

STORM SURGE MODELING IN PUERTO RICO IN SUPPORT OF EMERGENCY MANAGEMENT RESPONSE, RISK ASSESSMENT, COASTAL PLANNING AND CLIMATE CHANGE ANALYSIS

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OBJECTIVE: STORM SURGE MODELING IN PUERTO RICO IN SUPPORT OF EMERGENCY MANAGEMENT RESPONSE, RISK ASSESSMENT, COASTAL PLANNING AND CLIMATE CHANGE ANALYSIS. This involves the preparation of (seawater) flood maps for category 1 to 5 hurricanes for up to 3 Sea Level scenarios: actual, 0.5 m, and 1.0 m.

SPONSORS: Caribbean Coastal Ocean Observing System (CariCOOS/UPRM) and the Puerto Rico Coastal Zone Management Program/DRNA

MODELS USED: Tightly coupled, state-of-the-art, ADCIRC+SWAN models

REASONS FOR STUDY AND MAPPING:

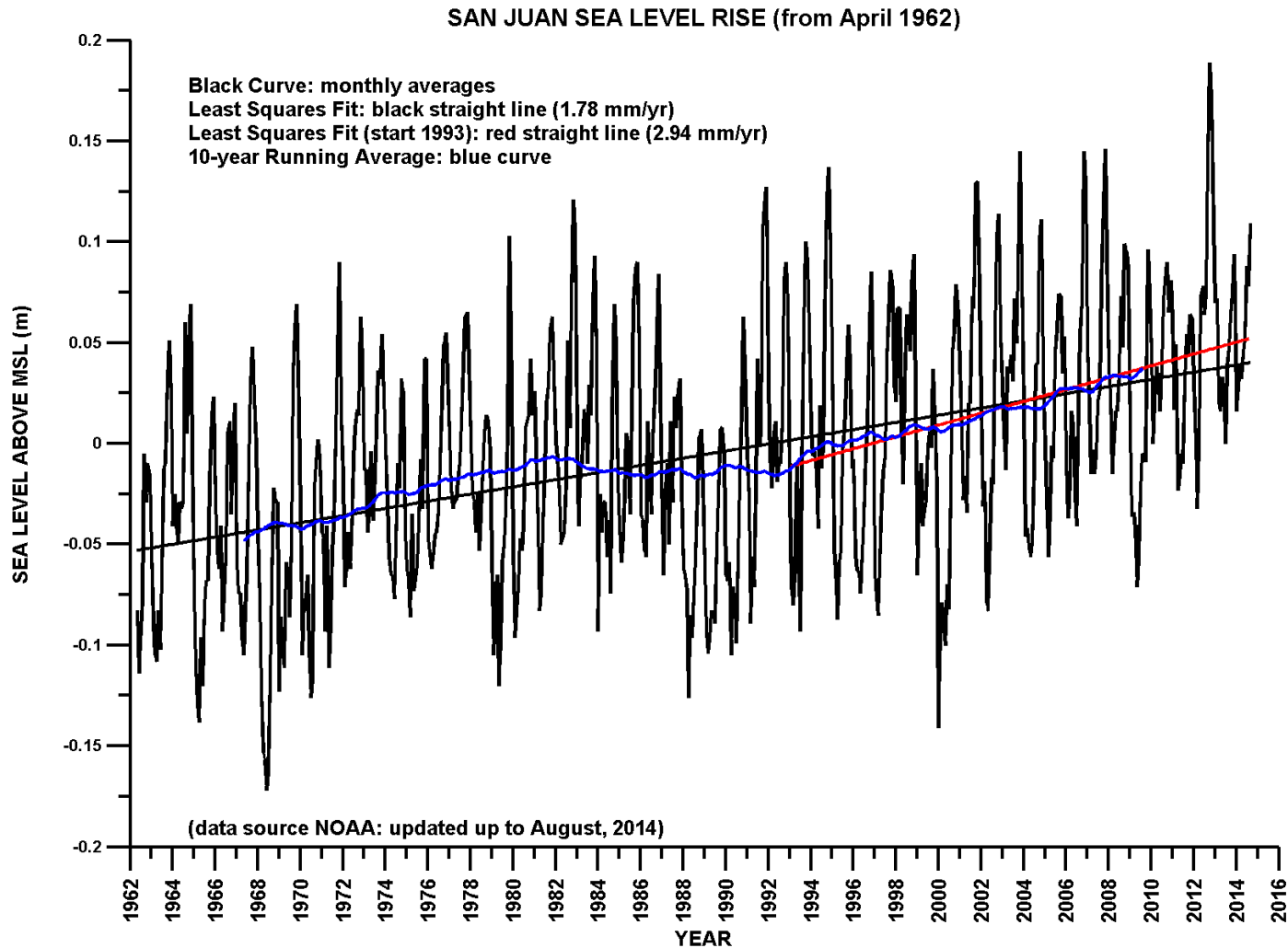
- The Puerto Rico Storm Surge Atlas hasn't been updated since the early 1990's
- New high-resolution bathymetric and topographic data (LIDAR)
- New state-of-the-art computer modeling software, including the coupling of hurricane-forced wind waves with a well-tested, and accepted, hydrodynamic model for estimation of the three storm surge drivers: wind, pressure, and wave setups.
- FEMA's Flood Insurance Rate Maps underestimate storm surge coastal flooding for intense hurricanes. Emergency managers need to know what to expect.
- The use of the concept of the 100-year hurricane is too risky, especially under present conditions of hydrological and climatological non-stationarity
- Climate Change effects are making inroads through our shores, especially through the effect of Sea Level Rise. We need to plan for this.
- Puerto Ricans, and especially worrisome, the authorities, have become too complacent/indifferent about the hurricane threat. This can be seen in the irresponsible way our coastlines have been developed. Hopefully this will serve as a wakeup call.

CAVEAT EMPTOR

- NO WAVE RUNUP IS INCLUDED
- NO STORM SURGE/RIVER FLOW INTERACTIONS ARE CONSIDERED
- DRY HURRICANES (NO RAINFALL)
- NO RIVERINE FLOODING IS CONSIDERED, JUST SEAWATER FLOODING

ALL OF THE ABOVE SUGGEST THAT THE FLOOD MAPS PRESENTED WILL ERR ON THE LOW SIDE

Sea Level Rise measured at San Juan Bay



IMPORTANT: In this study, although we consider Sea Level Rise as a contribution of Climate Change (CC) to coastal flooding, we are not considering the predicted increase in hurricane intensity due to CC.







Rising sea levels of 1.8 meters in worst-case scenario, researchers calculate

Date: October 14, 2014

Source: University of Copenhagen

Summary: The climate is getting warmer, the ice sheets are melting and sea levels are rising -- but how much? The report of the UN's Intergovernmental Panel on Climate Change (IPCC) in 2013 was based on the best available estimates of future sea levels, but the panel was not able to come up with an upper limit for sea level rise within this century. Now researchers have calculated the risk for a worst-case scenario. The results indicate that at worst, the sea level would rise a maximum of 1.8 meters.

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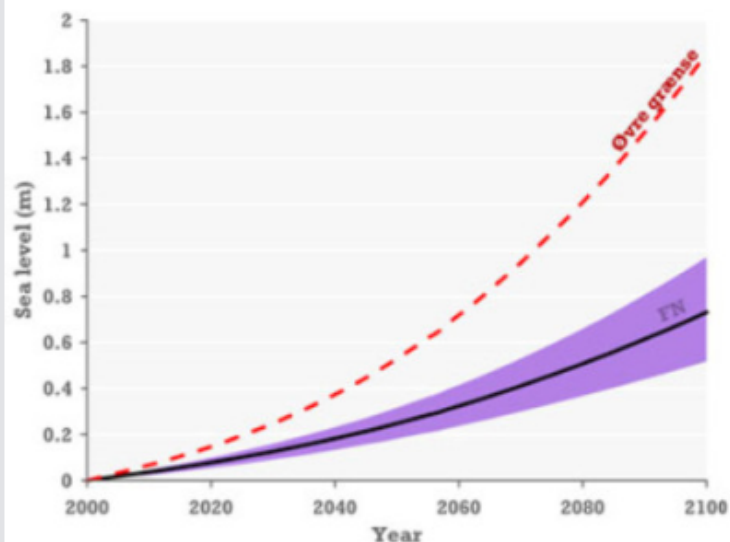
Related Topics

Earth & Climate

- > Global Warming
- > Climate
- > Oceanography
- > Environmental Awareness
- > Floods
- > Snow and Avalanches

Related Articles

- > IPCC Report on Climate Change - 2007
- > Global warming
- > Sea level
- > Consensus of scientists regarding global warming
- > Greenland ice sheet
- > Climate change mitigation

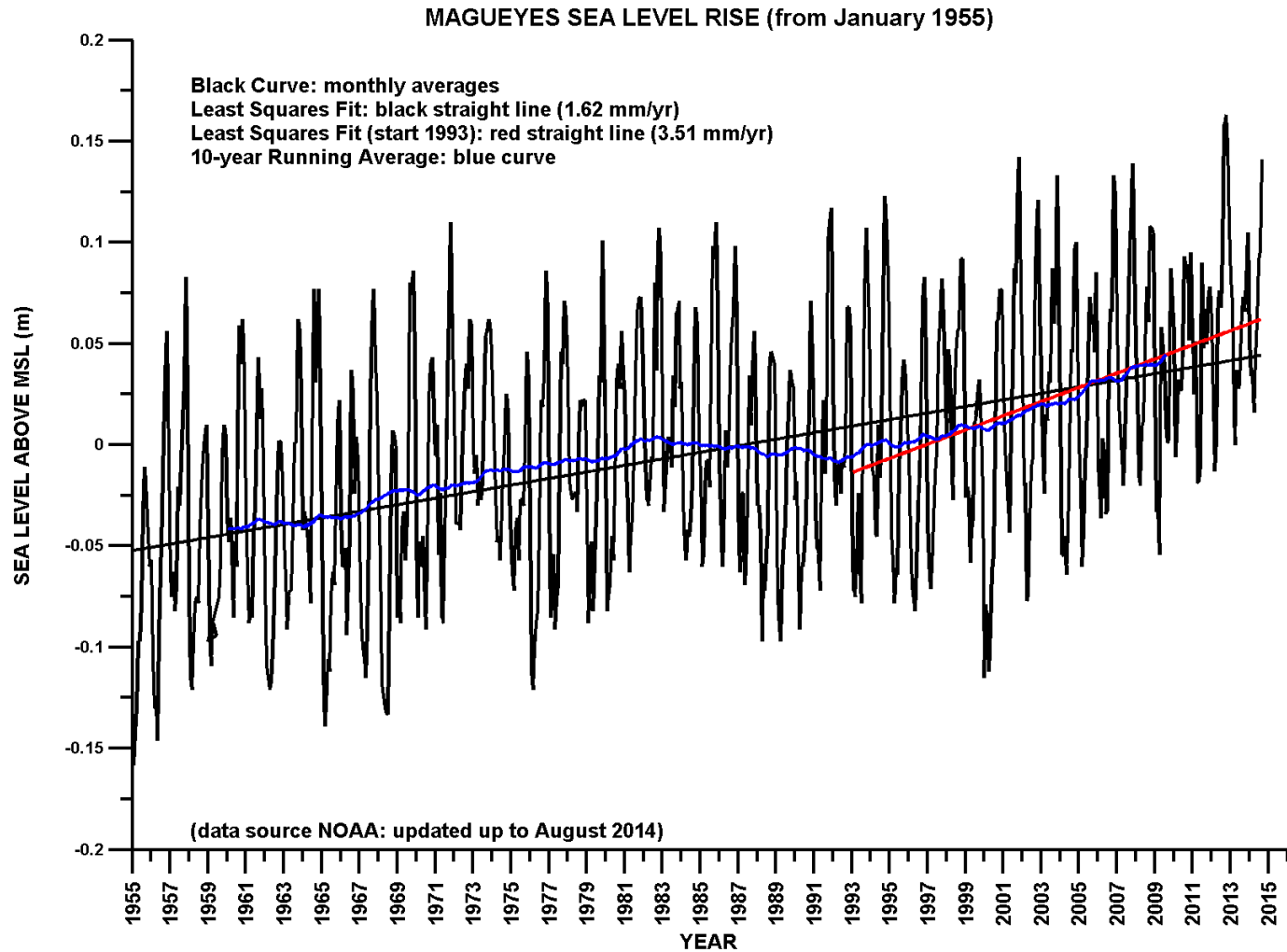


The worst-case sea level projections is shown in red. There is 95% certainty that sea level will not rise faster than this upper-limit. Purple shows the likely range of sea level rise as projected in the IPCC fifth assessment report under a scenario with rising emissions throughout the 21st century (RCP8.5).

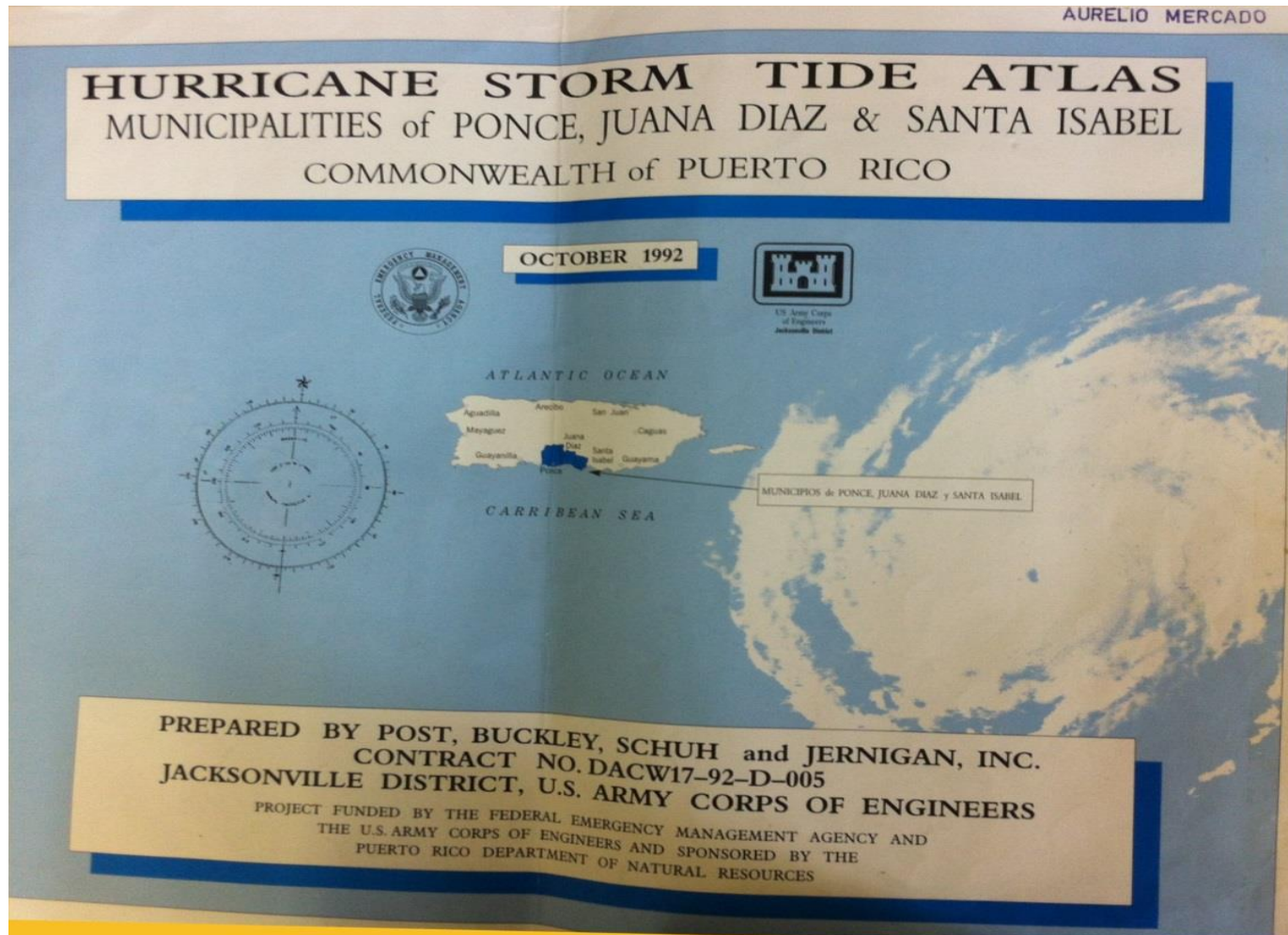
Credit: Aslak Grinsted, NBI

[Click to enlarge image]

