REPORT ON THE MINIMUM WATER DEPTH, AND DISTANCE FROM THE SHORELINE, REQUIRED FOR MOVING SHIPS AND BOATS OUTSIDE OF THE DANGER ZONE DUE TO TSUNAMI CURRENTS

submitted to the

Puerto Rico Seismic Network as part of the Puerto Rico Component of the National Tsunami Hazard Mitigation Program

by

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EXECUTIVE SUMMARY

As part of the Puerto Rico component of the National Tsunamis Hazard Mitigation Program (NTHMP) of NOAA, the Puerto Rico Seismic Network has been asked to estimate how far offshore ships and boats should move in case they have the time, when a tsunami alert is given. For that purpose, the Mapping and Modeling sub-committee of NTHMP has provided some guidance in the publication "Guidelines and Best Practices for Tsunami Hazard Analysis, Planning, and Preparedness for Maritime Communities – Maritime Planning and Preparedness Guidelines", draft June 2015.

In this report, using the MOST executable that is provided in the ComMit interface, we estimate that moving offshore to a depth of between 100 and 200 m is sufficient, given the Guidelines quoted above. With very few exceptions, due to the narrow shelf around Puerto Rico, this implies a distance that can be as short as less than 1 km (Patillas) and as large as 11 km off Boquerón Bay, Cabo Rojo, where the shelf widens to the west. These are straight line distances from the site to the envelope curve separating the no damage zone and the minor to moderate damage zones (based on the NTHMP Guidelines).

METHODOLOGY

For the preparation of tsunami inundation maps a few years ago, 312 local sources were simulated, plus three scenarios from Dr. Uri ten Brink, and four additional regional scenarios – all of Mw 8.5 (Haiti, Haiti Norte, Panama, and Bonaire) - supplied by Dr. Victor Huerfano. All were simulated using a 30 m resolution grid prepared from the NGDC DEMs for the island. For each simulation the current speeds were stored, and these are the results that have been used in this report. Separate reports for local and regional scenarios have been submitted. The local sources cover several regions all around Puerto Rico, while the regional sources are due to an Mw 8.7 earthquake in the curving subduction zone to the northeast of the British/French/Dutch islands east of Puerto Rico, as supplied by Uri ten Brink, two sources north of Hispaniola, one source north of Panama, and another source north of Bonaire, as supplied by Victor Huerfano.

It should be stated that the local sources scenarios were simulated using a version of MOST that had misidentified the speed units in the *sift.nc files as being cm/sec when in reality they were already in m/sec. This led to a division by 100 in order to change the (erroneous) units to m/sec, resulting in values smaller than the correct ones by a factor of 100. This error was later caught when using the version of MOST that came with the latest version of ComMit, where the units are correctly given as cm/sec. The speed files for local scenarios were re-processed and corrected for the error. For the regional scenarios we used the ComMit version of MOST and no error was introduced.

RESULTS

The Guidelines provide four current speed ranges which should be used for damage assessment:

1. Blue: 0 to 2.9 knots – no observed damage
2. Green: 3 to 5.9 knots – minor to moderate damage
3. Orange: 6 to 8.9 knots – damage observable, transition to major damage
4. Red: larger than, or equal to, 9 knots – major to complete damage

Figure 1 shows the maximum current speeds for the whole set of 312 local tsunamis. Based on the figure the boundary between the blue and the green was manually digitized, and shown as a white curve. The resulting curve will be called the “damage envelope”. The recommendation to ship captains and boat owners will be to move seaward of it if time allows it. Figure 2 shows the resulting curve on top of a Google Earth image.

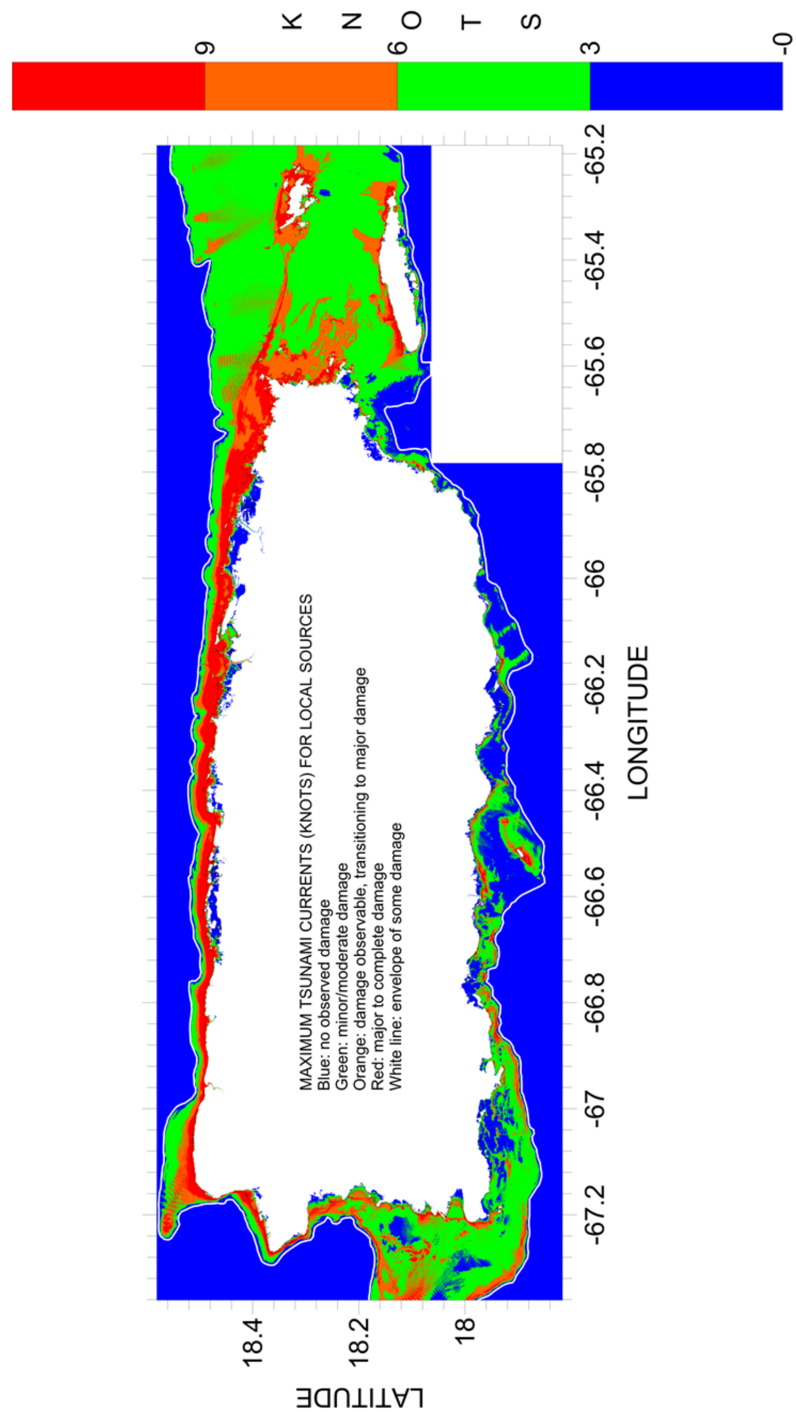


Figure 1 – Maximum tsunami currents (knots) for <u>local</u> sources. The NTHMP speed damage breakdown, and color convention, has been incorporated. The white line shows the boundary between no observed damage and minor to moderate damage, according to the NTHMP guidelines.

Figure 2 – Google Earth view of the location of the (white) line showing the boundary between no observed damage and minor to moderate damage for <u>local</u> tsunamis, according to NTHMP.

Now, the question is whether we can assign a given depth, or range of depths, to the damage envelope curve (white curve) shown in Figures 1 and 2. Figure 3 shows the no damage envelope curve (white curve), and superimposed on top of it is the 150 m isobath. It can be seen that, with just three exceptions, the 150 m isobaths follows very nicely the damage envelope curve. At these three locations the envelope curve moves inland of the 100 – 200 m isobaths. It should be stated that the 50, 100, 150, and 200 m isobaths practically fall on top of each other. This is a consequence of the very steep bottom slope seaward of the shelf break. For the sake of security the 150 m isobath has been chosen. The three exceptions are a region extending eastward of Isla Caja de Muertos and south of Jobos Bay, a region east of Humacao, and a region south of Vieques Island.

Now we must determine the no damage envelope curve for regional tsunamis. Figure 4 shows the maximum tsunami currents for regional tsunamis. Superimposed is the no damage envelope curve for local tsunamis (white curve) and the 100 and 200 m isobaths (red curves). We can see that the envelope curve for local tsunamis serves very well for most of the regional tsunamis, with the exception of the same three locations mentioned above. In these locations the potentially damaging regional tsunami currents extend seaward of the local tsunami currents no damage envelope curve. But the potentially damaging regional currents do not extend seaward of the 100 – 200 m isobaths. This conclusion is based on the fact that the figure also shows the location of the 100 and 200 m isobaths, and it can be seen that all of the painted area showing the 3 to larger than 9 knots regions fall landward of the two isobaths. The two isobaths fall one on top of the other due to the extreme steepness of the island slope seaward of the shelf break, and the use of just the 150 m isobath is a good option.

Therefore, we can conclude that the 150 m isobath depth is a safe option to use as a no damage envelope curve for watercrafts, big and small, for both local and regional tsunamis.

It might be desired to assign an offshore distance to move, instead of a water depth, but determining this offshore distance to the 100 to 200 m isobaths is not easy due to the irregular bathymetry that characterizes the sea bottom around Puerto Rico. I would suggest that the issue of the offshore distance to move is better left to ship and boat captains. Based on the information provided here they can easily determine that distance based on their berthing location. Obviously, consideration should be given that sometimes the best direction is not to move shore perpendicular, but at a certain angle to the coastline. A good example is for boaters who use Puerto Real, or Boquerón Bay, Cabo Rojo, for their boats. It is quite possible that traveling to the northwest is better than traveling directly west. But that can depend on the presence of dangerous reefs and shallow spots along the chosen direction. In any case, a rough measure of the distance to be traveled is given in the table below, showing the straight line distance to the 150m isobath.

Figure 5 shows a Google Earth image with painted areas showing the tsunami currents for both local and regional tsunamis, and the no damage envelope curve based on the 150 m depth isobath.

