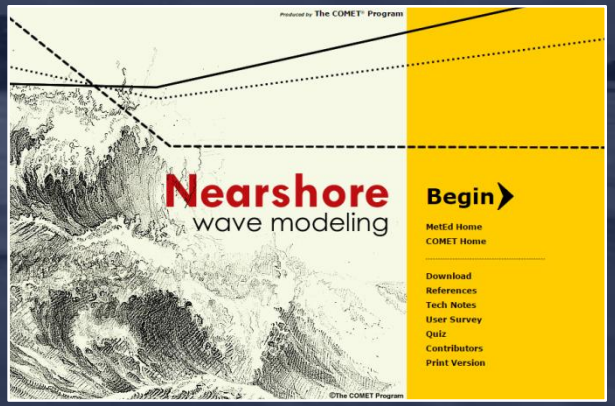
Tropical Cyclone Forecast Uncertainty





Storm Surge Forecasting





NHC's Storm Surge Unit

Jamie Rhome, Team Lead
Dr. Brian Zachry
Tarah Sharon
William Booth
Ethan Gibney
Cody Fritz
Laura Paulik
Taylor Trogdon

ncep.nhc.ssmia@noaa.gov
(305) 229-4448
hurricanes.gov/surge
@NHC_Surge