Sea Level Rise measured at Magueyes Island, La Parguera, Lajas



WHAT WE ARE TRYING TO UPDATE



Cluster:

- 7 blades with 64 CPU's each for a total of 448 cores
- AMD Opteron 64 bits
- PGI Fortran
- TB's of hard disks (Network-attached storage – NAS)



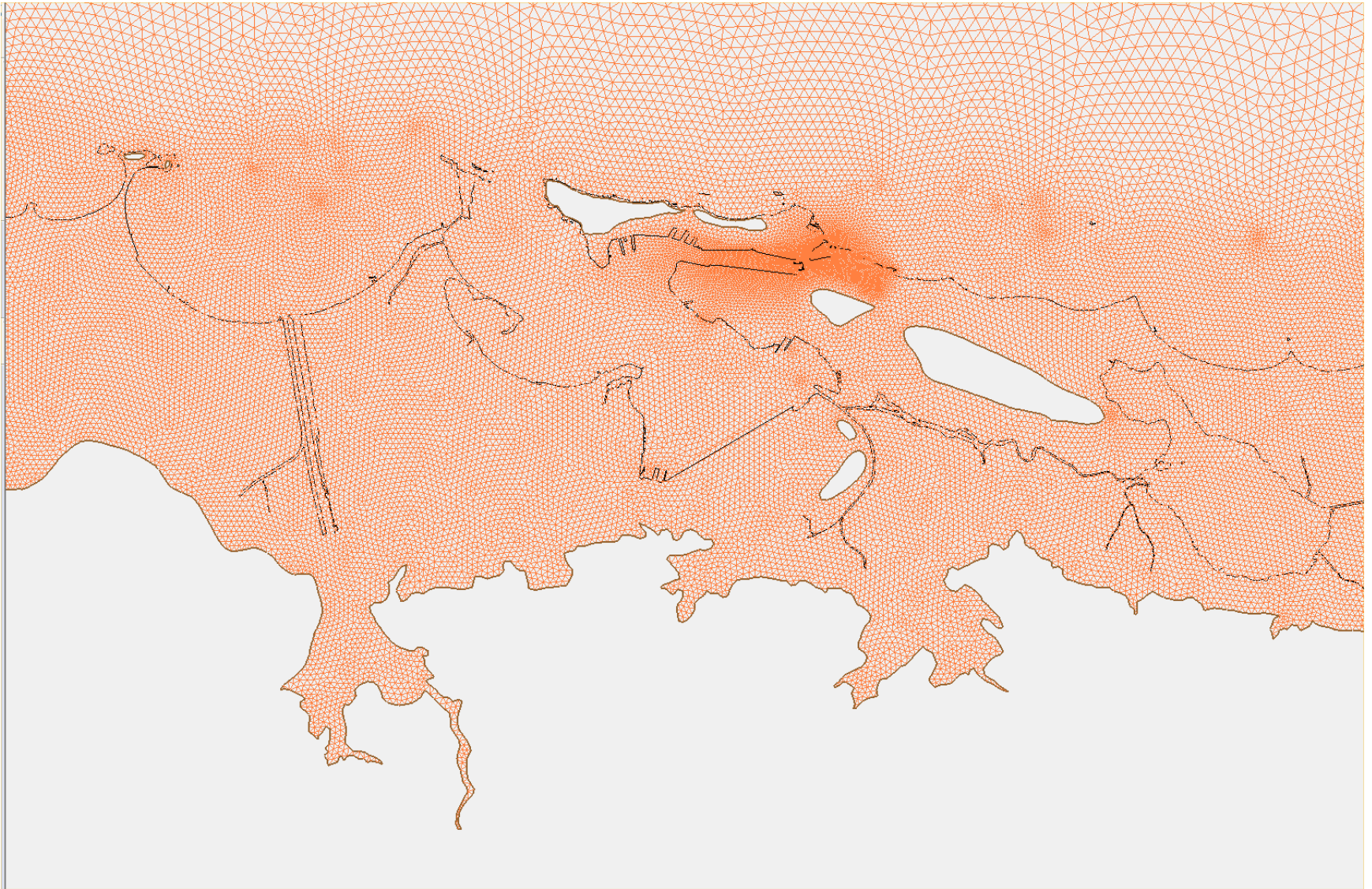
ADCIRC+SWAN

Computational mesh
(prepared by former
MS student, Juan
Gonzalez, now a PhD
student at Notre
Dame, and edited by
Jose Benitez.)

- Unstructured
- *** nodes
- *** triangles



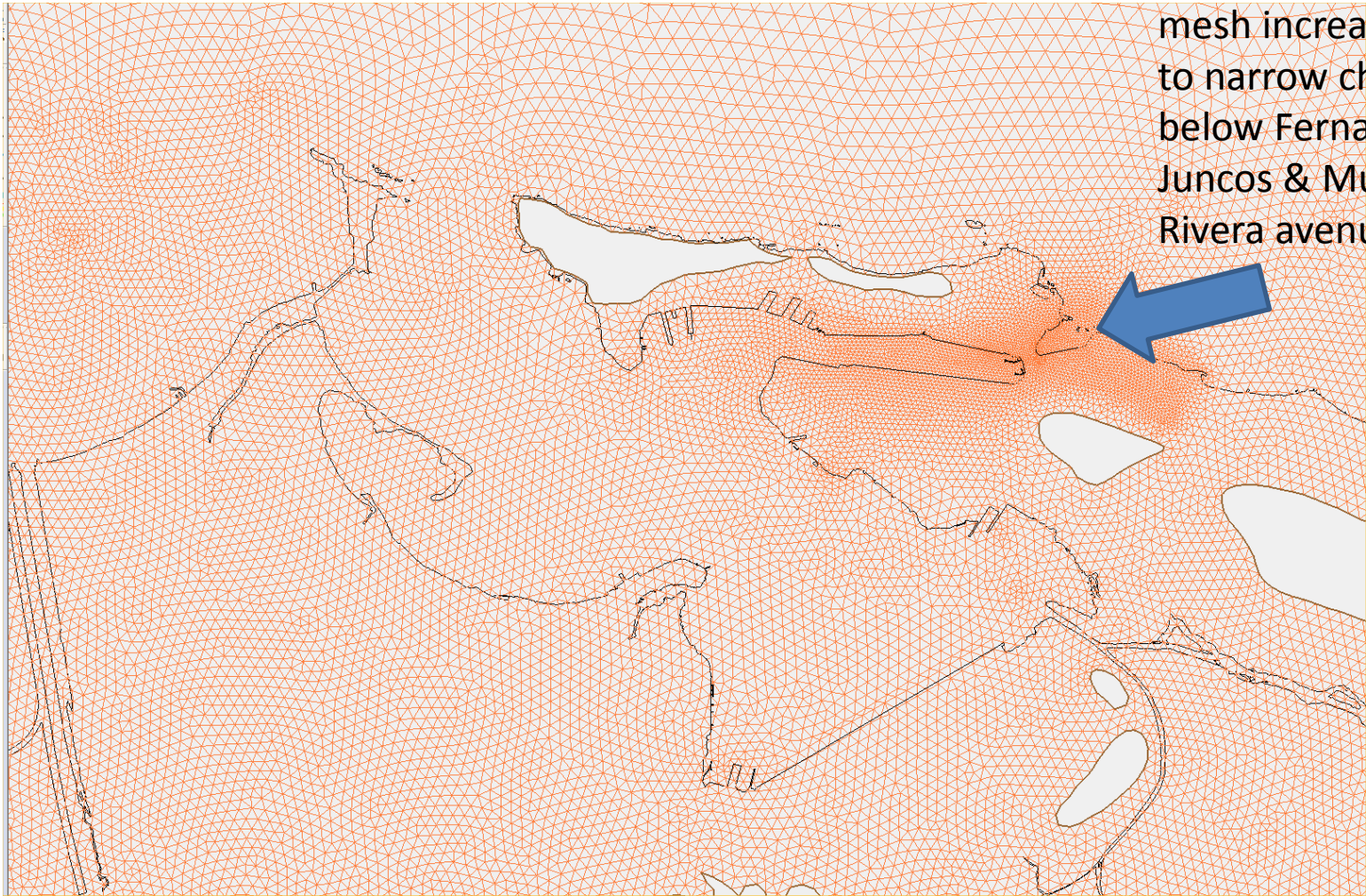
San Juan Bay



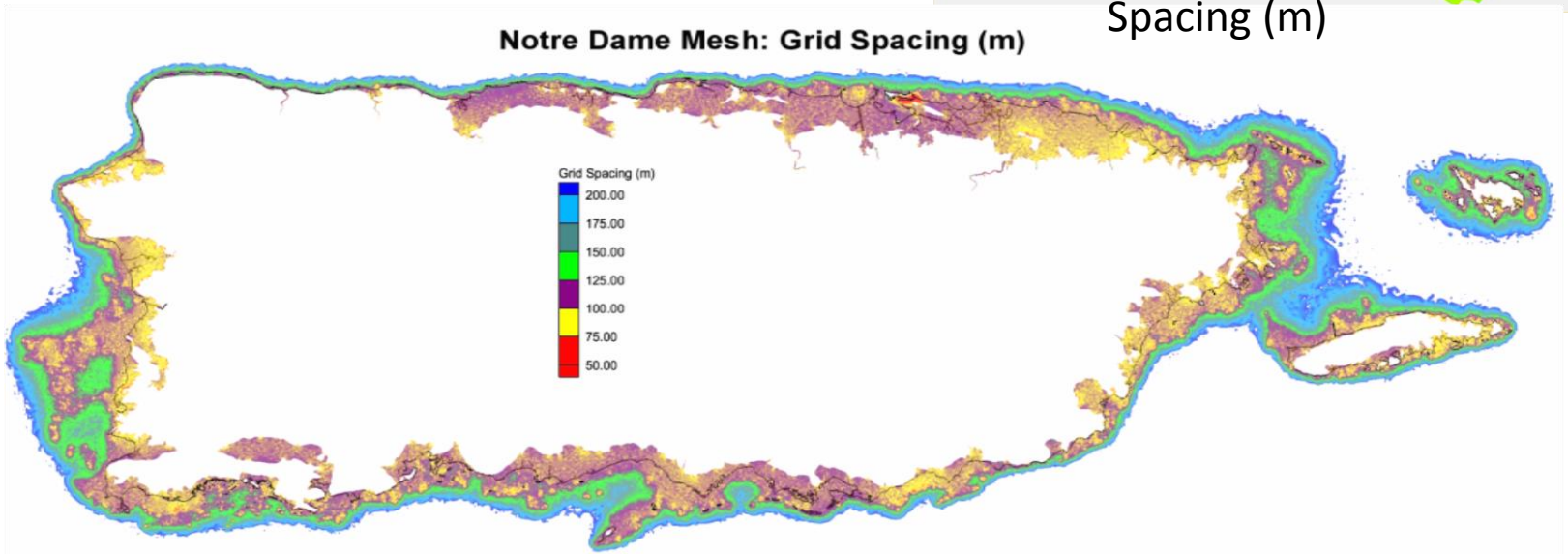
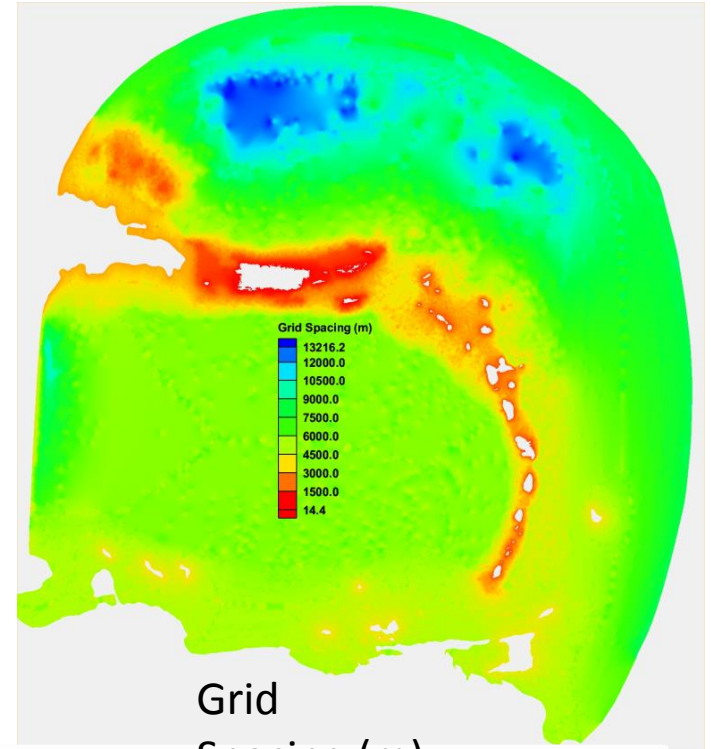
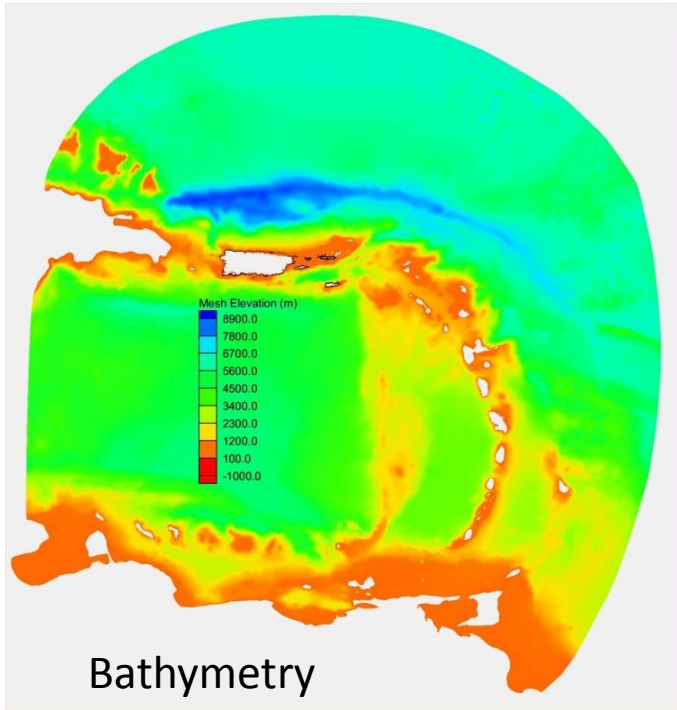
In the old days all of San Juan Bay was covered by just 3 computational cells!