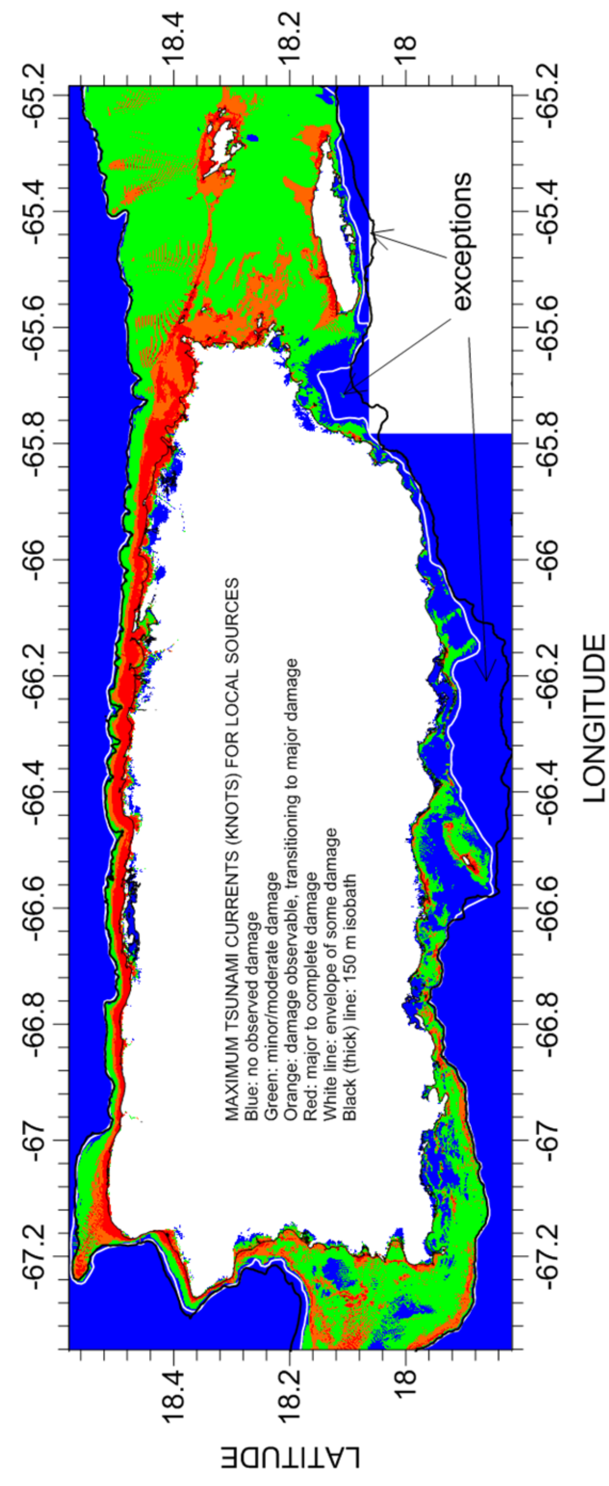


Figure 3 – Image of the local tsunamis no damage envelope curve (white curve) and the 150 m isobaths (black curve), showing that they practically overlap all around the island, with just three exceptions. This shows that the local tsunamis no damage envelope curve follows the (abrupt) shelf break, with just three exceptions.

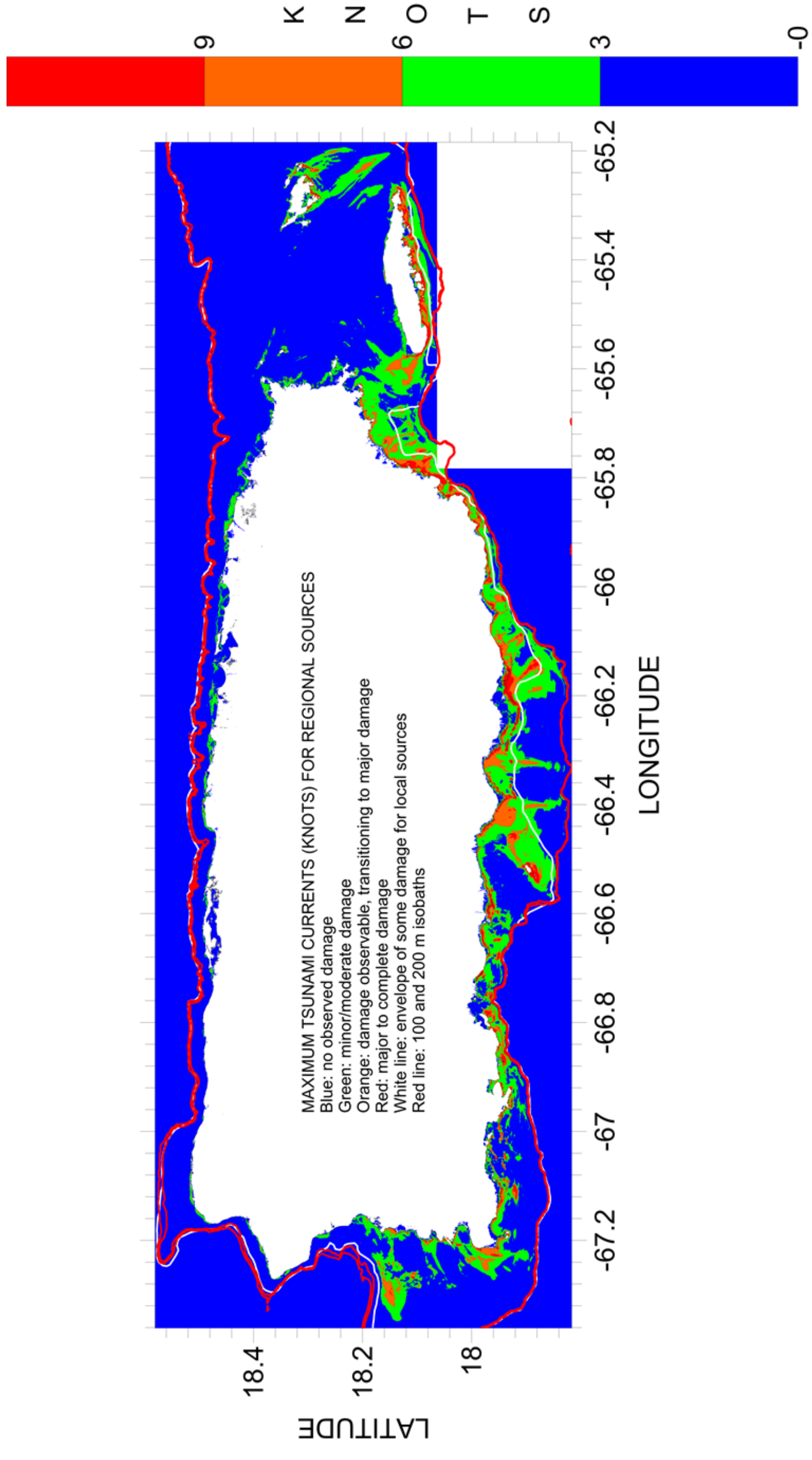


Figure 4 - Maximum tsunami currents (knots) for <u>regional</u> sources. The NTHMP speed damage breakdown, and color convention, has been incorporated. The white line shows the boundary between no observed damage and minor to moderate damage for <u>local</u> tsunamis, according to NTHMP. The two red curves show the 100 and 200 m isobaths. Note that the 100-200 m isobaths are literally on top of each other (and also on top of the local tsunamis envelope curve) and that they serve as a no damage envelope for both <u>local</u> and <u>regional</u> tsunamis.

Location	Distance (nm)[1]	Azimuth
San Juan: Entrance to San Juan Bay	1.2	North
Arecibo: tip of breakwater	1.	North
Aguadilla: tip of breakwater	1.2	Northwest
Rincon: Black Eagle Marina	0.7	Southwest
Mayaguez: west end of the port dock	2.7	West
Cabo Rojo: entrance to Puerto Real Bay	8.3	Northwest
Cabo Rojo: from the Boqueron Village	10.8	Southwest
Lajas: La Parguera nautical club	5.6	South
Guanica: entrance to the bay	2.7	Southeast
Guayanilla: Punta Gotay at entrance to the Guayanilla Bay	1.4	South
Ponce: from Club Nautico	2.4	Southwest
Bahía de Jobos, Aguirre: from Cayos de Barca	5.3	South
Bahia de Yabucoa: from entrance	1.5	Southeast
Ceiba: from entrance to Roosevelt Roads Bay	8	Southwest
Fajardo: north from Isleta Marina	8.5	North
Culebra: from entrance to Ensenada Onda	10.6	Southeast
Vieques: from Esperanza	2	Southwest
Vieques: from Isabel Segunda	13	West and then southwest

1 – These are approximate straight line distances

Finally, although not part of the scope of this report, we will present zooms of the impact of local and regional tsunamis in the major ports of Puerto Rico in terms of tsunami-induced currents. These should help in hazard mitigation and planning in these ports. These are: San Juan Bay, Mayagüez, Puerto Real (Cabo Rojo), Boquerón (Cabo Rojo), La Parguera (Lajas), Guanica Bay, Guayanilla/Tallaboa Bay, Ponce port, Jobos Bay (Aguirre), Roosevelt Roads (Ceiba), Fajardo, Vieques, and Culebra. These are shown in Figures 6 to 31. In the figures the thin white line is the MHW shoreline from the 30 m resolution DEM.

CONCLUSION

Based on the use of the non-linear, non-dispersive, shallow water model, MOST, we can conclude that the 150 m isobath depth is a safe option to use as a no damage envelope curve for watercrafts, big and small, for both local and regional tsunamis. This approximately corresponds to the shelf break all around Puerto Rico.

ACKNOWLEDGMENTS

Both of us would like to acknowledge the support of the Puerto Rico Seismic Network/National Tsunami Hazard and Mitigation Program. And special thanks to Dr. Diego Arcas and Dr. Christopher Moore, both at the NOAA Center for Tsunami Research, PMEL/NOAA, Seattle, WA.