San Juan Bay

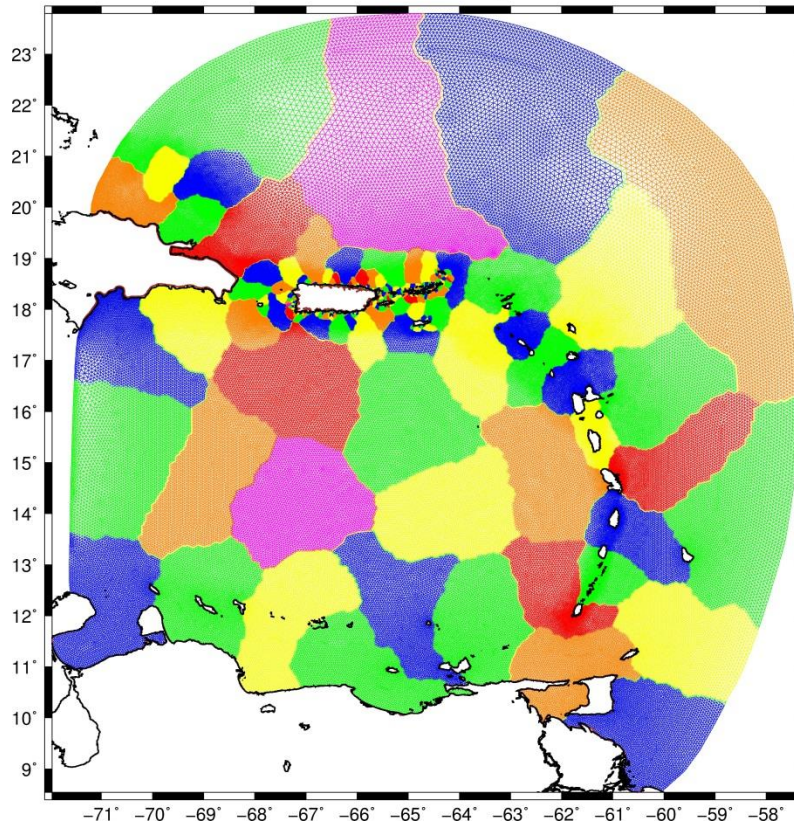
Resolution of the mesh increases due to narrow channel below Fernandez Juncos & Muñoz Rivera avenues



COMPUTATIONAL MESH

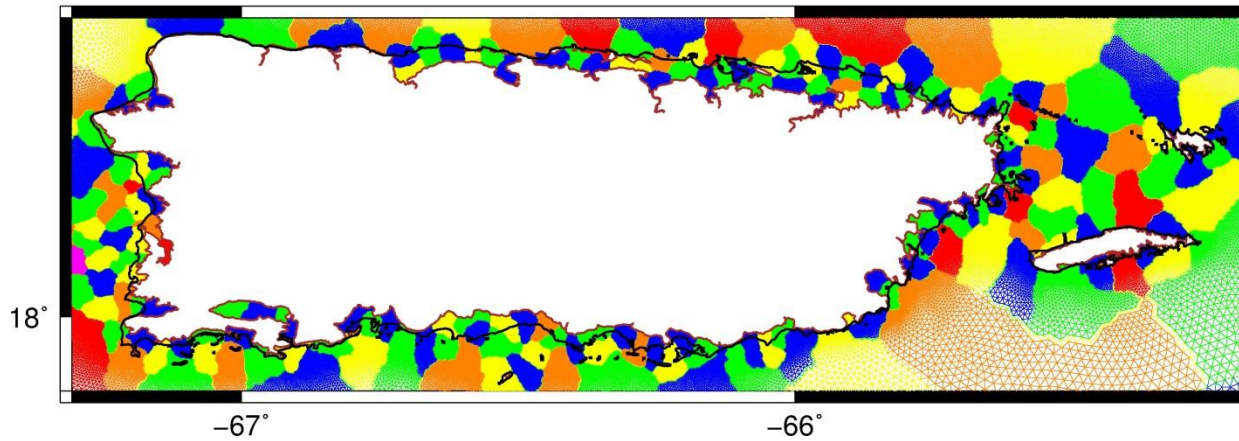


CariCOOS Puerto Rico Mesh Decomposition-448Cores

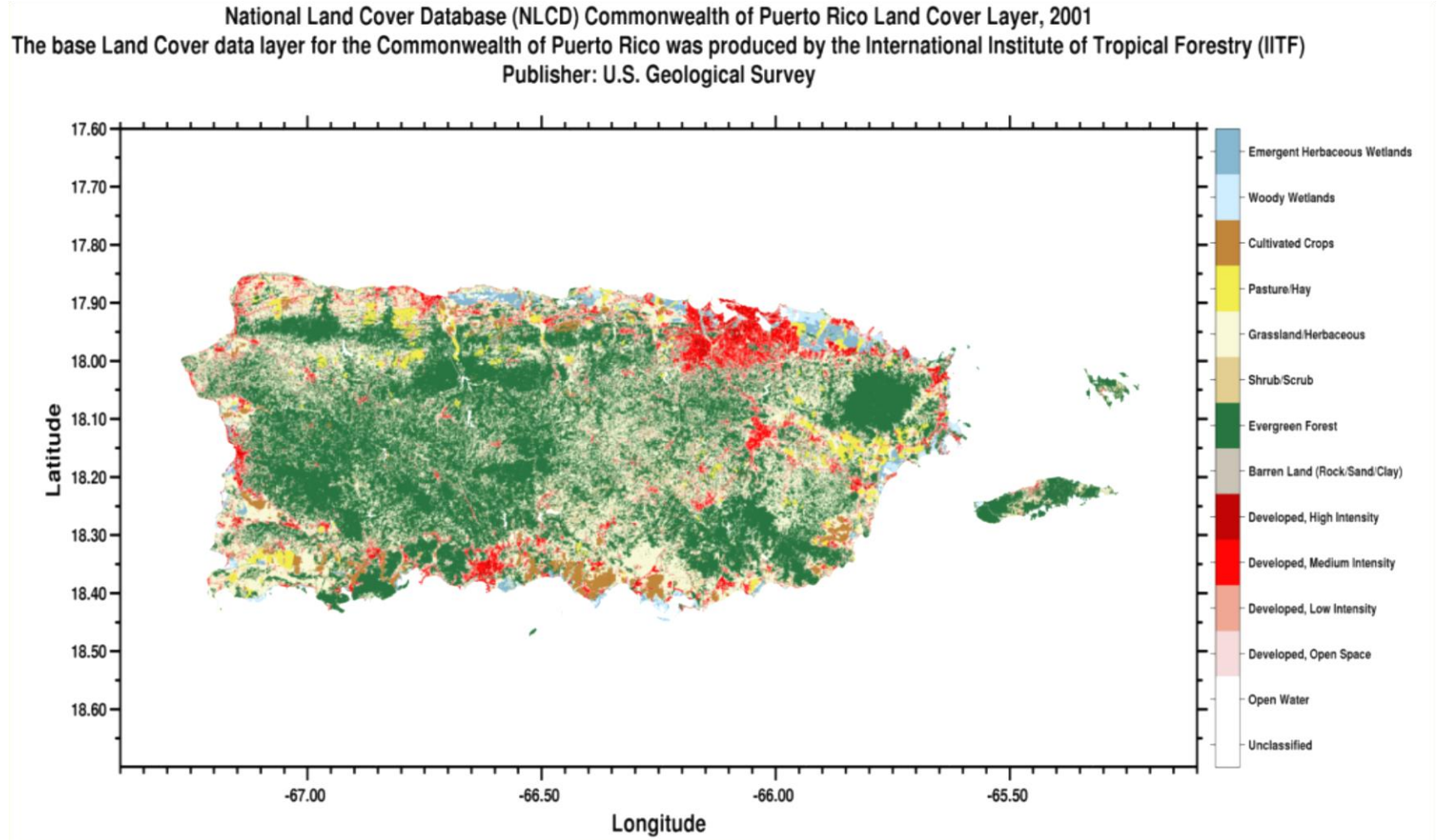


Each colored area is assigned a separate CPU

CariCOOS Puerto Rico Mesh Decomposition-448Cores

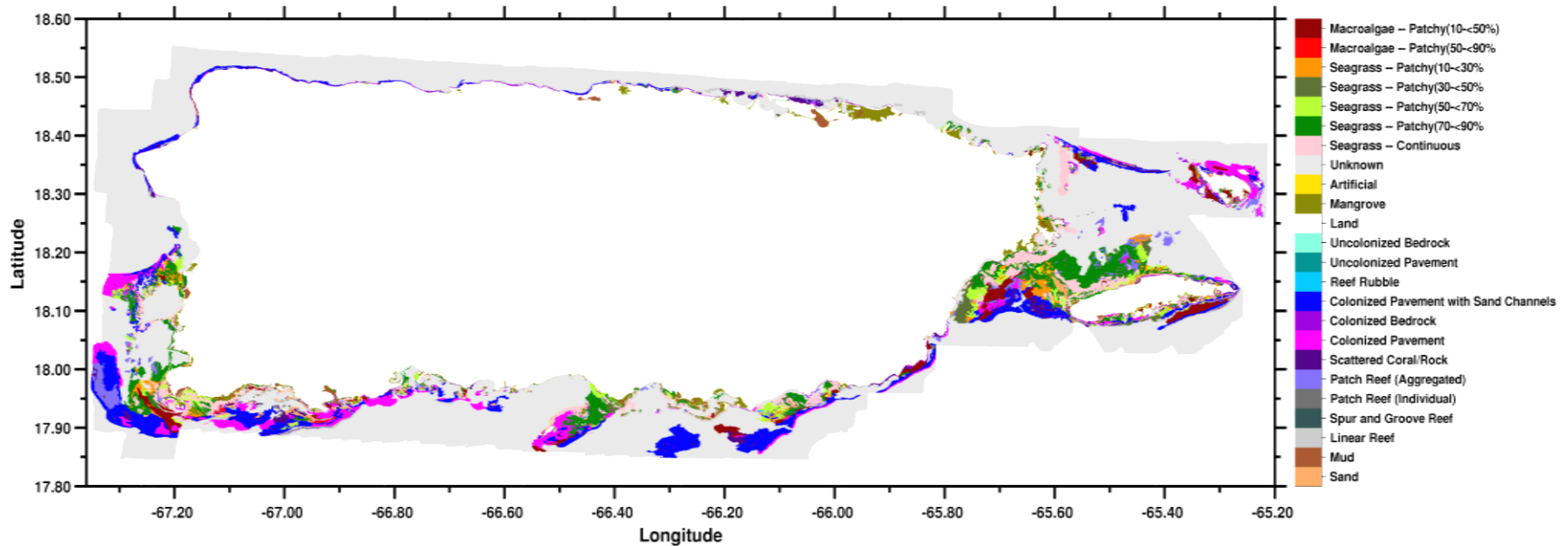


Takes into consideration type of land use, assigning a variable frictional coefficient (Manning) to each computational node

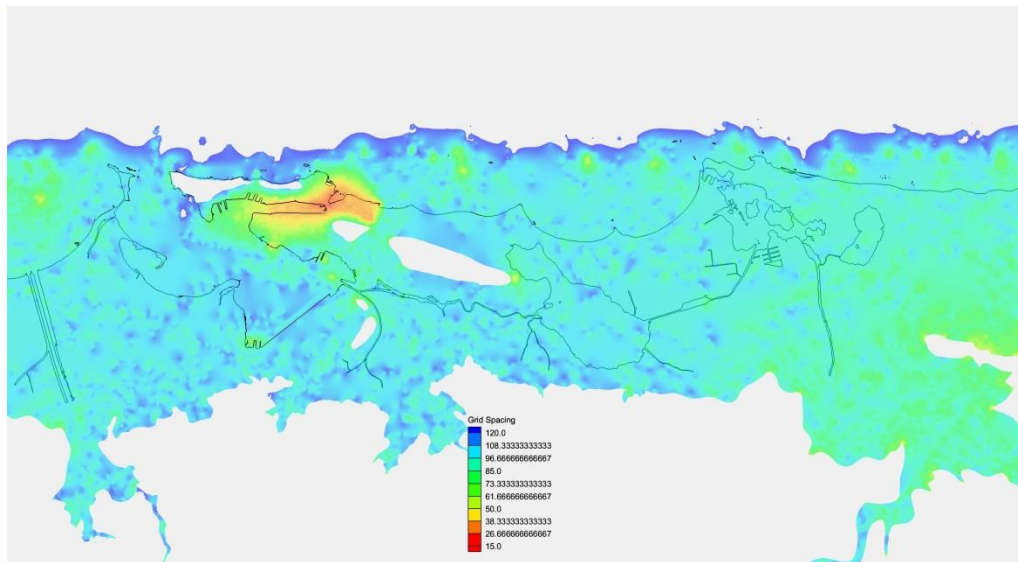
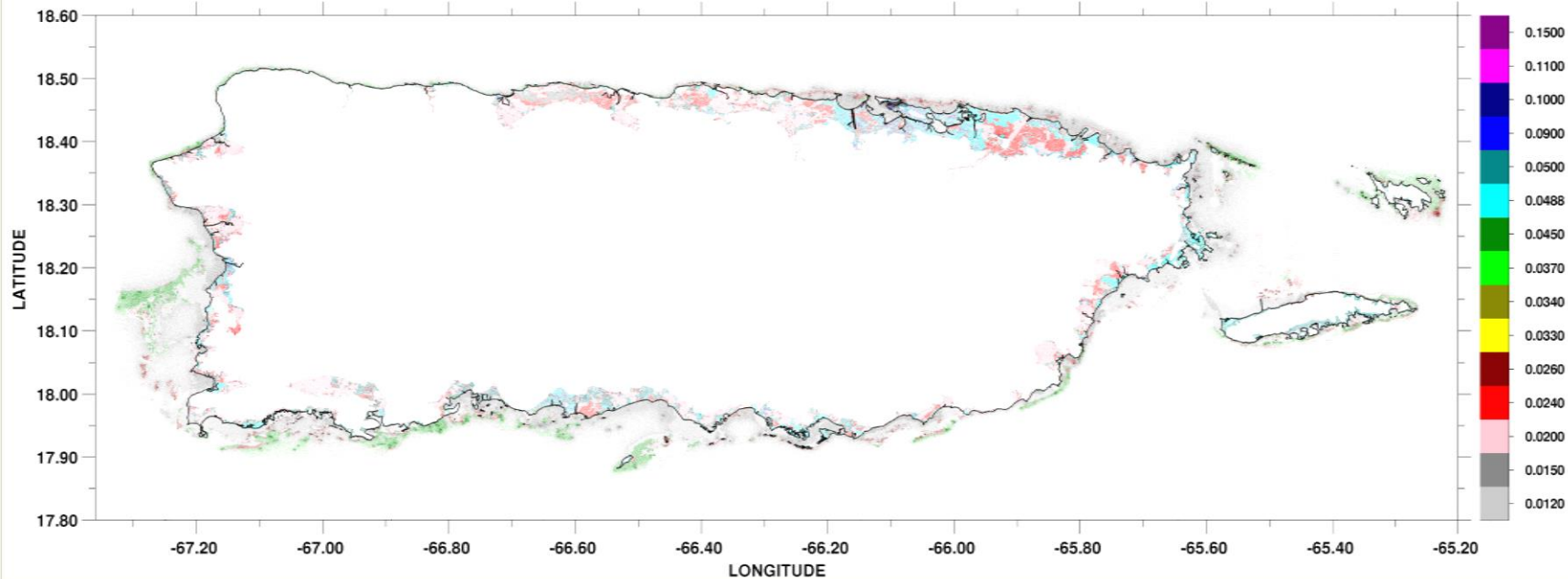


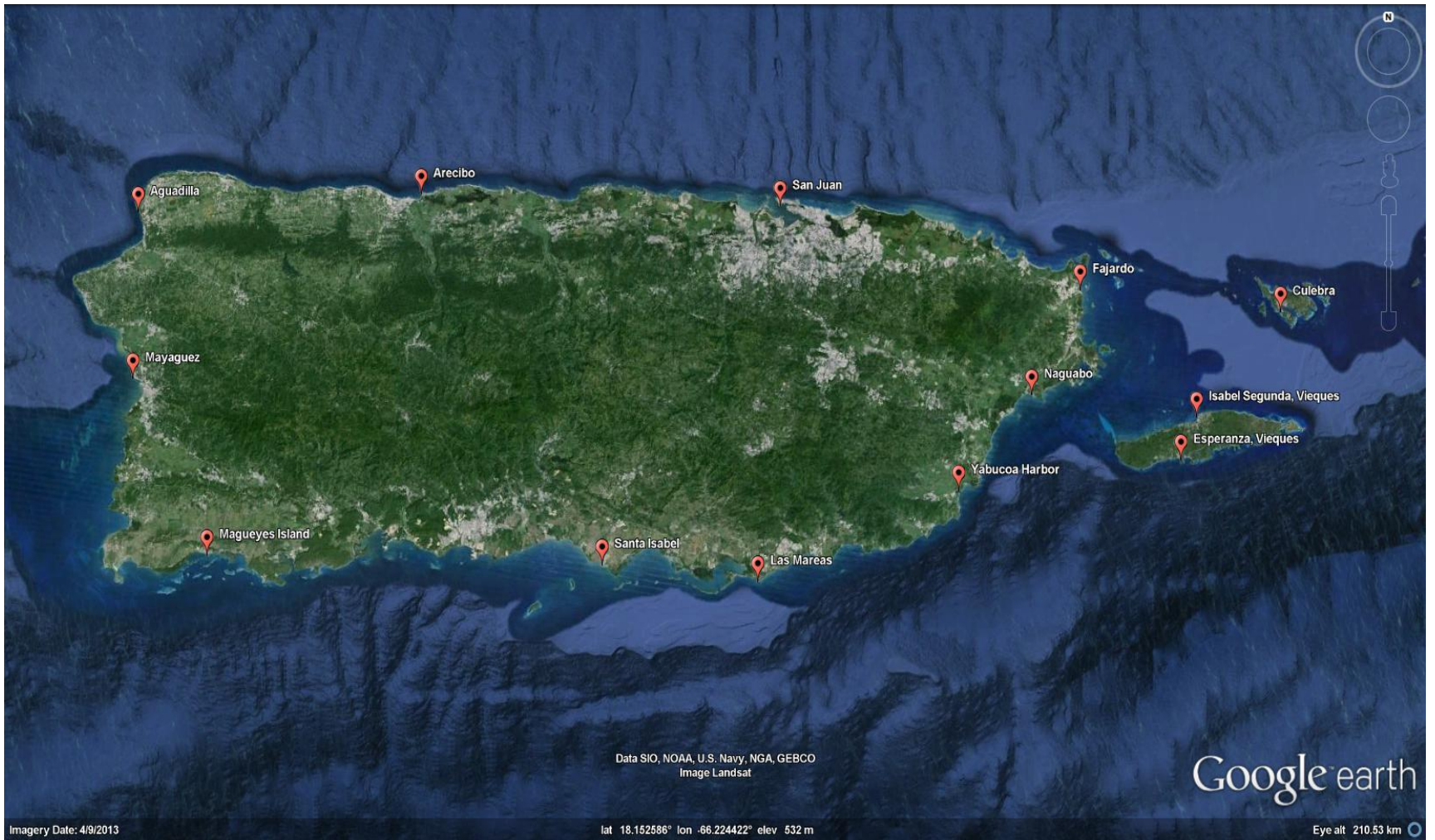
Takes into consideration type of bottom type, assigning a variable frictional coefficient (Manning) to each computational node

Benthic Habitats of Puerto Rico, 2001
A cooperative effort between NOAA's National Centers for Coastal Ocean Science (NCCOS),
U.S. Geological Survey, National Park Service, and the National Geophysical Data Center,
to produce benthic habitat maps and georeferenced imagery for Puerto Rico.



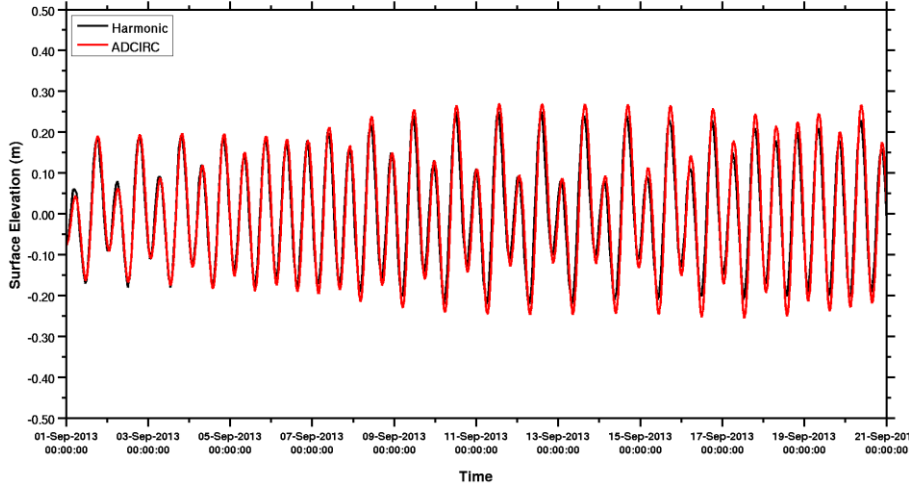
Manning n values at Land Cover and Benthic Zones nodes
for the Notre Dame Mesh of the region of Puerto Rico



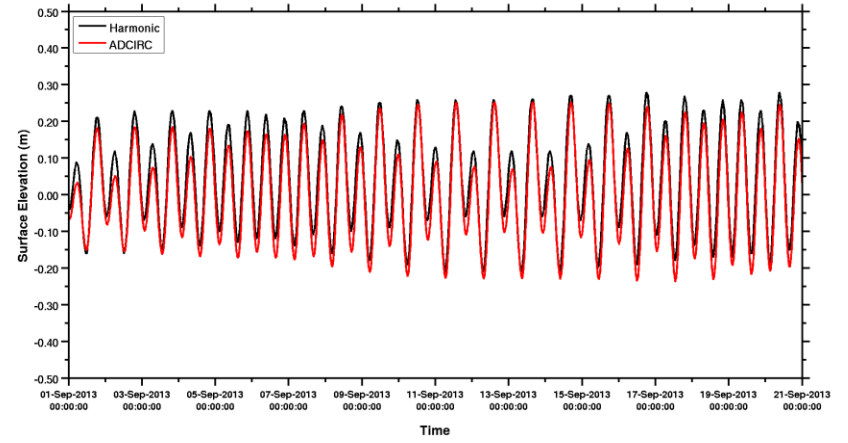


VALIDATION with TIDE GAUGES

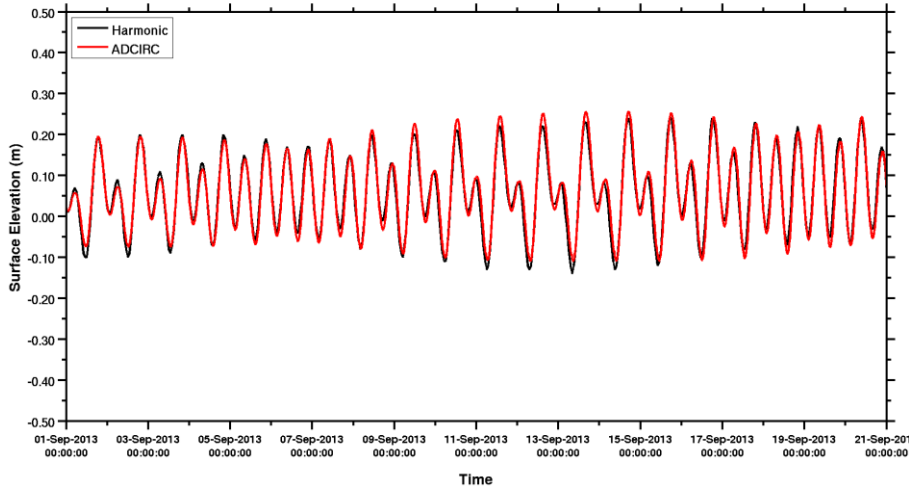
Aguadilla (Station #9759412)



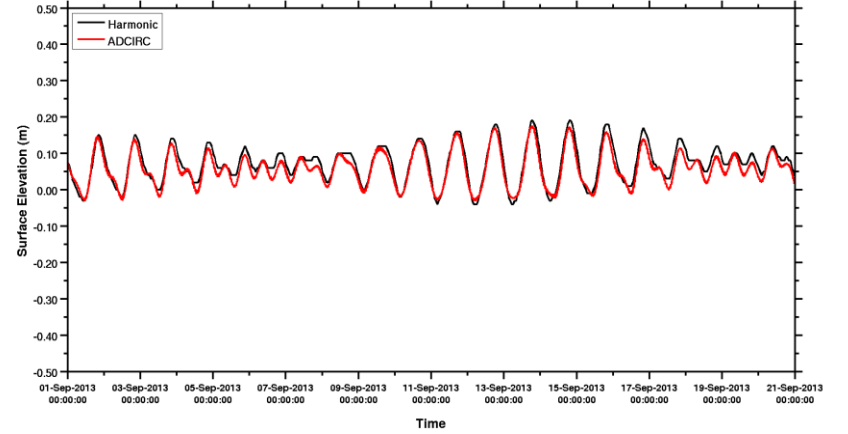
Fajardo (Station #9753216)



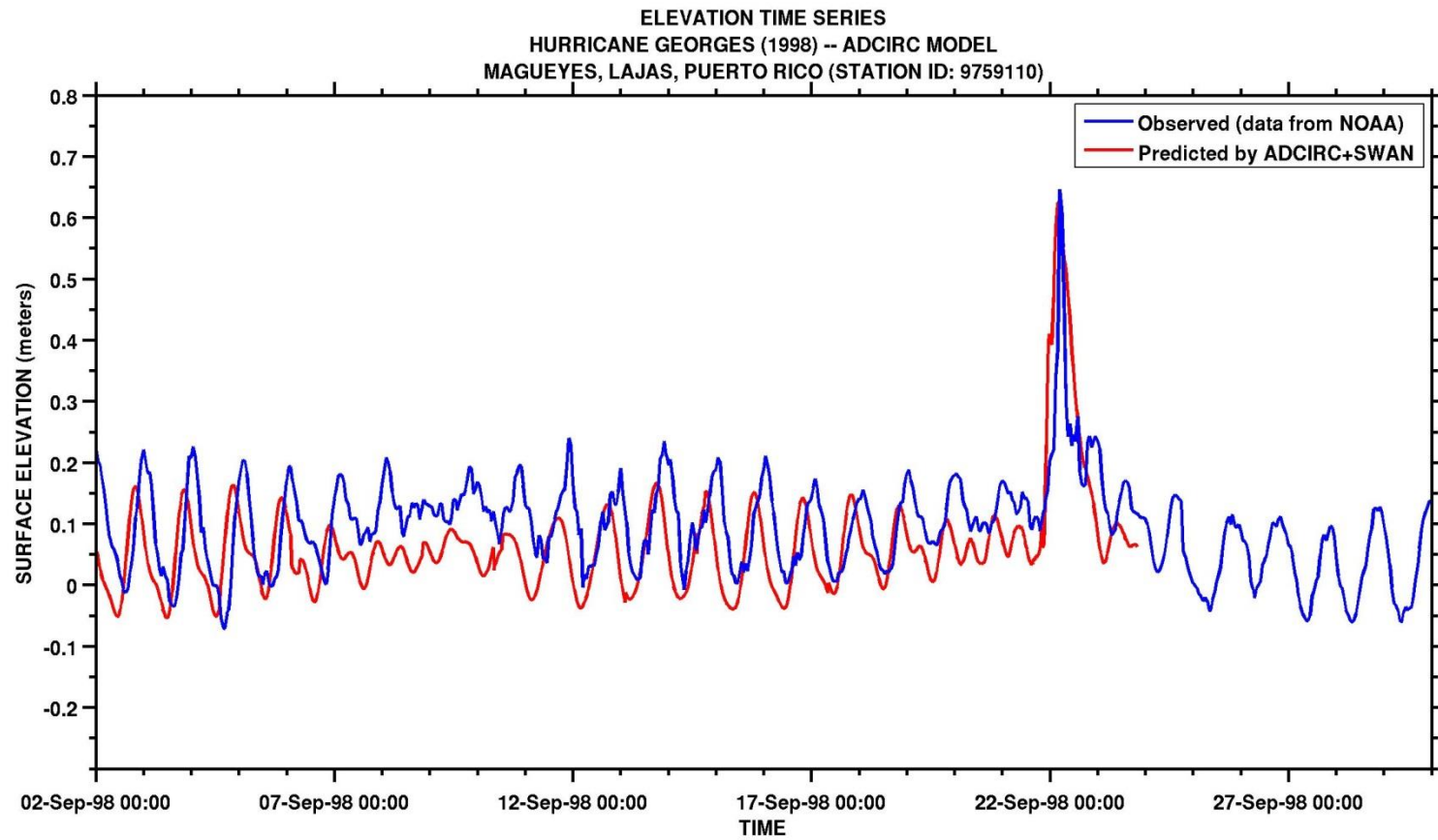
Culebra Island (Station #9752235)



Magueyes Island (Station #9759110)



VALIDATION WITH ASTRONOMICAL TIDES AT TIDE GAUGES

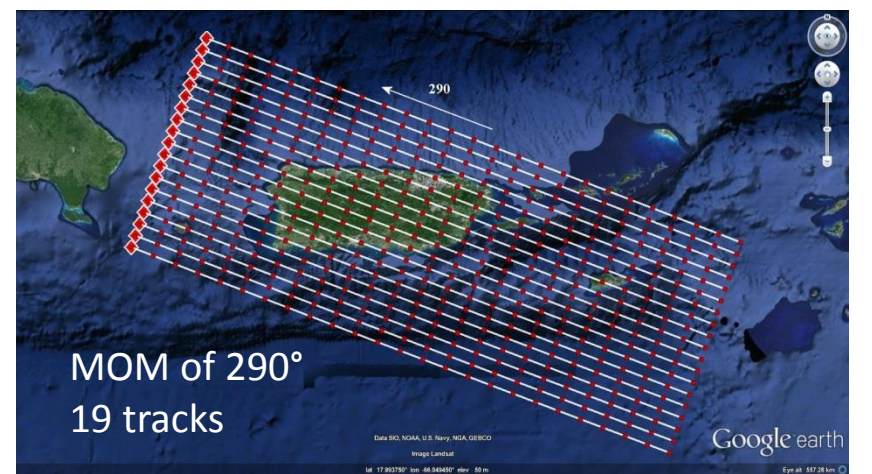
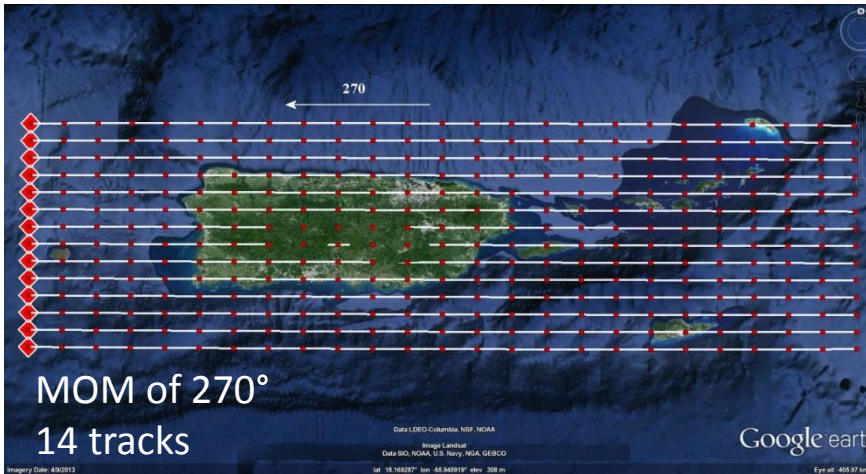
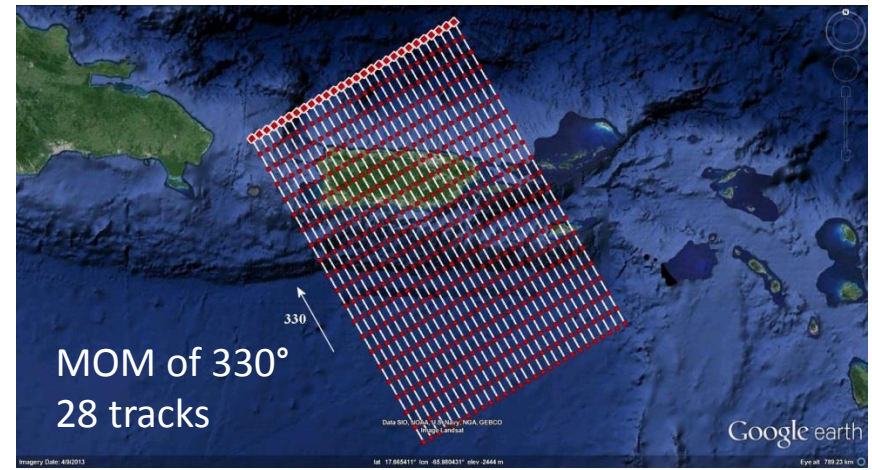
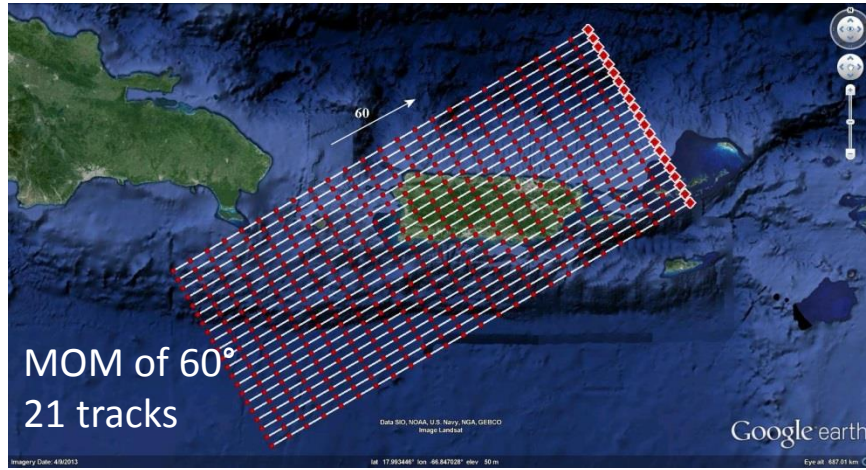