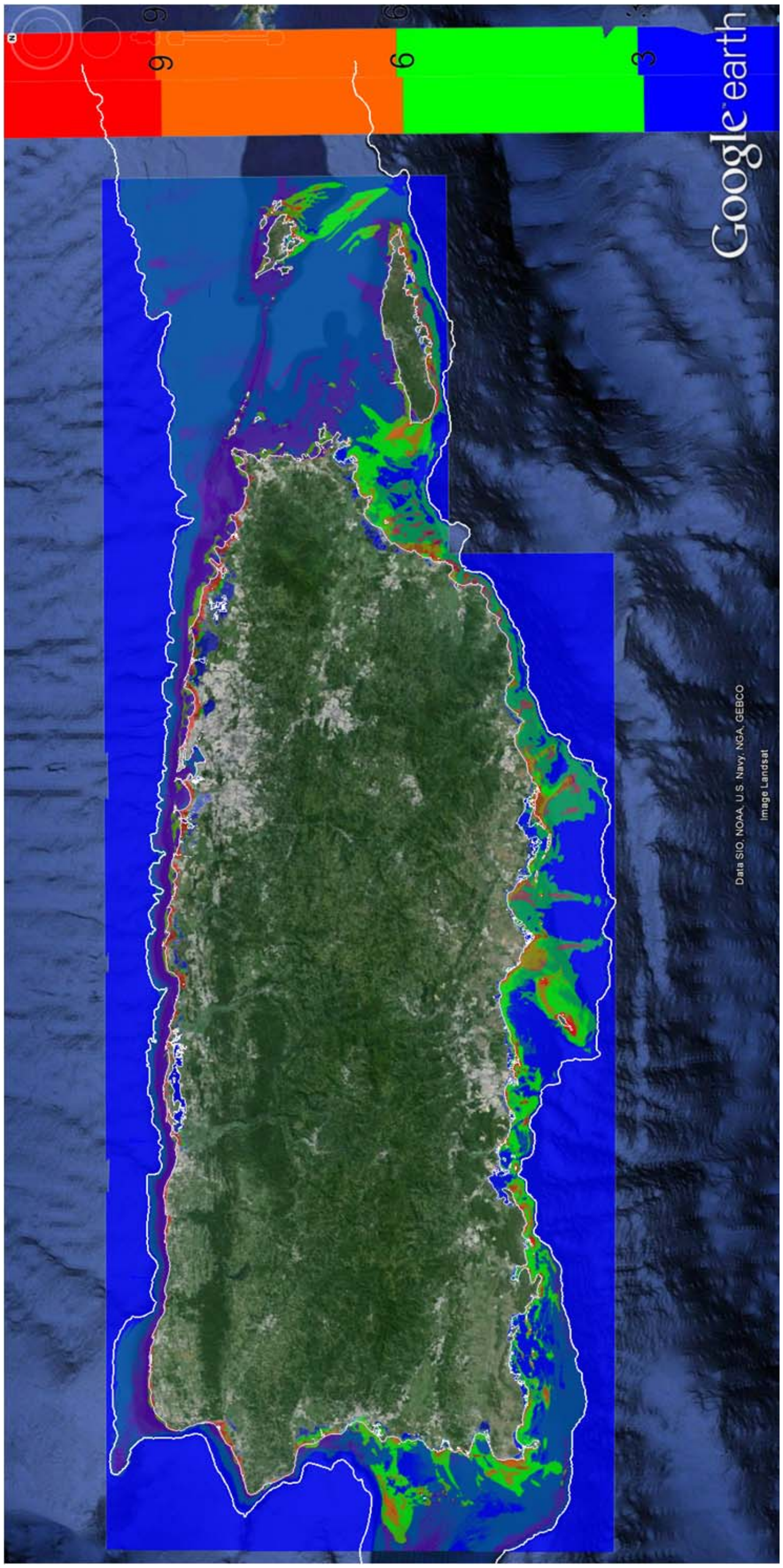


Figure 5 – Google Earth image showing the máximum tsunami current speeds (knots) for both local and regional tsunamis, and the no damage envelope curve based on the 150 m depth isobath.

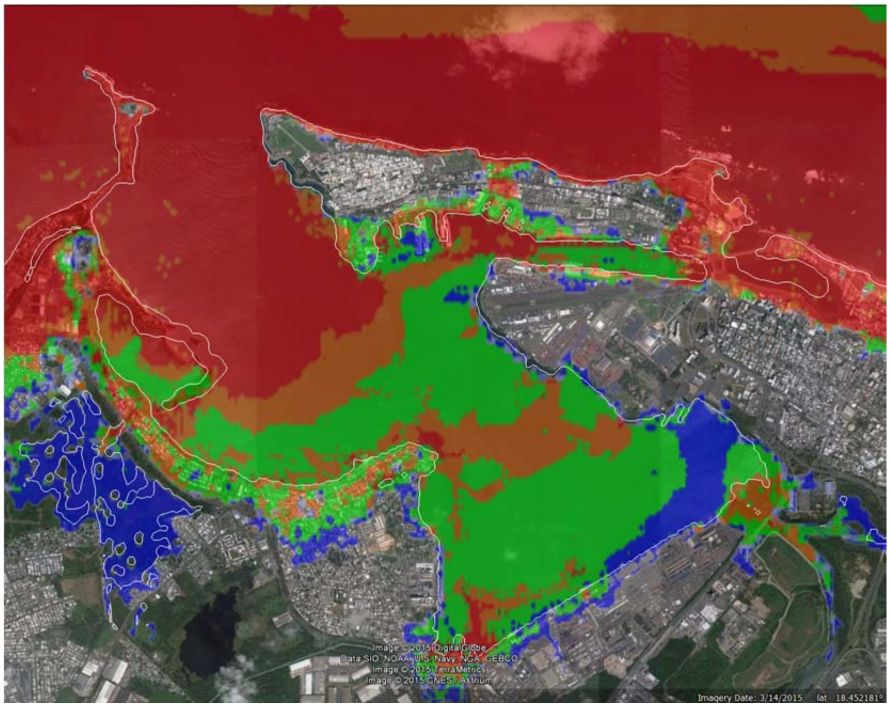


Figure 6 – Maximum speed. Local tsunamis. San Juan Bay.

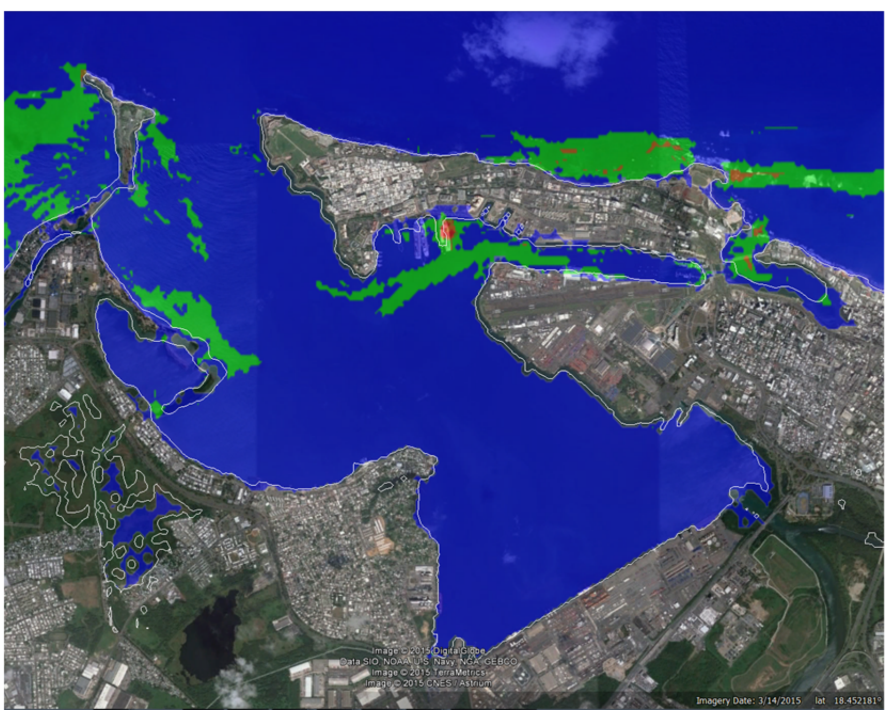


Figure 7 – Maximum speed. Regional tsunamis. San Juan Bay.

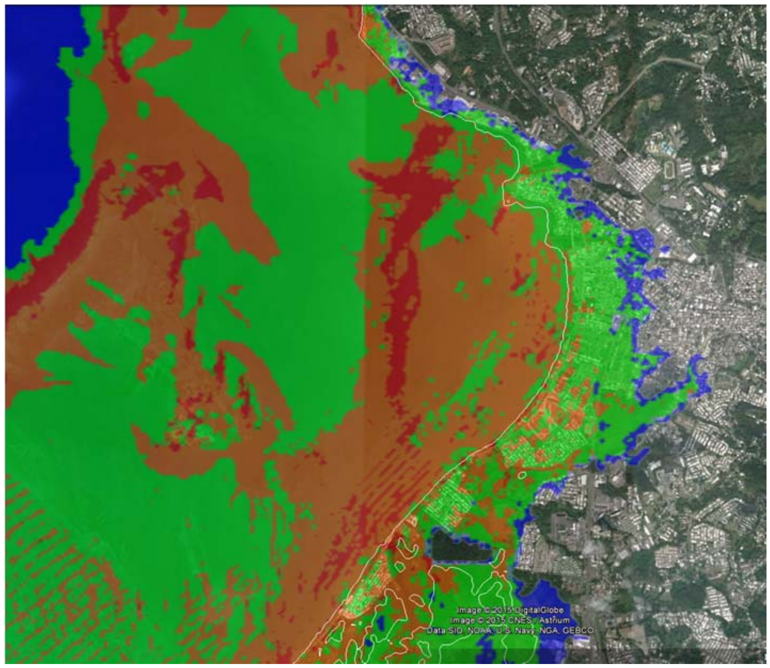


Figure 8 – Maximum speed. Local tsunamis. Mayaguez Bay.