VALIDATION WITH MEASURED STORM SURGES AT TIDE GAUGES

Total of 82 tracks/category

TRAJECTORIES

82x3x5 = 1230 runs in total



- Each tracks outputs a Maximum Envelope of Water (MEOW).
- For each hurricane heading, the maximum of all MEOWS's produces a Maximum of the Maximums (MOM), so there is one MOM per heading. This gives the maximum

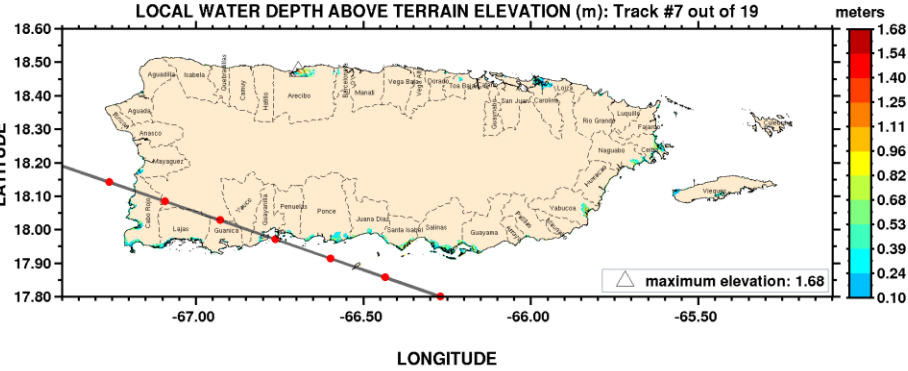
- flooding for each heading.
- The MOM's for 270°, 290°, and 330° are processed to produce the MOM of the MOM's. This gives the maximum flooding irrespective of heading.
- The heading of 60° is not included in the MOM of MOM.

HURRICANE PARAMETERS USED IN THE MODELING

Cat	Central pressure (mb)	RMW (nm)	Vf (kn)	Vmax (kn)	Separation between tracks (nm)
1	980	25	10	78	5
2	969	25	10	92	5
3	950	20	10	108	5
4	926	15	10	131	5
5	900	10	10	150	5

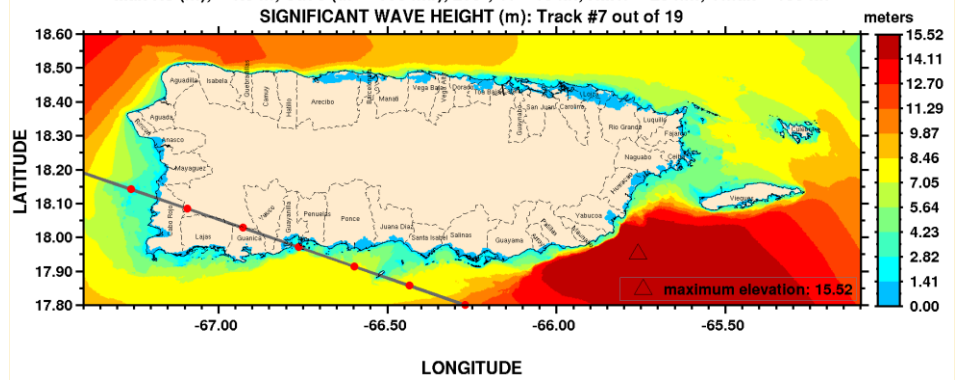
CariCOOS PUERTO RICO STORM SURGE ATLAS

LWD, SLR = 0.0 m, Cat 3 (dP = 950 mb), 290°, Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m): Track #7 out of 19



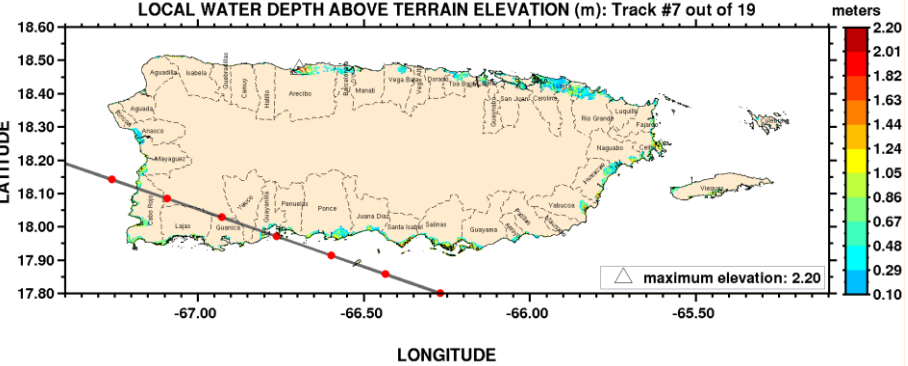
CariCOOS PUERTO RICO STORM SURGE ATLAS

Max Hs (m), = 1.0 m, Cat 3 (dP = 950 mb), 290°, Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
SIGNIFICANT WAVE HEIGHT (m): Track #7 out of 19



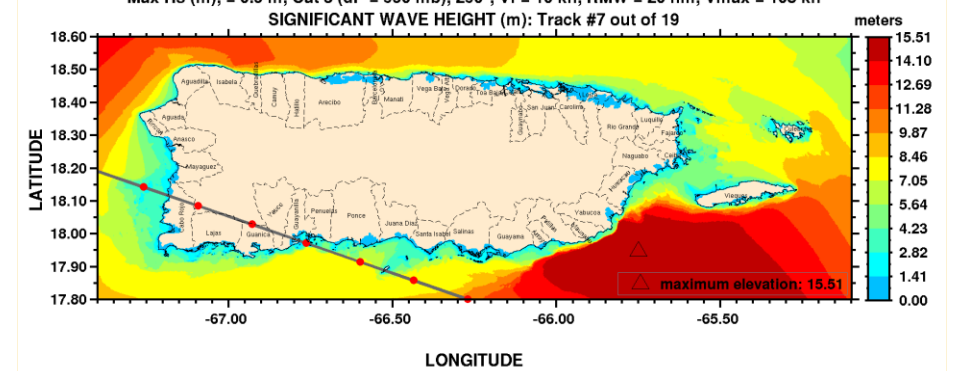
CariCOOS PUERTO RICO STORM SURGE ATLAS

LWD, SLR = 0.5 m, Cat 3 (dP = 950 mb), 290°, Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m): Track #7 out of 19



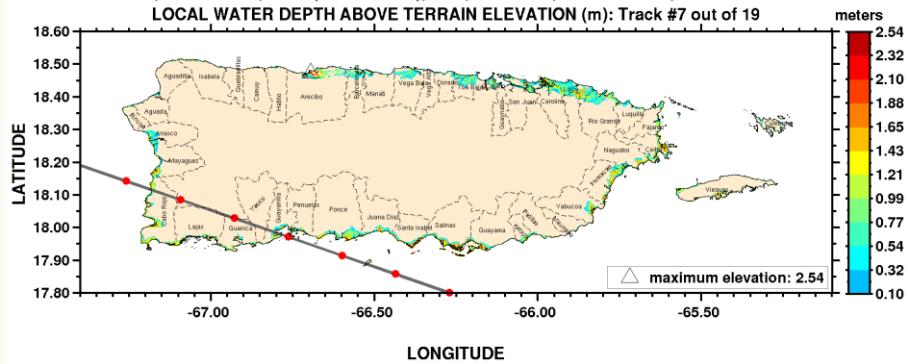
CariCOOS PUERTO RICO STORM SURGE ATLAS

Max Hs (m), = 0.5 m, Cat 3 (dP = 950 mb), 290°, Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
SIGNIFICANT WAVE HEIGHT (m): Track #7 out of 19



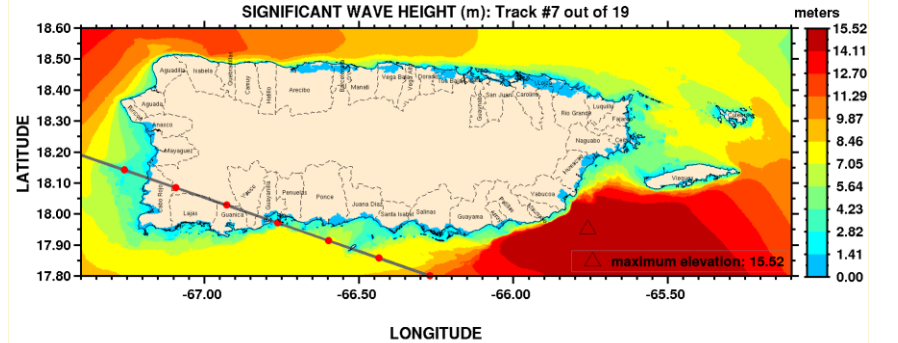
CariCOOS PUERTO RICO STORM SURGE ATLAS

LWD, SLR = 1.0 m, Cat 3 (dP = 950 mb), 290°, Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m): Track #7 out of 19

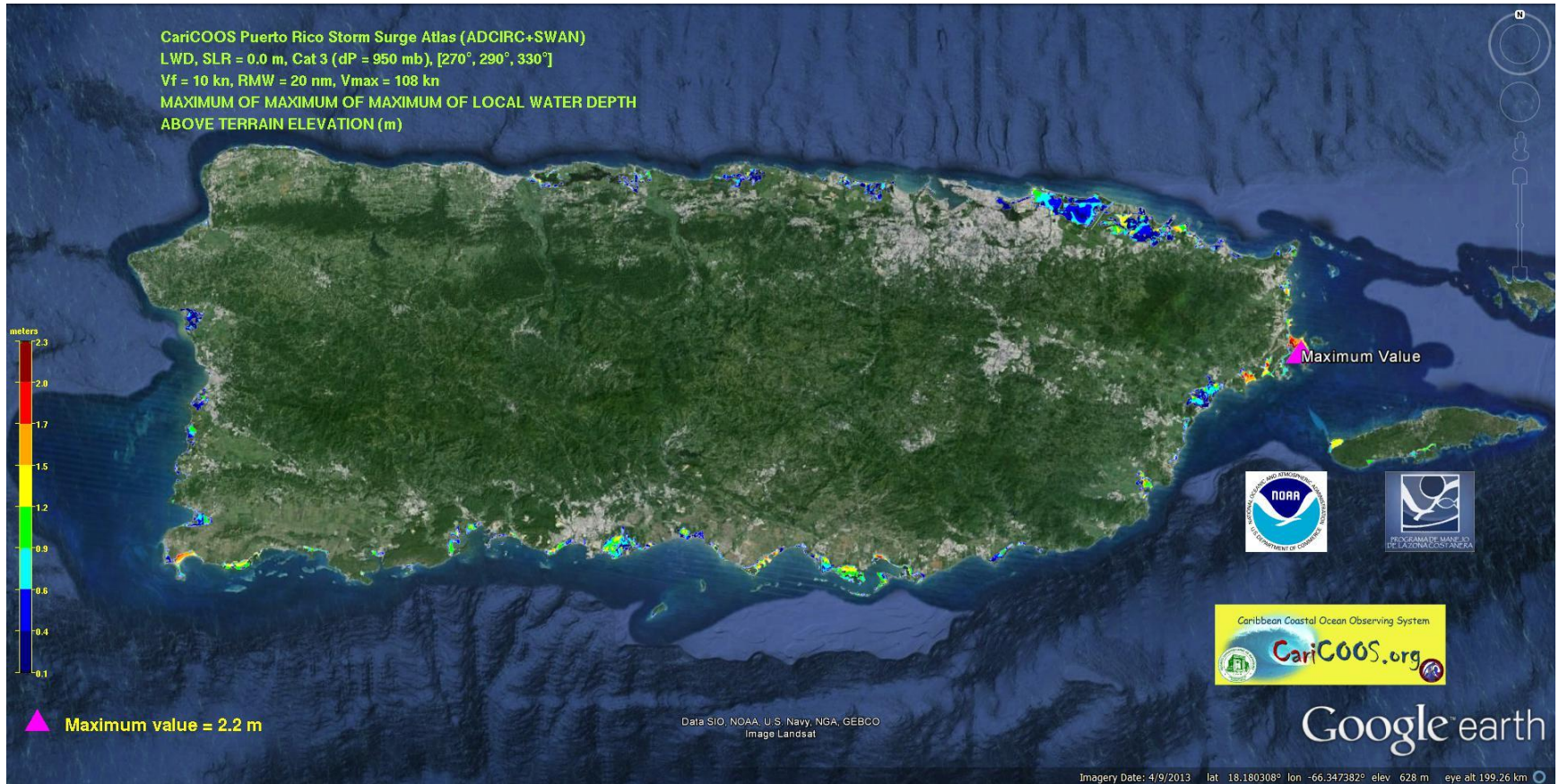


CariCOOS PUERTO RICO STORM SURGE ATLAS

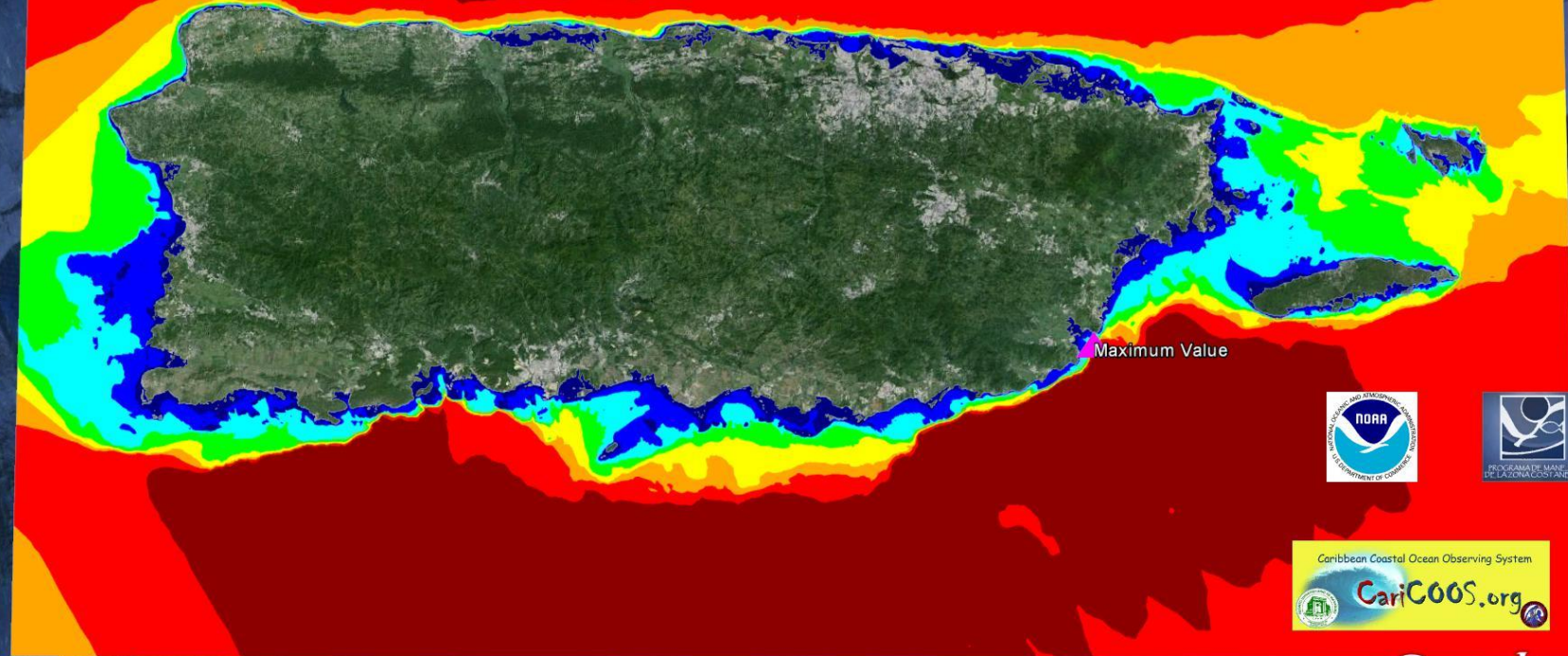
Max Hs (m), = 1.0 m, Cat 3 (dP = 950 mb), 290°, Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
SIGNIFICANT WAVE HEIGHT (m): Track #7 out of 19