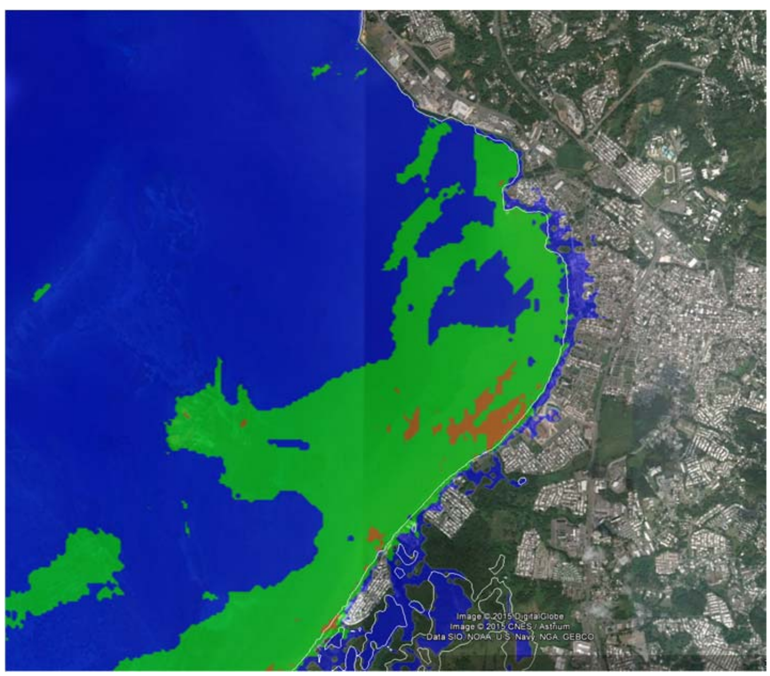


Figure 9 – Maximum speed. Regional tsunamis. Mayaguez Bay.

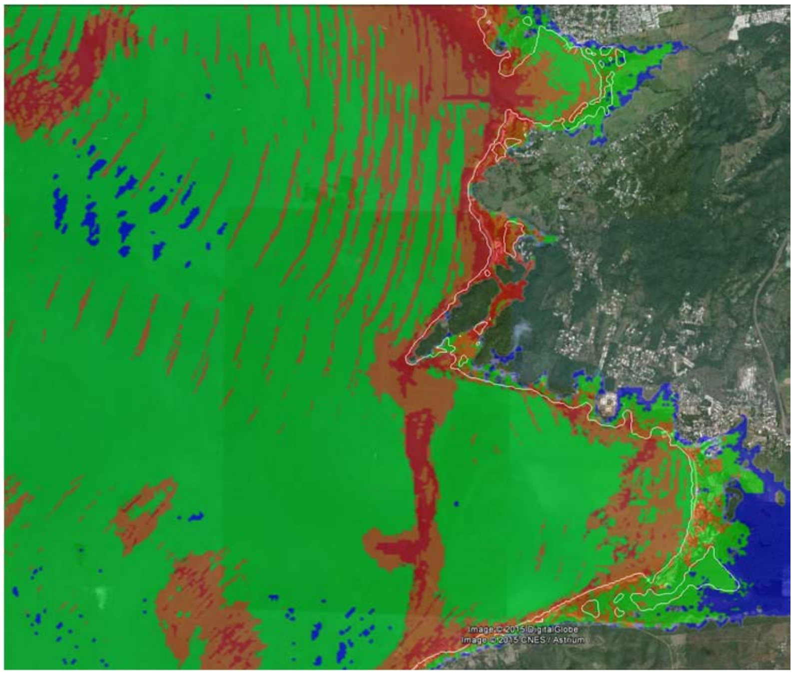


Figure 60 – Maximum speed. Local tsunamis. Puerto Real and Boquerón Bays, Cabo Rojo.

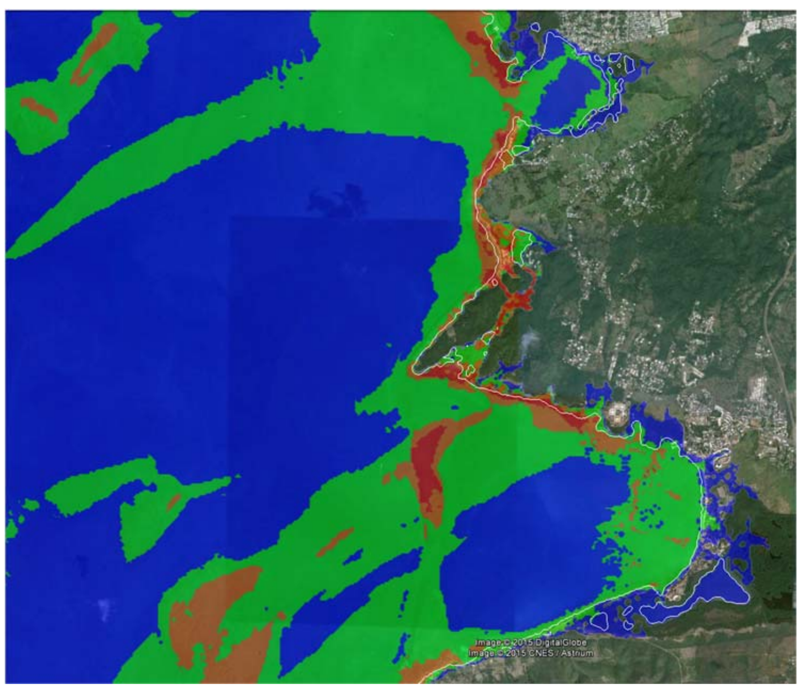


Figure 11 – Regional tsunamis. Puerto Real and Boquerón, Cabo Rojo.

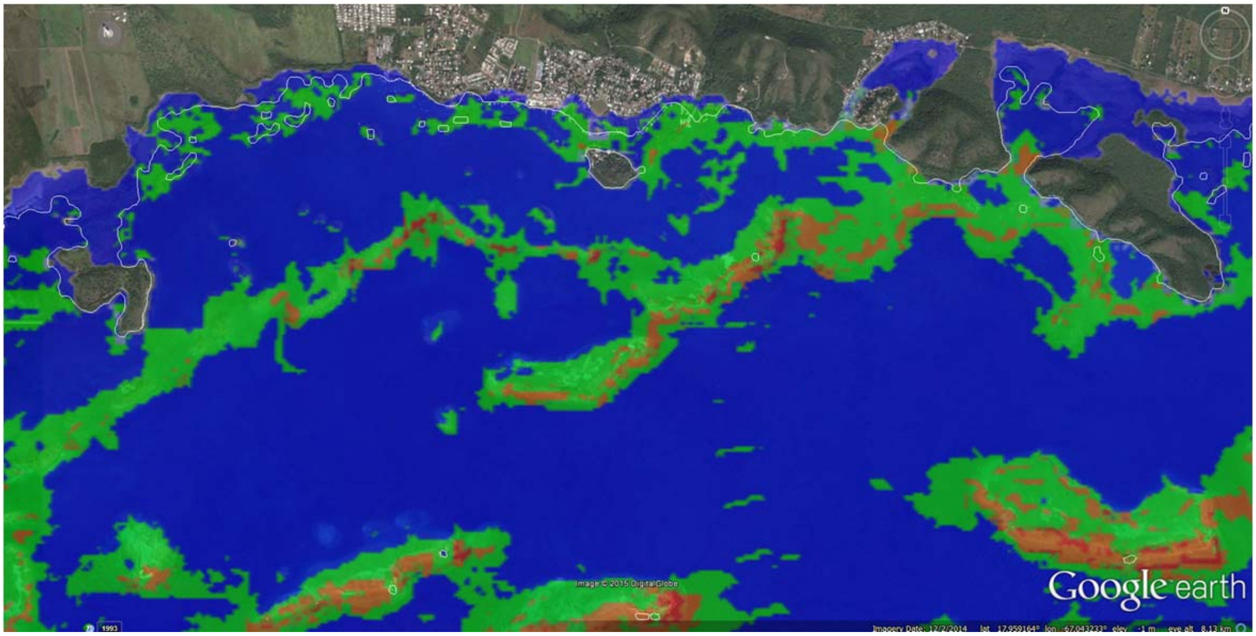


Figure 7 – Maximum speed. Local tsunamis. La Parguera, Lajas.

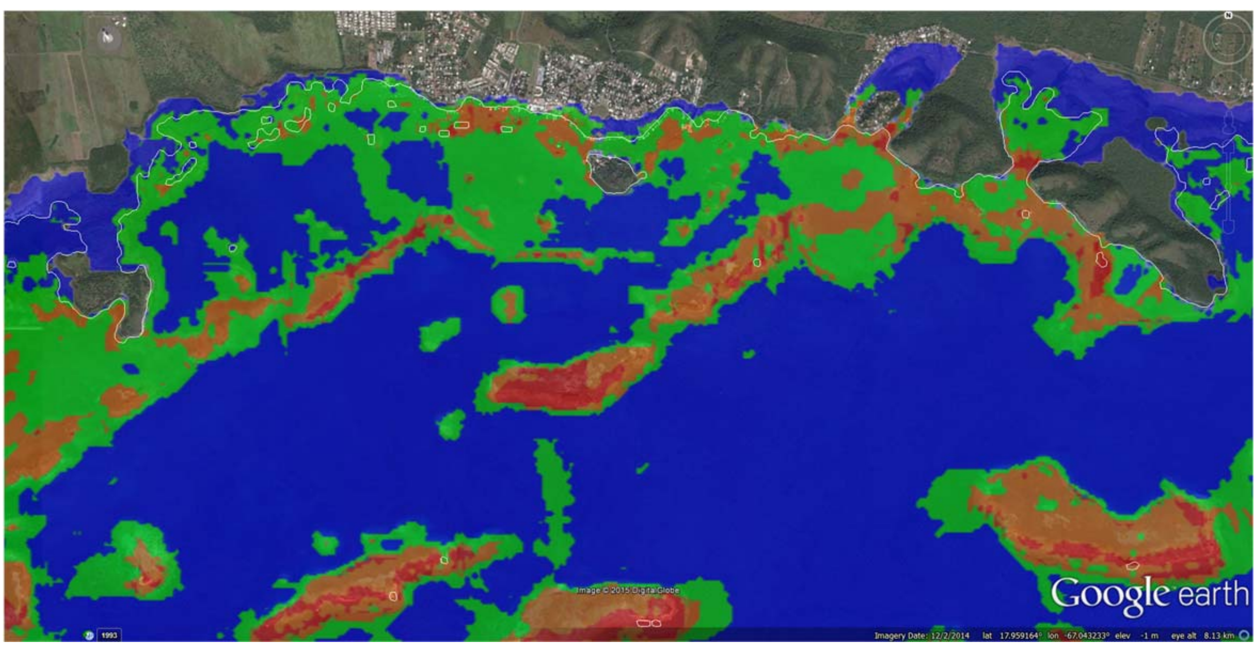


Figure 8 – Maximum speed. Regional tsunamis. La Parguera, Lajas.