Category 3: Maximum of Maximum of Maximum of Local Water Depth in meters above local terrain elevation (SuperMOM) Sea Level: actual



CariCOOS Puerto Rico Storm Surge Atlas (ADCIRC+SWAN)
SLR = 0.0 m, Cat 3 (dP = 950 mb), [270°, 290°, 330°]
Vf = 10 kn, RMW = 20 nm, Vmax = 108 kn
MAXIMUM OF MAXIMUM OF MAXIMUM OF SIGNIFICANT WAVE HEIGHT (m)



▲ Maximum value = 18.7 m

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Image Landsat

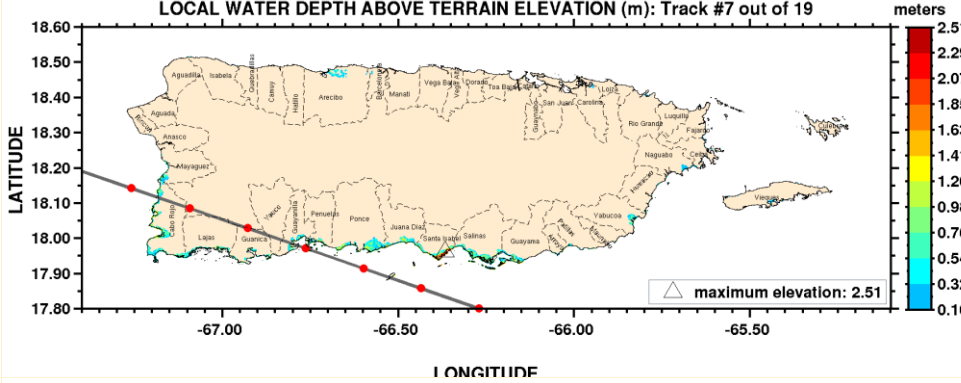
Imagery Date: 4/9/2013 lat 18.093508° lon -66.230700° elev 696 m eye alt 233.48 km

A collection of logos in the bottom right corner. From top to bottom: the NOAA logo (National Oceanic and Atmospheric Administration, U.S. Department of Commerce); the logo for the Puerto Rico Department of Environment and Natural Resources (Programa de Manejo de Recursos Costeros); and the CariCOOS.org logo (Caribbean Coastal Ocean Observing System).

Google earth

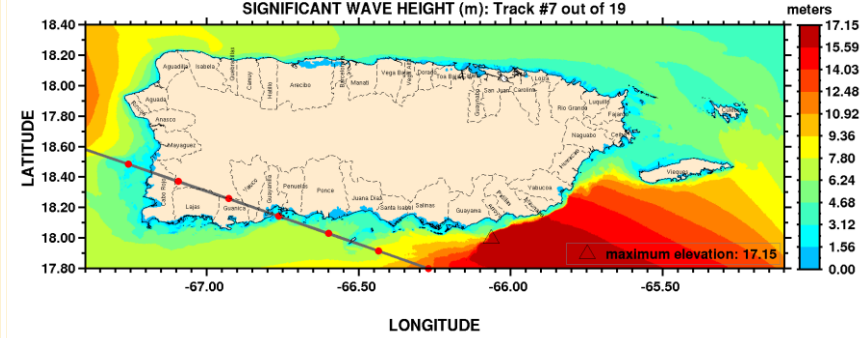
CariCOOS PUERTO RICO STORM SURGE ATLAS

LWD, SLR = 0.0 m, Cat 5 (dP = 900 mb), 290°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m): Track #7 out of 19



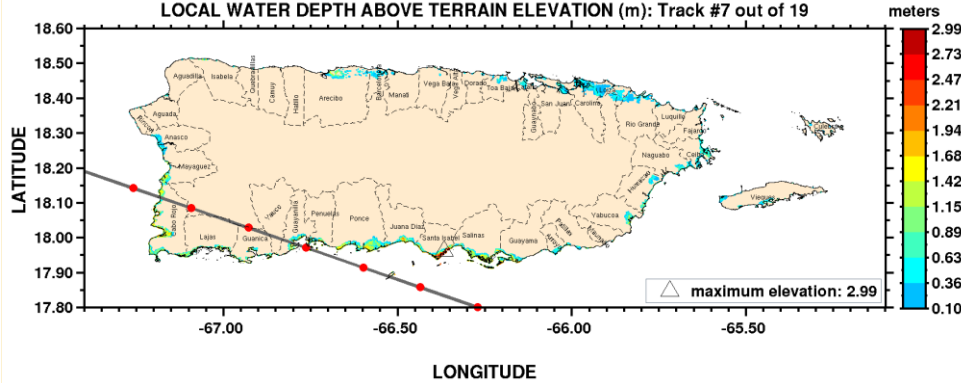
CariCOOS PUERTO RICO STORM SURGE ATLAS

Max Hs (m), = 0.0 m, Cat 5 (dP = 900 mb), 290°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
SIGNIFICANT WAVE HEIGHT (m): Track #7 out of 19



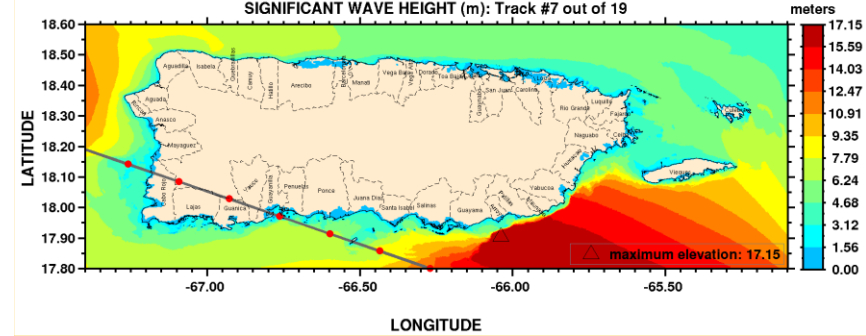
CariCOOS PUERTO RICO STORM SURGE ATLAS

LWD, SLR = 0.5 m, Cat 5 (dP = 900 mb), 290°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m): Track #7 out of 19



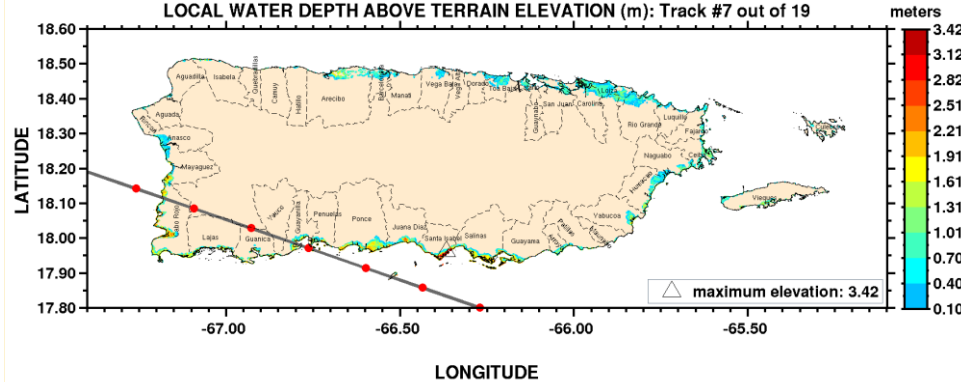
CariCOOS PUERTO RICO STORM SURGE ATLAS

Max Hs (m), SLR = 0.5 m, Cat 5 (dP = 900 mb), 290°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
SIGNIFICANT WAVE HEIGHT (m): Track #7 out of 19



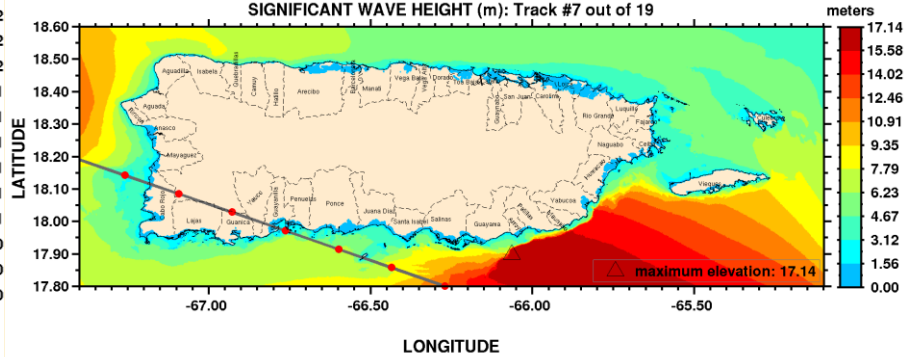
CariCOOS PUERTO RICO STORM SURGE ATLAS

LWD, SLR = 1.0 m, Cat 5 (dP = 900 mb), 290°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m): Track #7 out of 19



CariCOOS PUERTO RICO STORM SURGE ATLAS

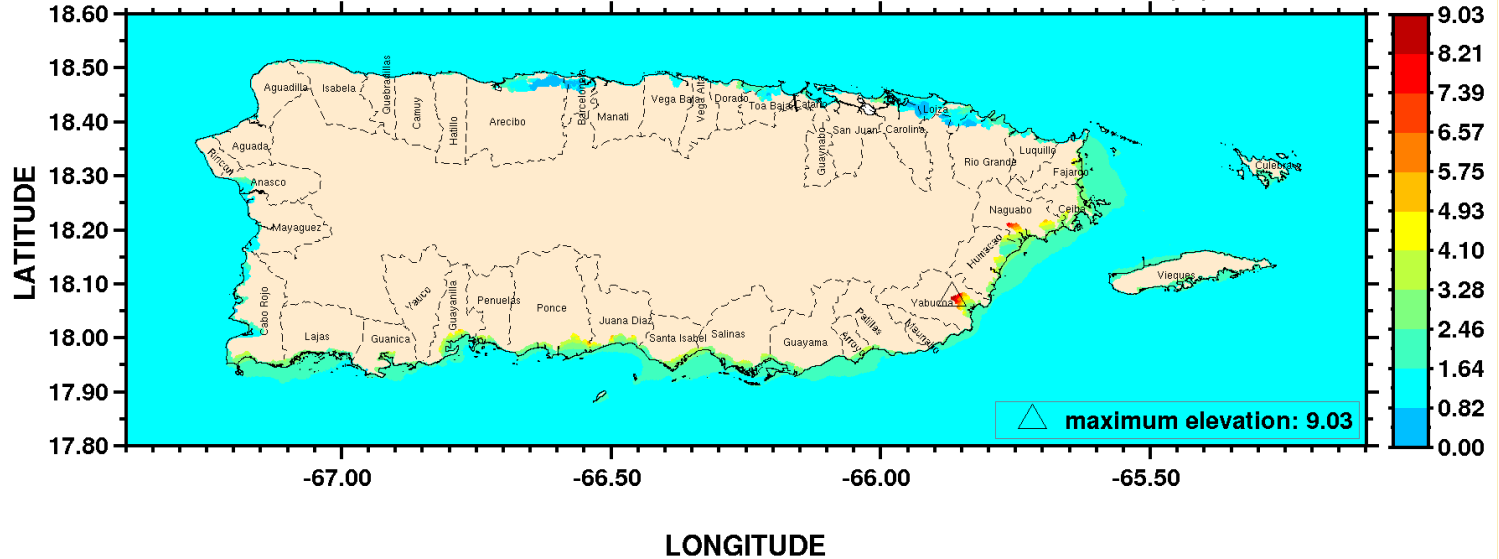
Max Hs (m), SLR = 1.0 m, Cat 5 (dP = 900 mb), 290°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
SIGNIFICANT WAVE HEIGHT (m): Track #7 out of 19



CariCOOS PUERTO RICO STORM SURGE ATLAS

MOM of MEOW, SLR = 0.0 m, Cat 5 (dP = 900 mb), 330°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn

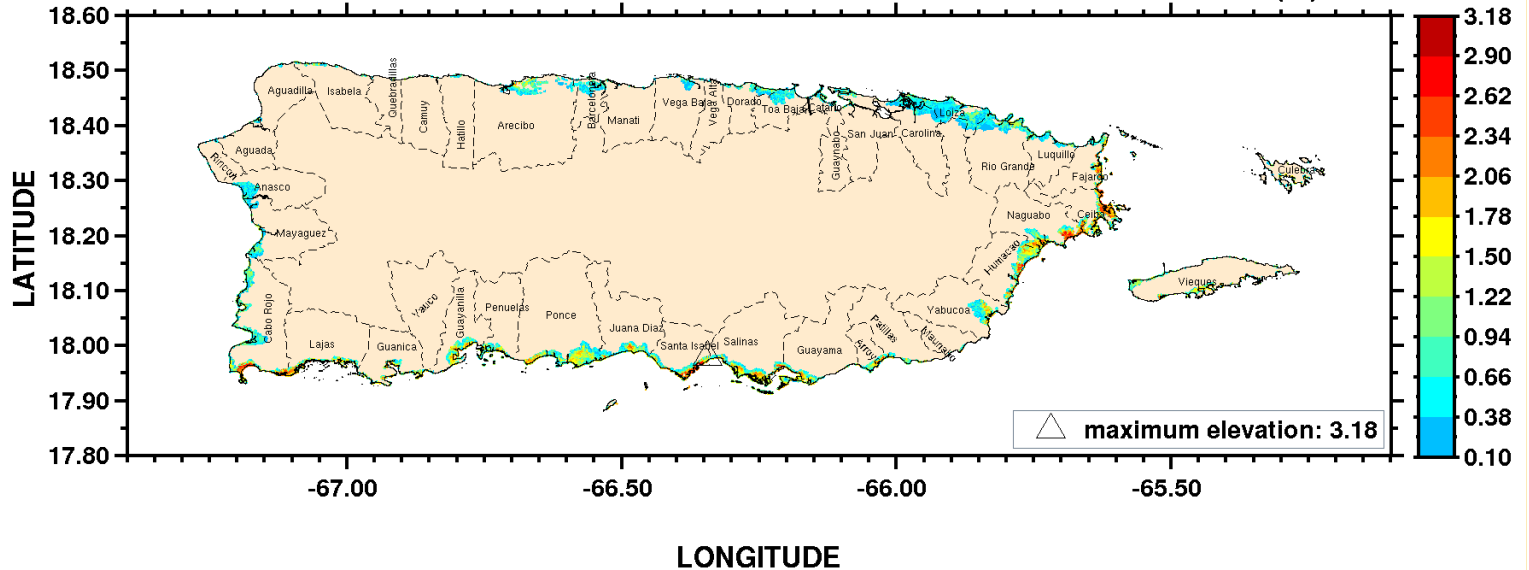
MAXIMUM OF MAXIMA OF STILLWATER ELEVATIONS ABOVE MSL (m)