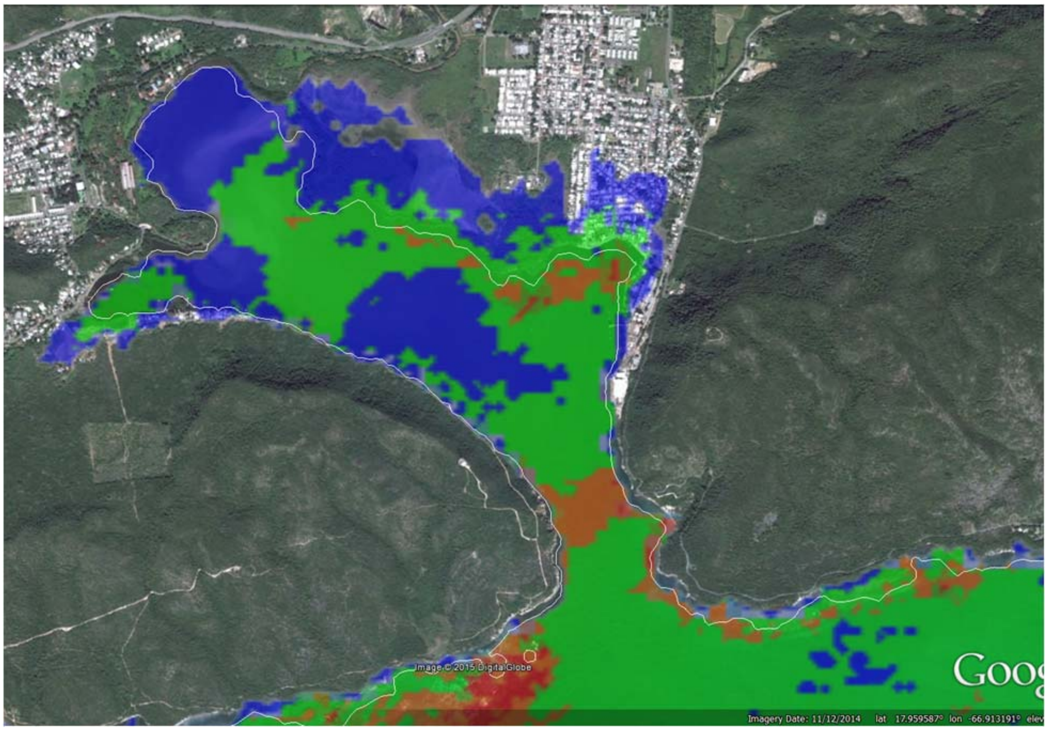


Figure 9 – Maximum speed. Local tsunamis. Guanica Bay.

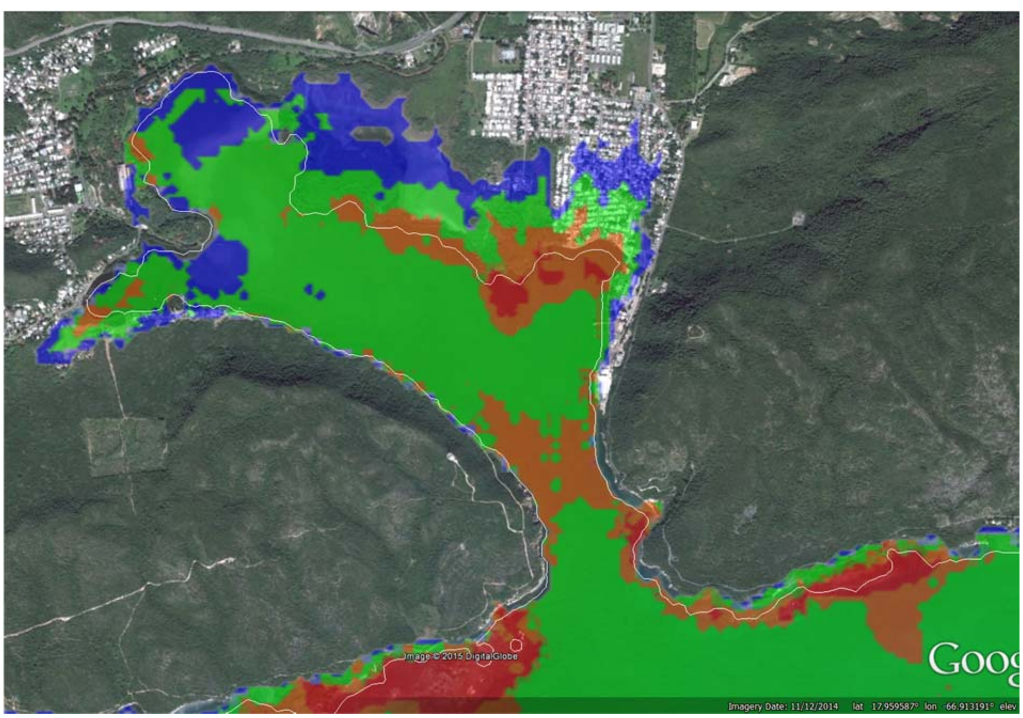


Figure 10 – Maximum speed. Regional tsunamis. Guanica Bay.

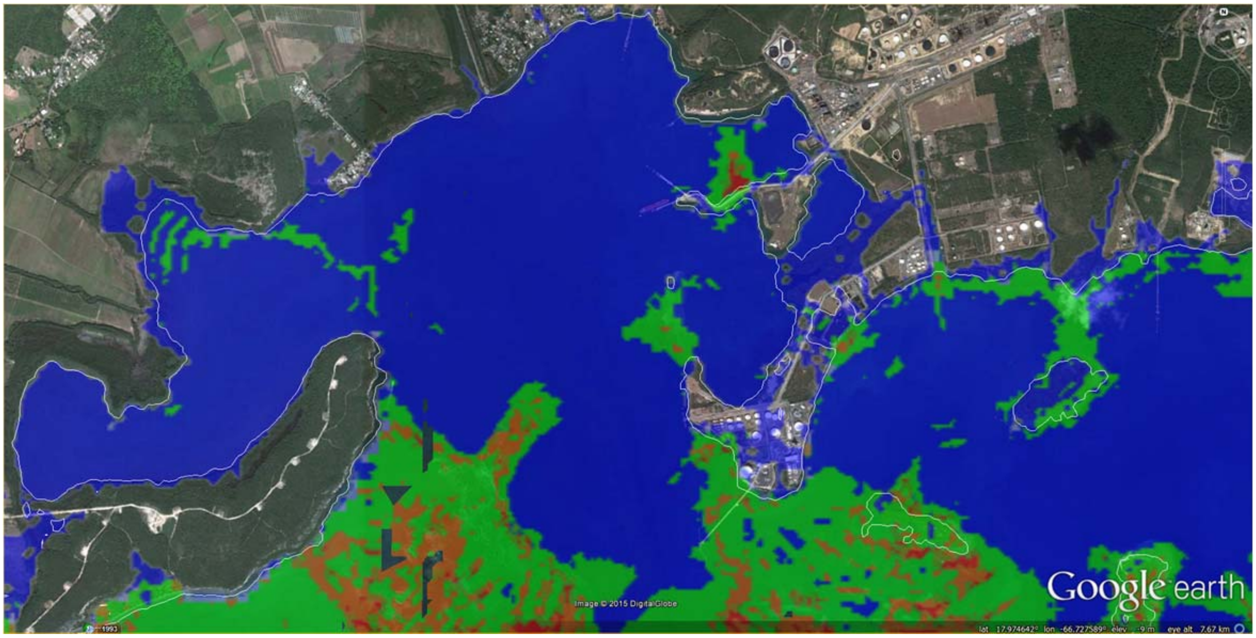
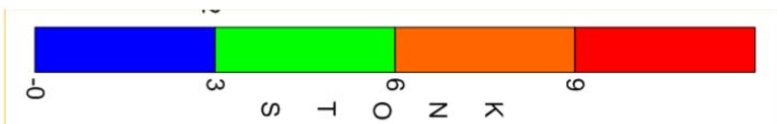


Figure 11 – Maximum speed. Local tsunamis. Guayanilla/Tallaboa Bay.



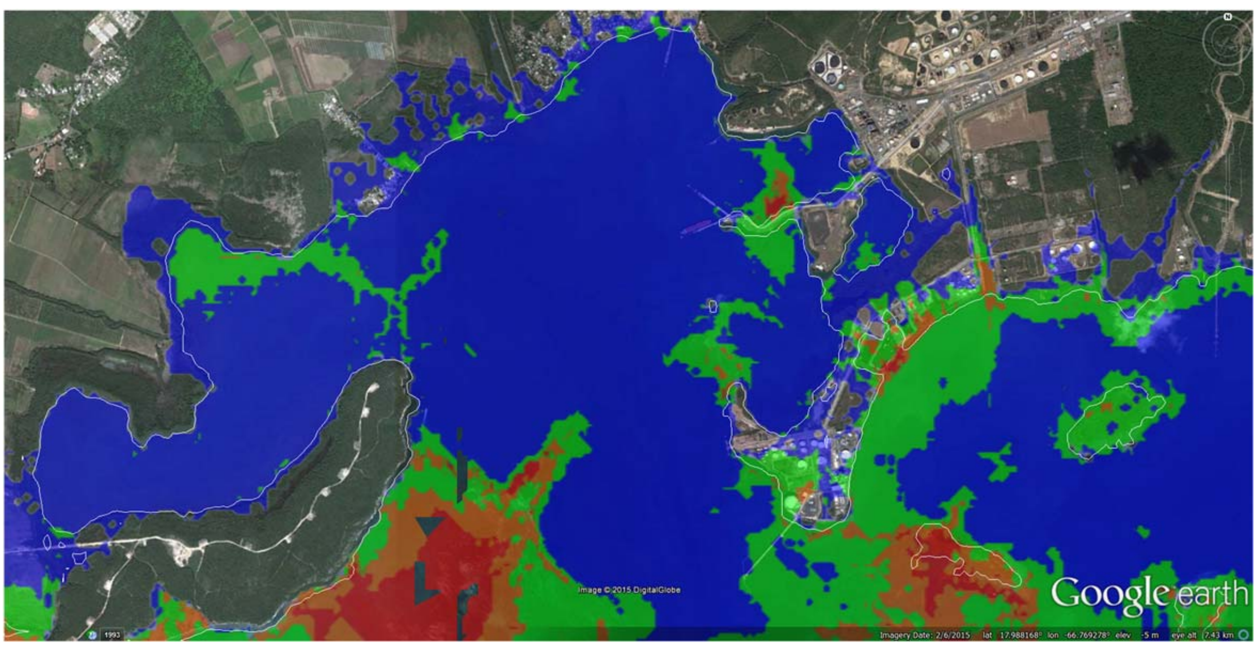


Figure 12 – Maximum speed. Regional tsunamis. Guayanilla/Tallaboa Bay.

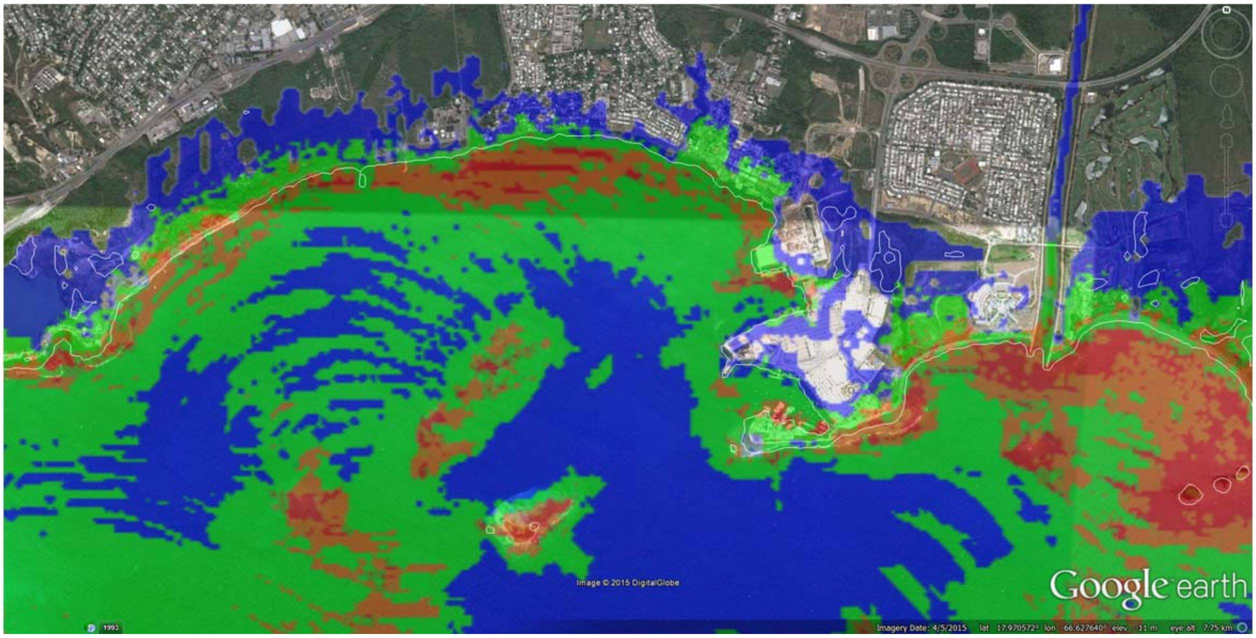
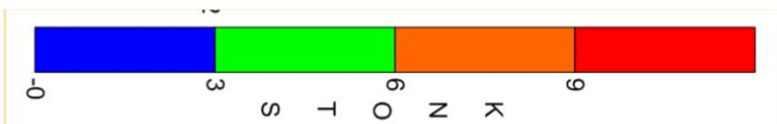


Figure 13 –Maximum speed. Local tsunamis. Ponce Bay.



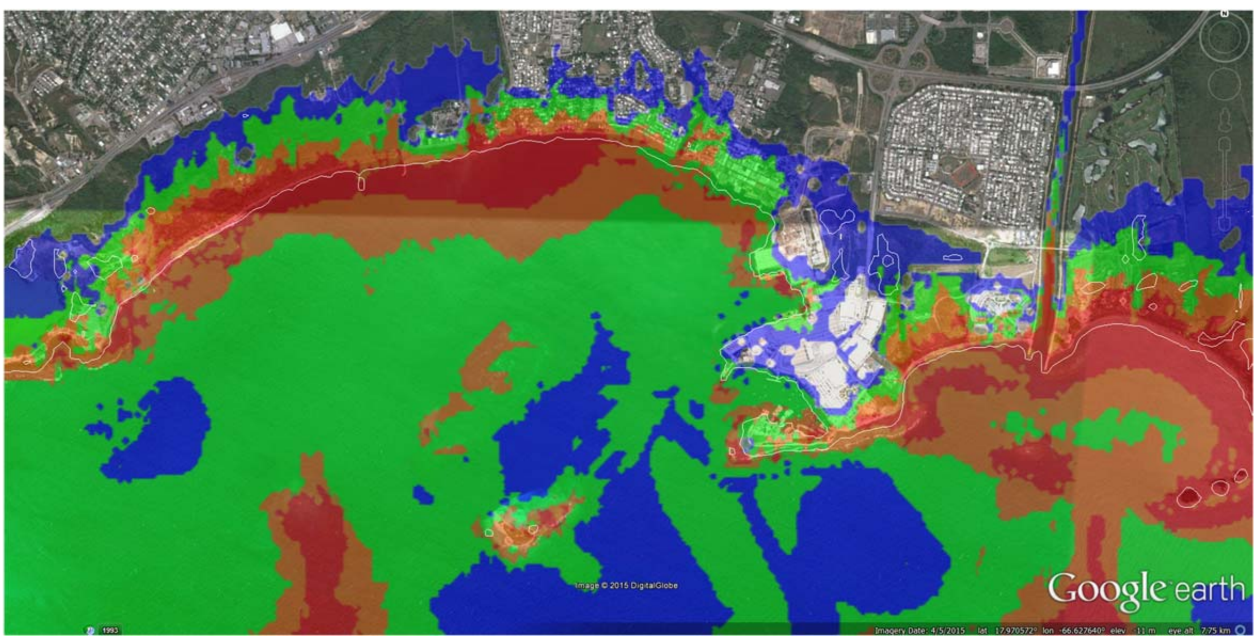


Figure 19 – Maximum speed. Regional tsunamis. Ponce Bay.

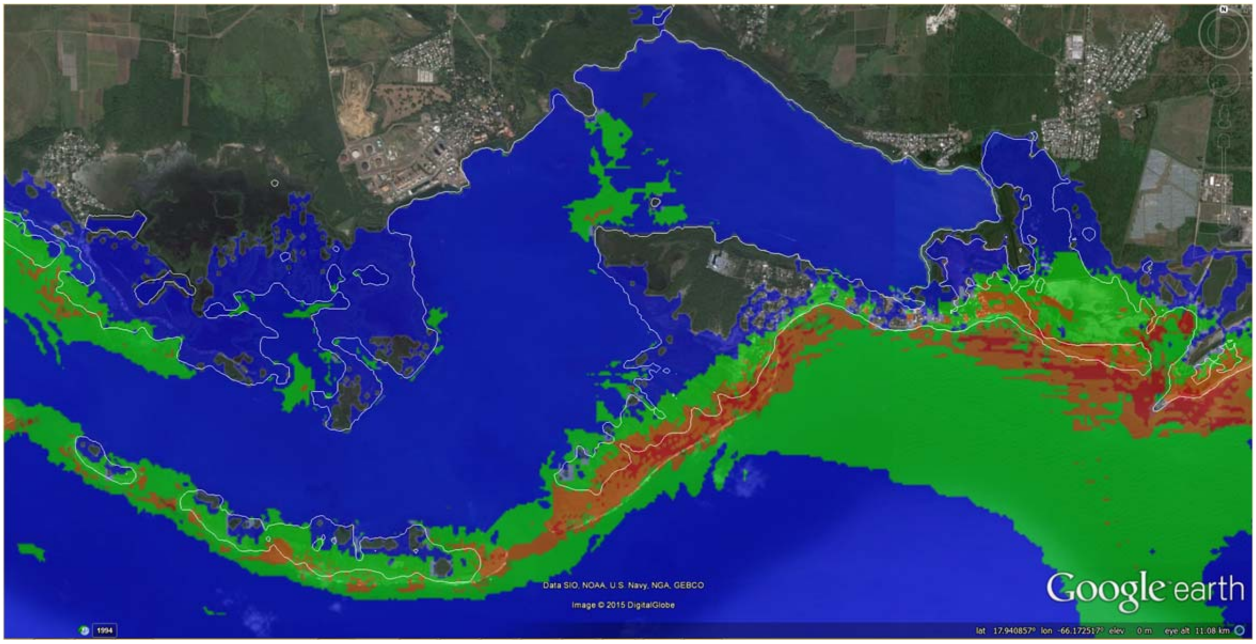
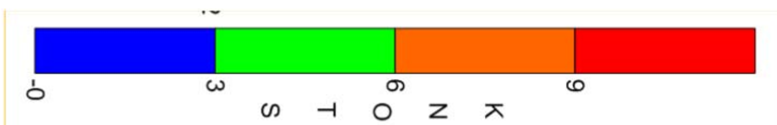


Figure 14 – Maximum speed. Local tsunamis. Jobos Bay, Aguirre.



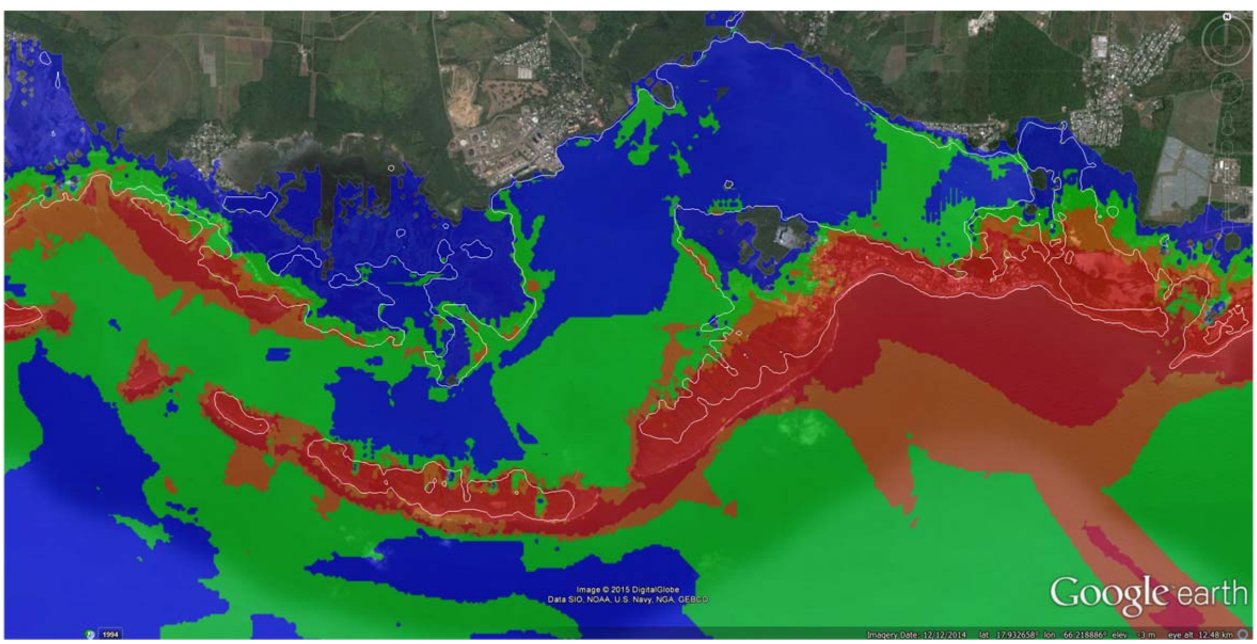


Figure 15 – Regional tsunamis. Jobos Bay, Aguirre.