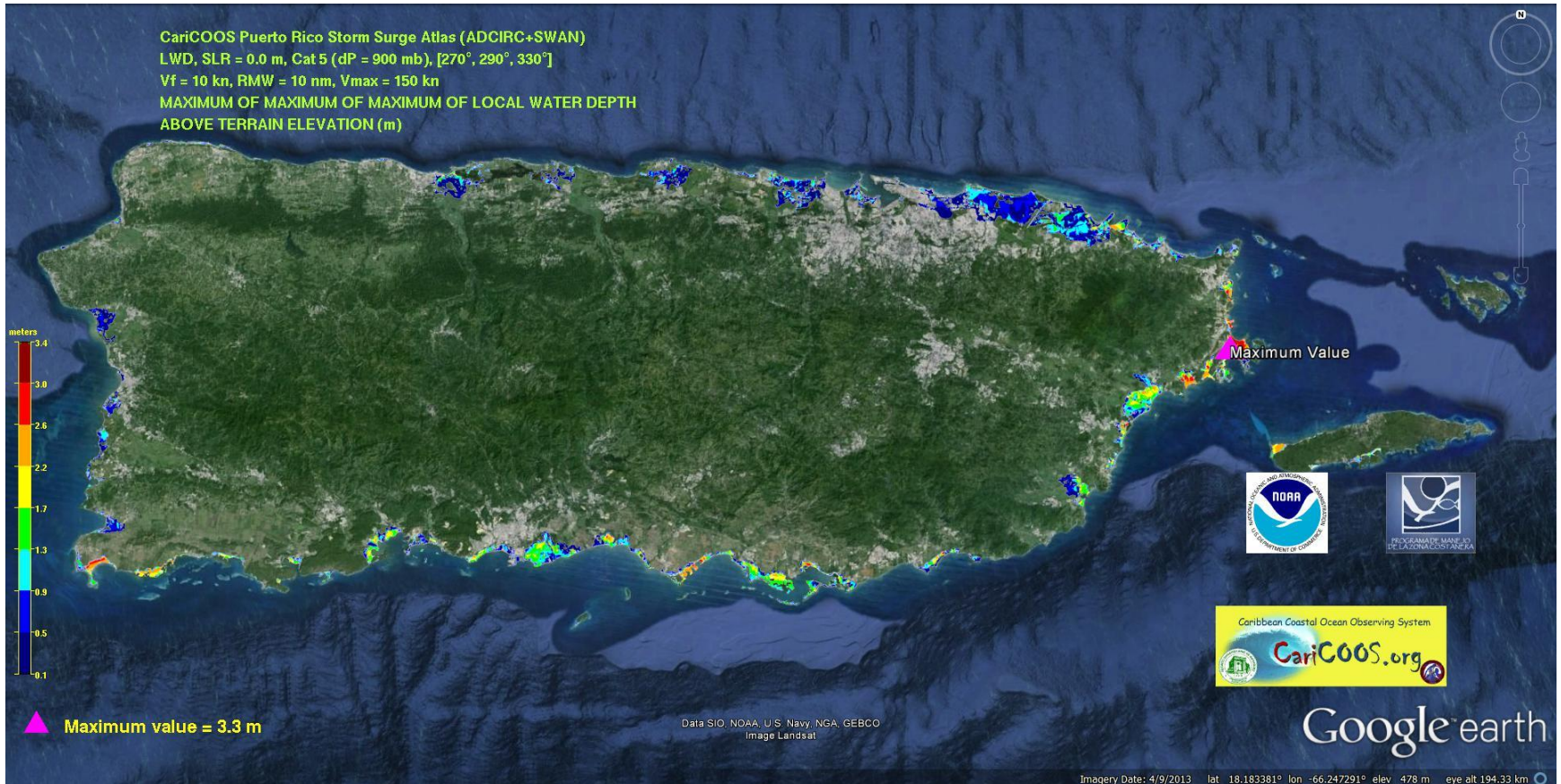
CariCOOS PUERTO RICO STORM SURGE ATLAS

MOM of LWD, SLR = 0.0 m, Cat 5 (dP = 900 mb), 330°, Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn

MAXIMUM OF MAXIMA OF LOCAL WATER DEPTH ABOVE TERRAIN ELEVATION (m)



Category 5: Maximum of Maximum of Maximum of Local Water Depth in meters above local terrain elevation (SuperMOM) Sea Level: actual



CariCOOS Puerto Rico Storm Surge Atlas (ADCIRC+SWAN)
LWD, SLR = 0.0 m, Cat 5 (dP = 900 mb), [270°, 290°, 330°]
Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
MAXIMUM OF MAXIMUM OF MAXIMUM OF LOCAL WATER DEPTH
ABOVE TERRAIN ELEVATION (m)



Maximum value = 3.3 m

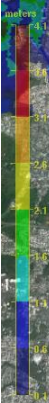


Google earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2014 CNES, Astrium
Image © 2014 DigitalGlobe

Imagery Date: 10/4/2013 lat 18.428315° lon -66.046775° elev 0 m eye alt 29.70 km

CariCOOS Puerto Rico Storm Surge Atlas (ADCIRC+SWAN)
LWD, SLR = 0.5 m, Cat 5 (dP = 900 mb), [270°, 290°, 330°]
Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
MAXIMUM OF MAXIMUM OF MAXIMUM OF LOCAL WATER DEPTH
ABOVE TERRAIN ELEVATION (m)



Maximum value = 4.0 m



Data: LDEO, Columbia, NSF, NOAA
Image: © 2014 DigitalGlobe
Data SRTM: NOAA, U.S. Navy, NSA, GEBCO
Image: © 2014 CNES/Airbus

Google earth

Imagery Date: 10/4/2013 lat 18.443089° lon -66.038552° elev 0 m eye alt 27.62 km



CariCOOS Puerto Rico Storm Surge Atlas (ADCIRC+SWAN)
LWD, SLR = 1.0 m, Cat 5 (dP = 900 mb), [270°, 290°, 330°]
Vf = 10 kn, RMW = 10 nm, Vmax = 150 kn
MAXIMUM OF MAXIMUM OF MAXIMUM OF LOCAL WATER DEPTH
ABOVE TERRAIN ELEVATION (m)



Maximum value = 4.2 m

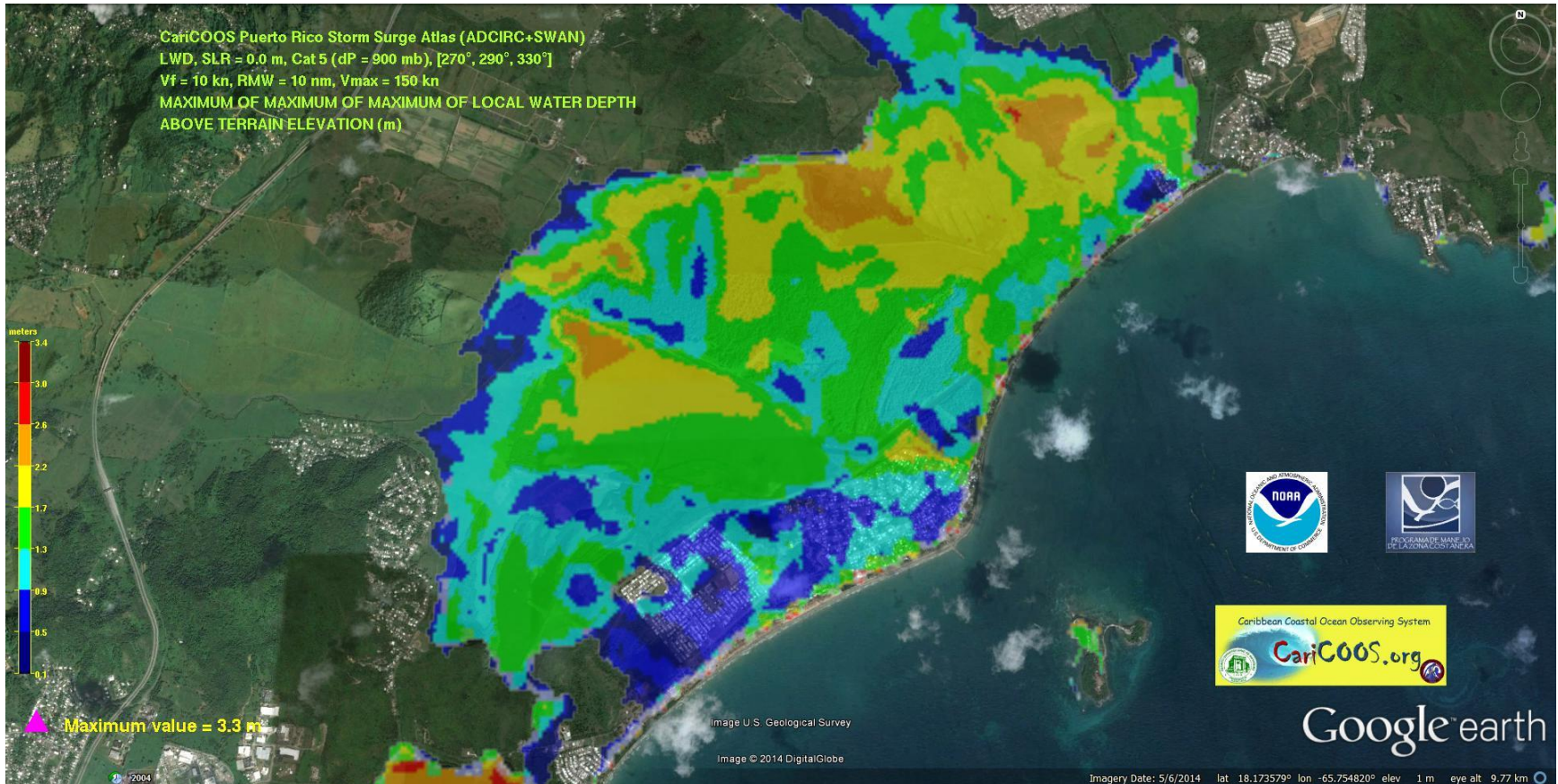


Google earth

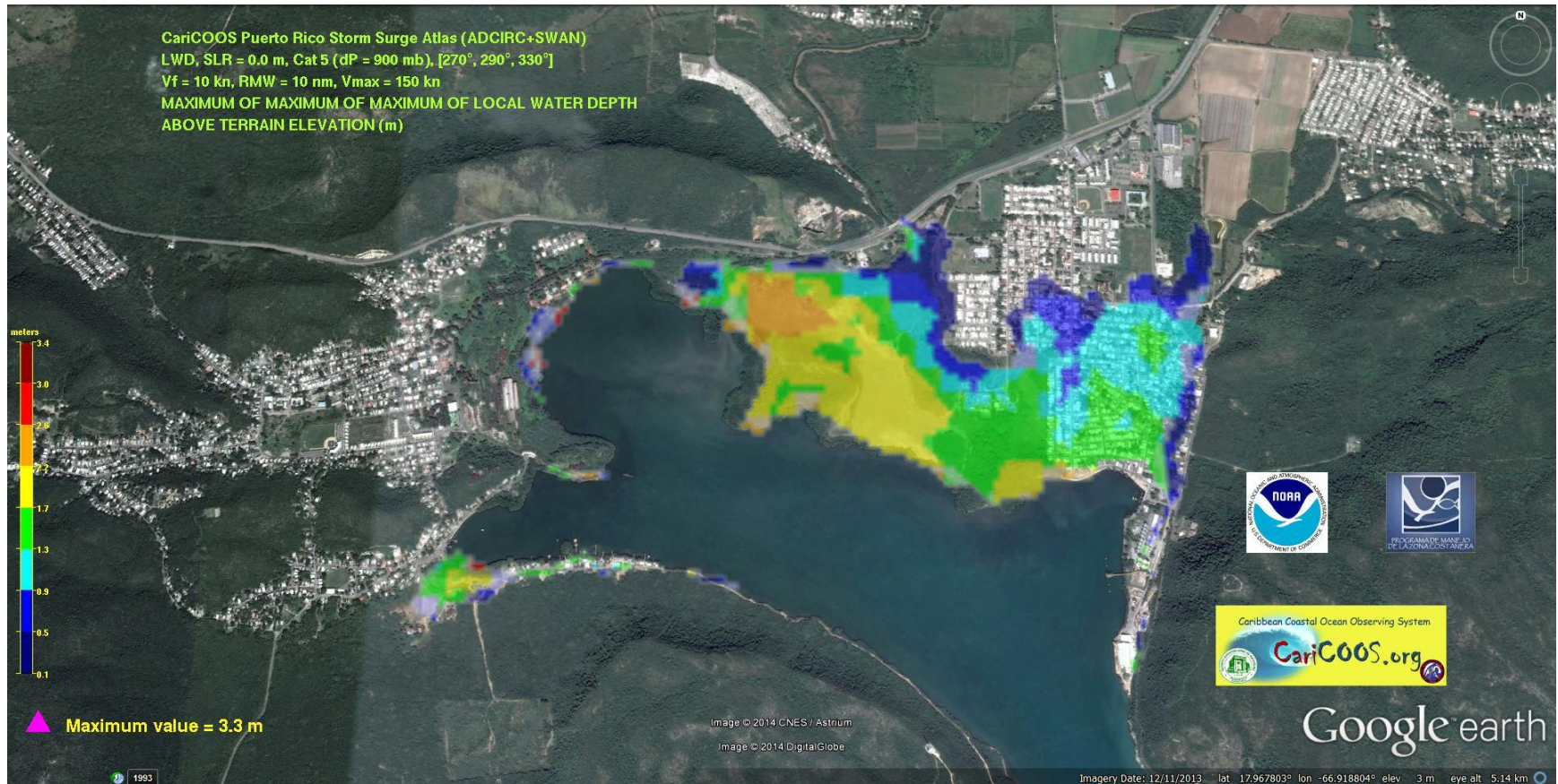
Image © 2014 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2014 CNES / Astrium