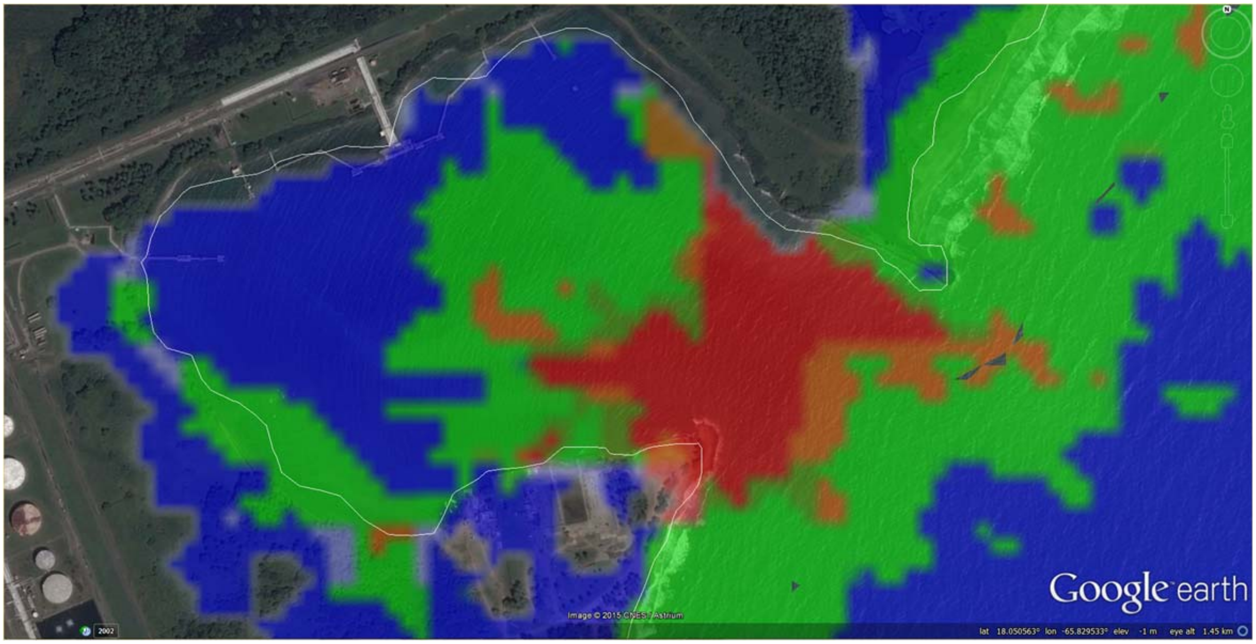
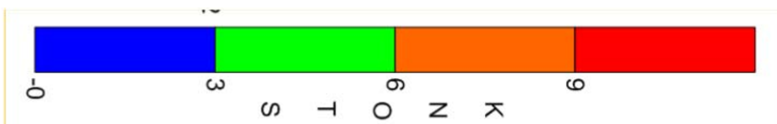


Figure 16 – Maximum speed. Local tsunamis. Yabucoa Bay.



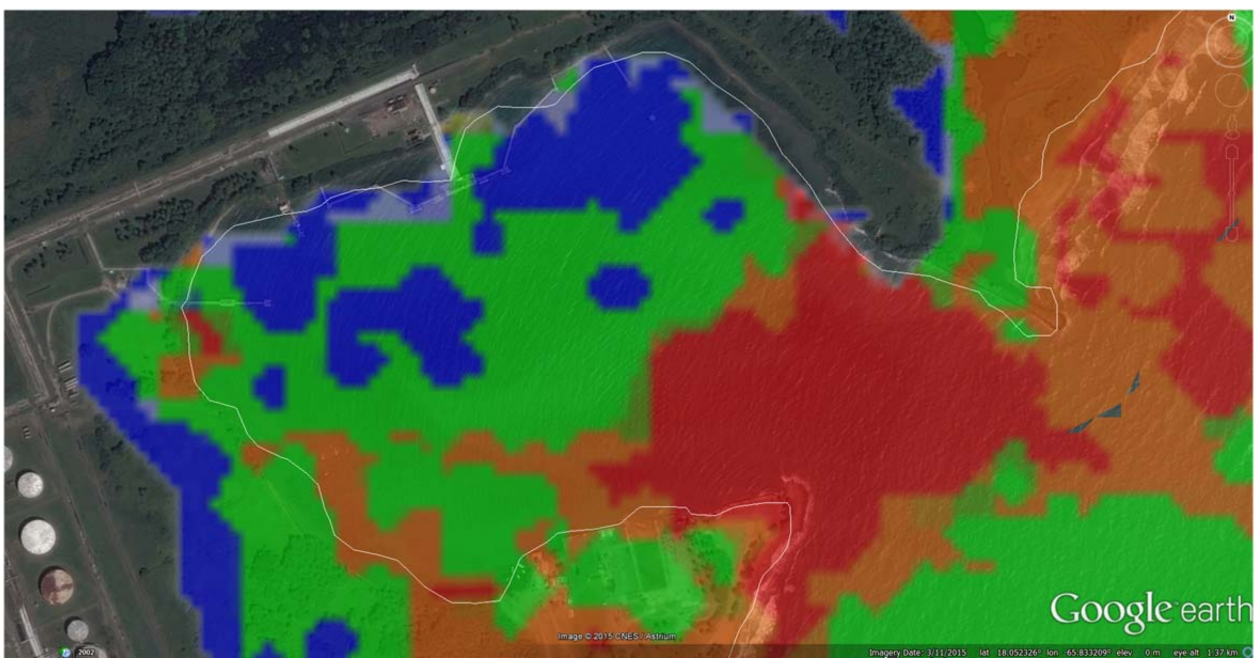


Figure 17 – Regional tsunamis. Yabucoa Bay.

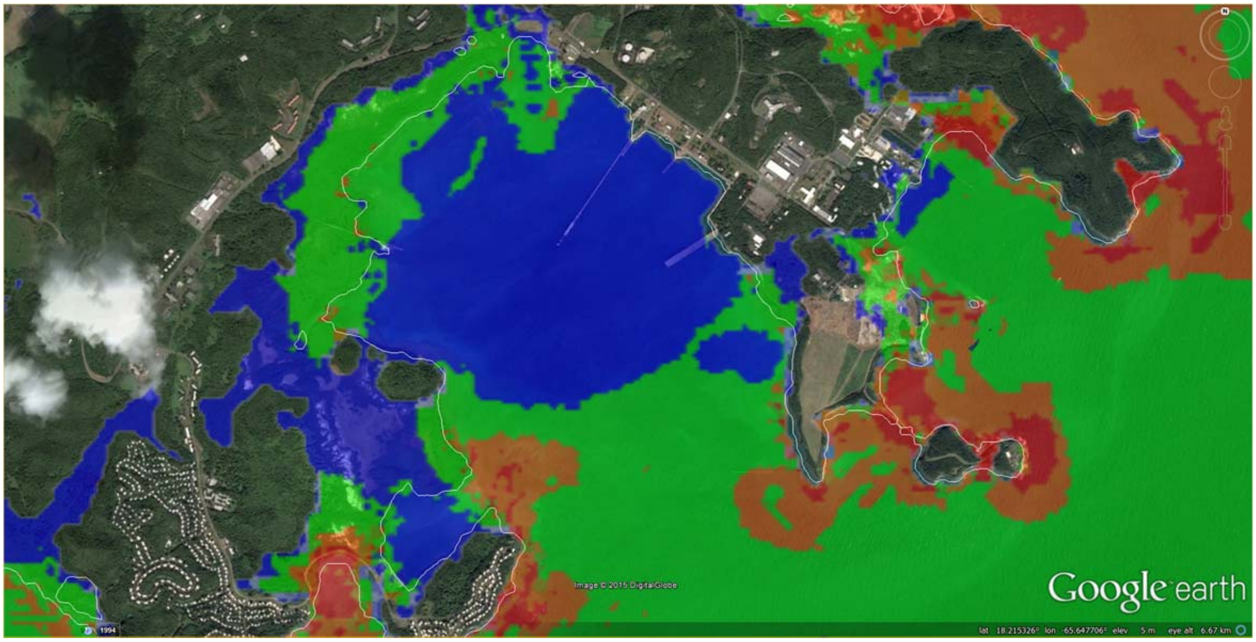


Figure 18 – Maximum speed. Local tsunamis. Roosevelt Roads, Ceiba.