Imagery Date: 10/4/2013 lat 18.431877° lon -66.047627° elev 0 m eye alt 24.76 km

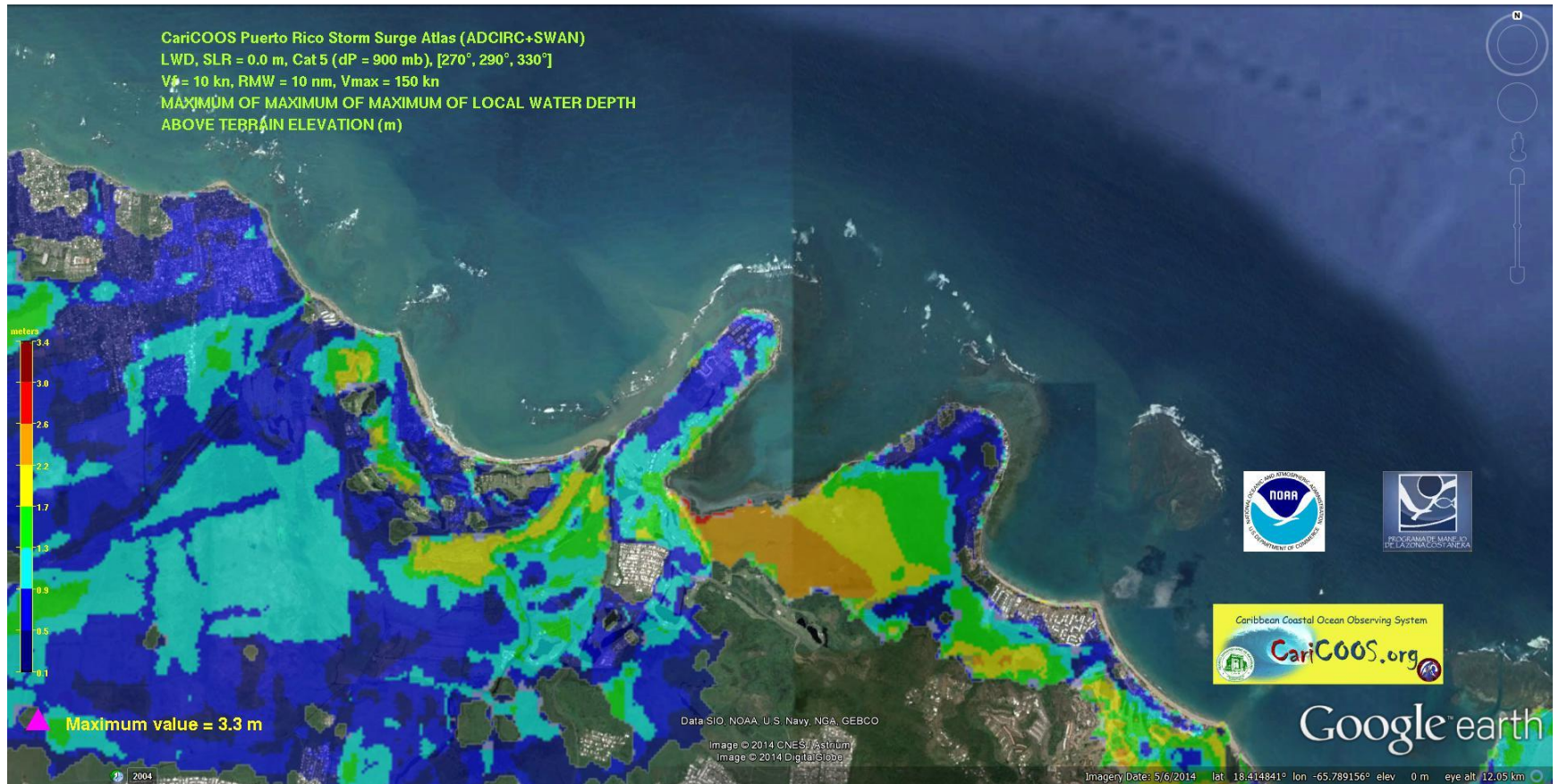
PUNTA SANTIAGO, HUMACAO: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: actual



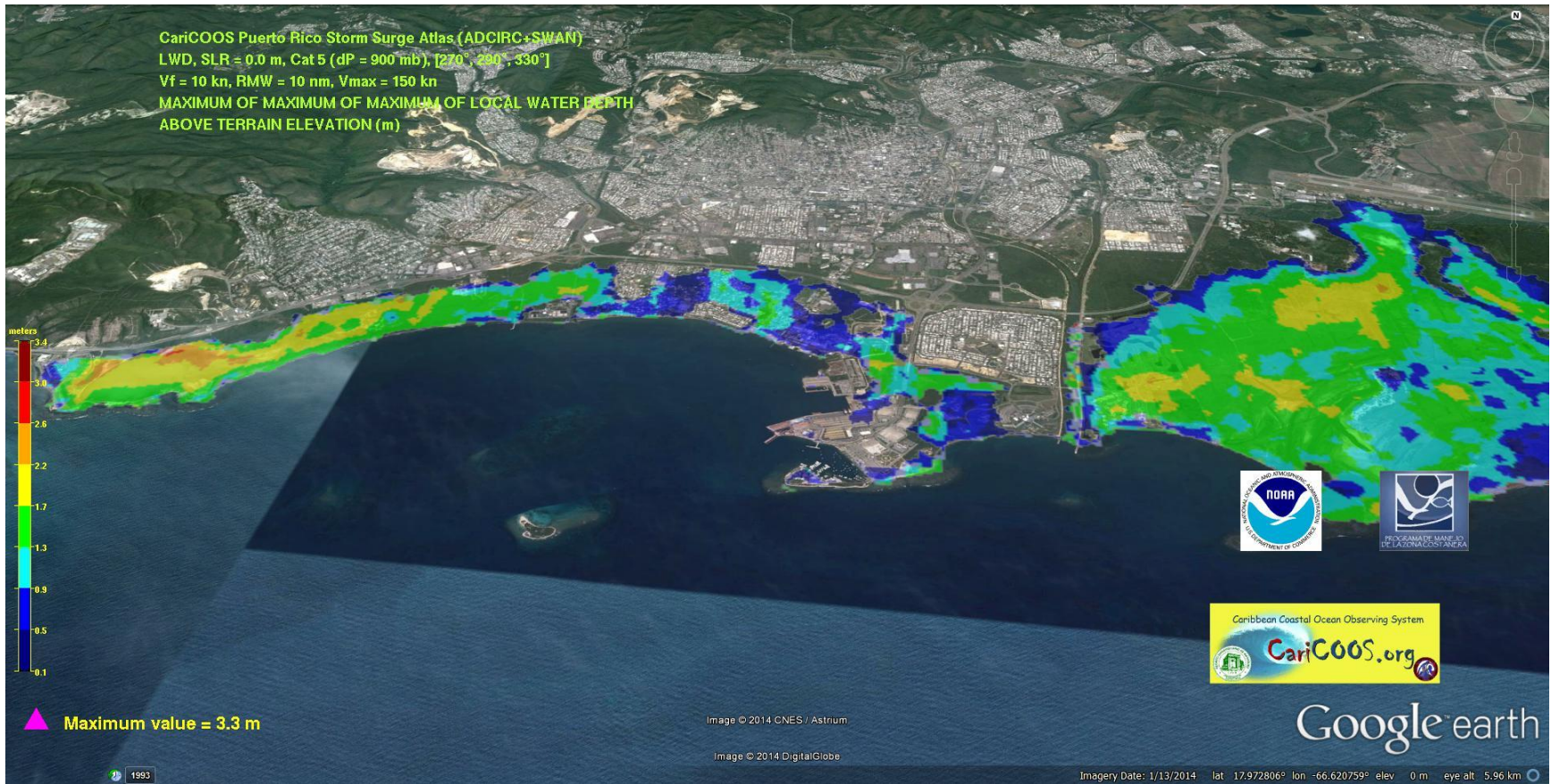
GUANICA: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: actual



PUNTA MIQUILLO, RIO GRANDE: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: actual



PONCE: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: actual



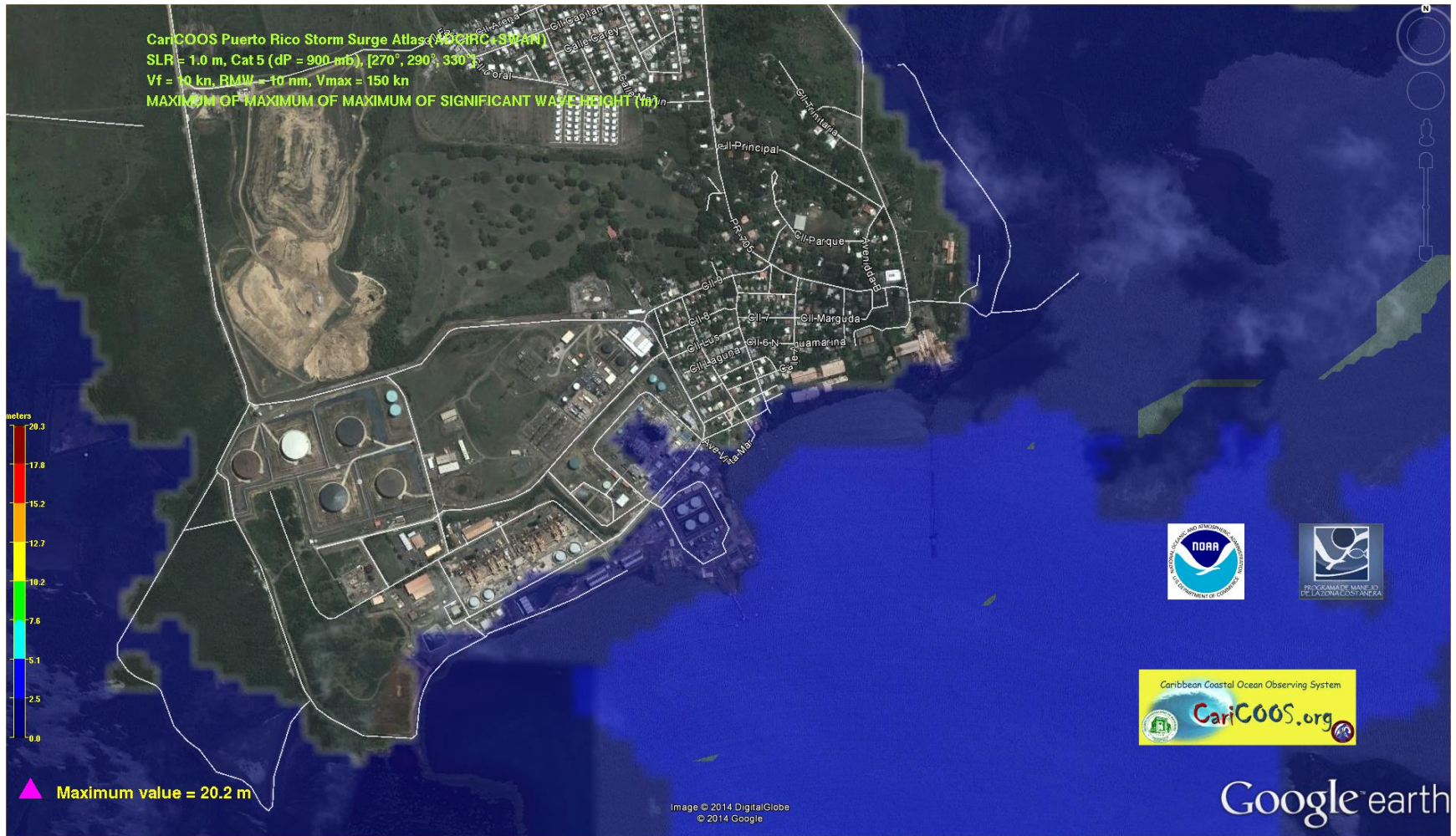
JOBOS, AGUIRRE THERMOELECTRIC PLANT: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: actual



JOBOS, AGUIRRE THERMOELECTRIC PLANT: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: 0.5 m

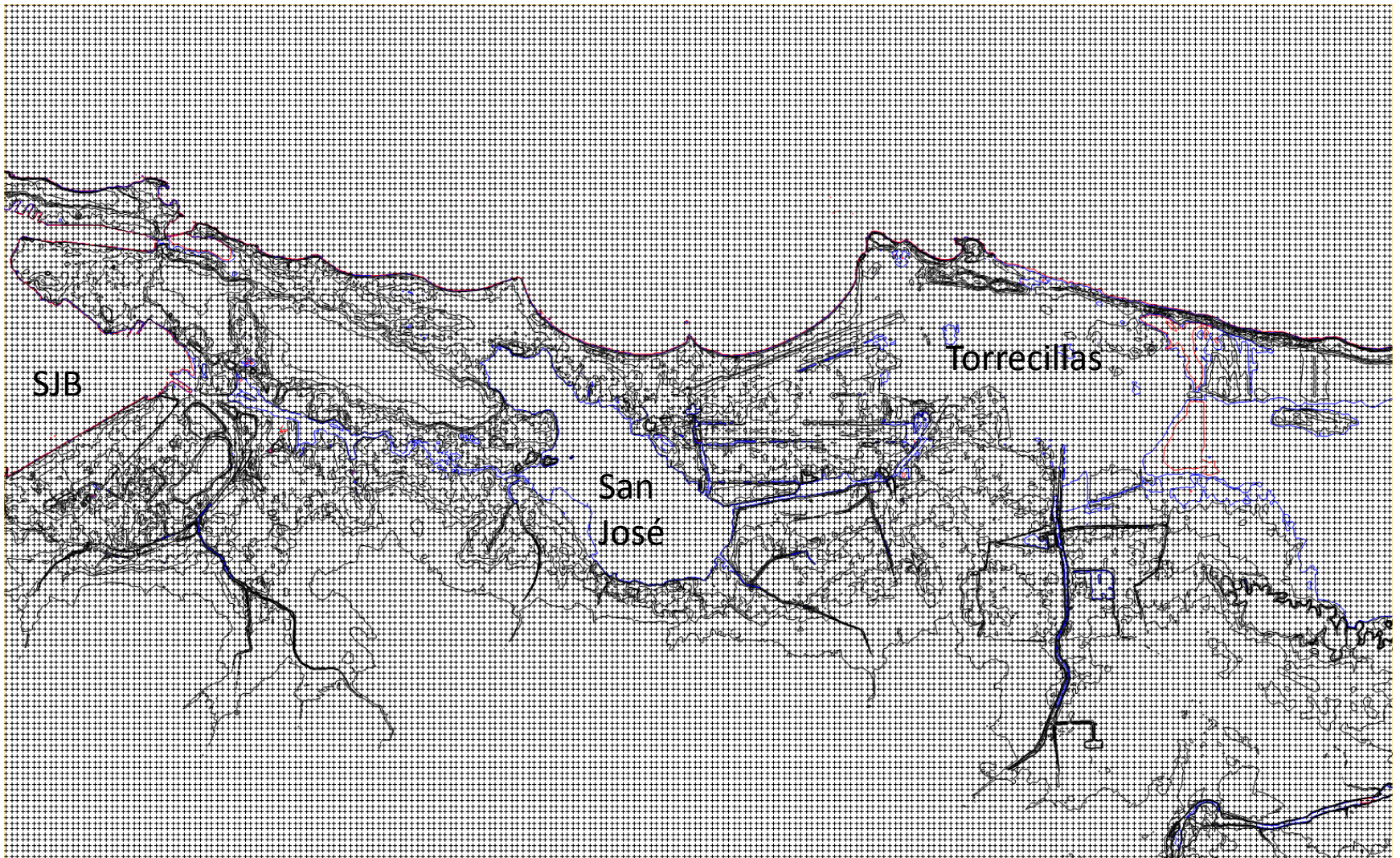


JOBOS, AGUIRRE THERMOELECTRIC PLANT: Cat 5: Maximum of Maximum of Maximum of Inundation (m) above local terrain elevation. Sea Level: 1.0 m



EL PROBLEMA CON EL ESTUARIO DE LA BAHIA DE SAN JUAN

Modelo de Elevación Digital de 10 metros de resolución



Red: MHW shoreline; Blue: +0.5 m

- As part of the University of Puerto Rico contribution to the testbed, personnel from the University will partner with USGS staff in the island in deploying HOBO water level meters at a sub-sample of pre-selected locations around the island.
- The aim is not just capturing the peak of the storm surge, but also the possibility of coastally trapped infragravity waves (periods \approx 25 sec), which could play a large role in enhancing coastal inundation.
- A training workshop by USGS personnel will be carried out on August 12, 2014, at the University.
- Plans are to divide the island in a section to be handled by the USGS and the other section by University personnel.
- The USGS, Department of Marine Sciences/UPRM, CariCOOS/NOAA/UPRM, and the Sea Grant Program/NOAA are involved.

HOBO® U20 Water Level

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Noticias
15 agosto 2014
00:09 a.m.

Cazahuracanes de la UPR Mayagüez

Mejorarán los modelos de predicción de inundaciones costeras provocadas por eventos atmosféricos como huracanes





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