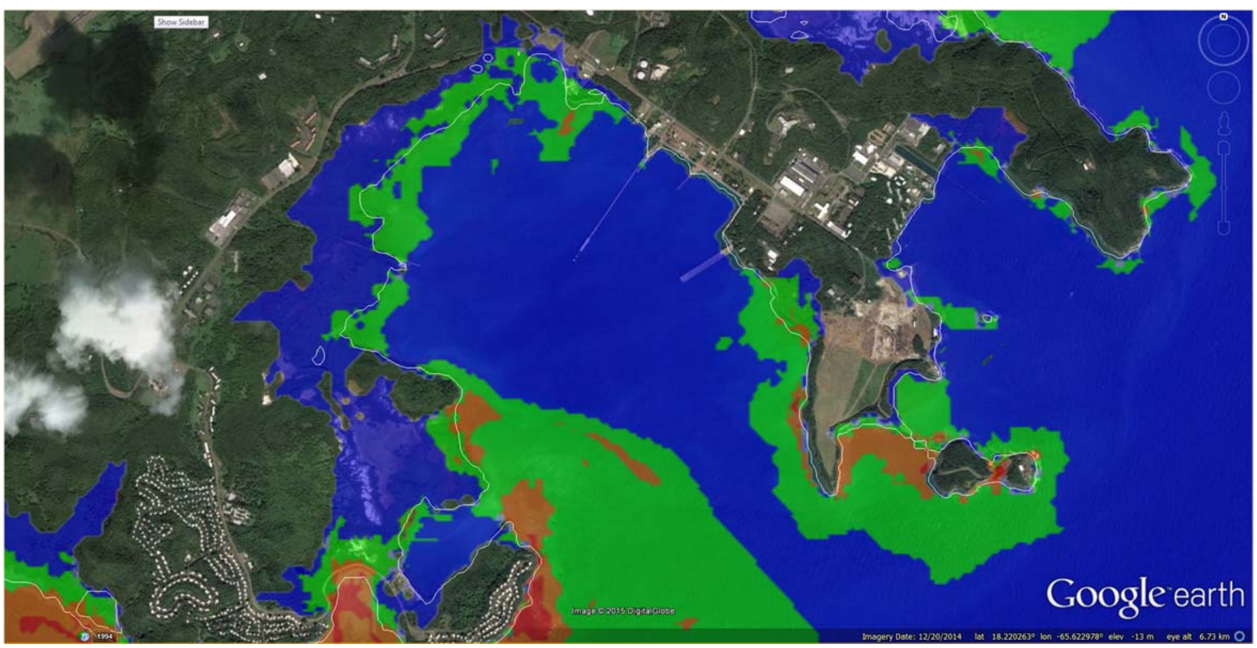


Figure 19 – Regional tsunamis. Roosevelt Roads, Ceiba.

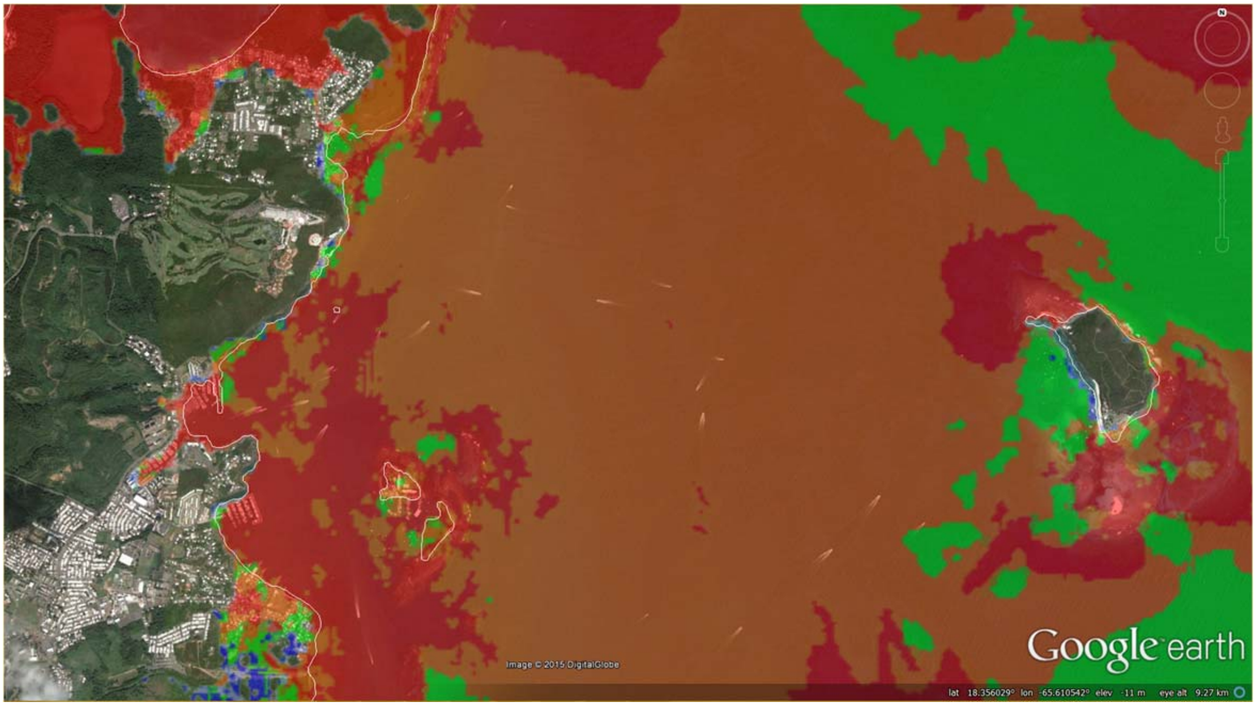


Figure 20 – Maximum speed. Local tsunamis. Fajardo.

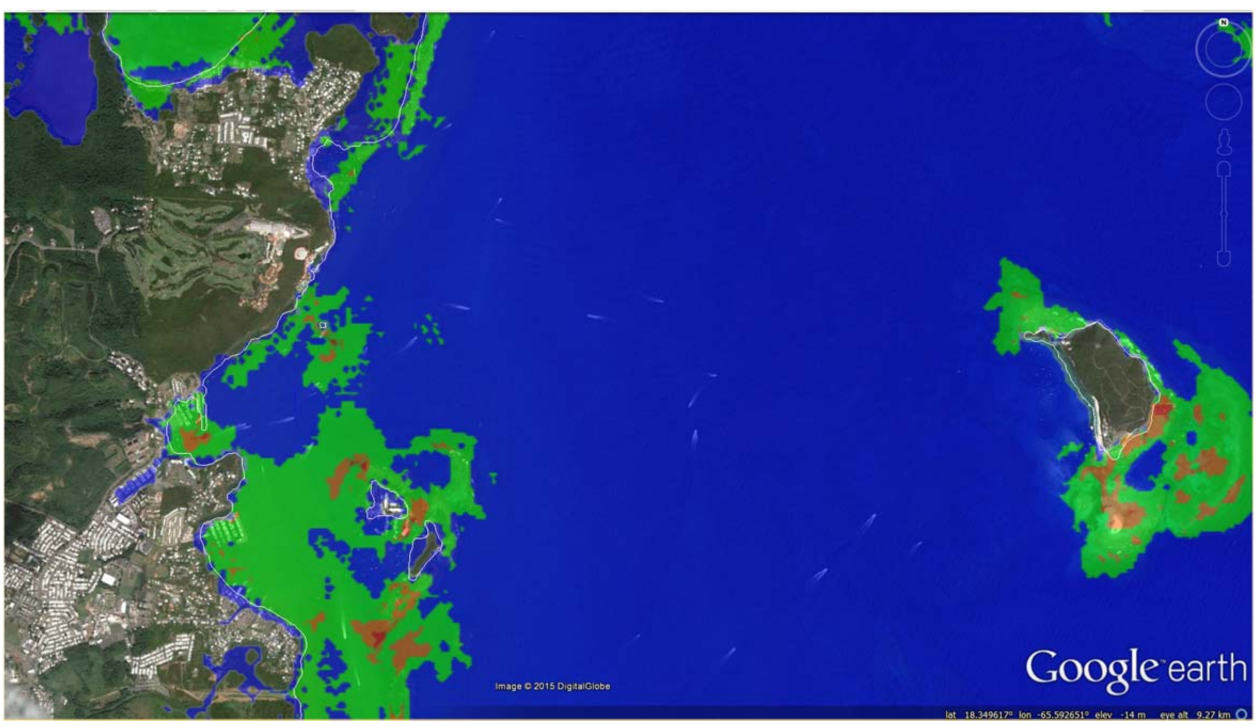


Figure 21 – Maximum speed. Regional tsunamis. Fajardo.

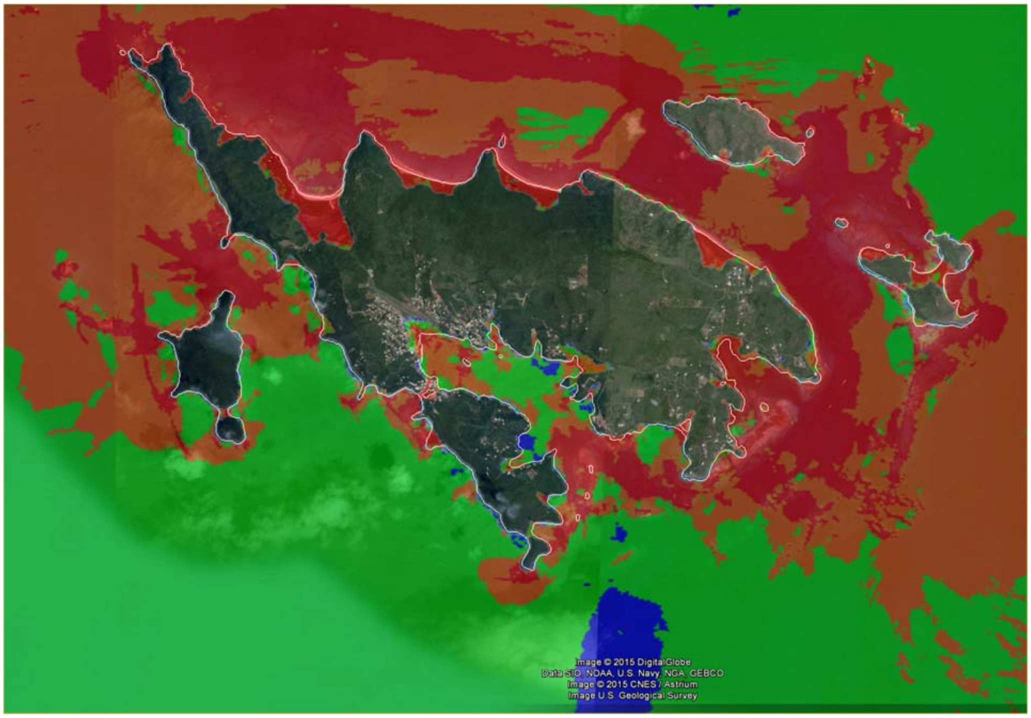


Figure 22 – Maximum speed. Local tsunamis. Culebra Island.

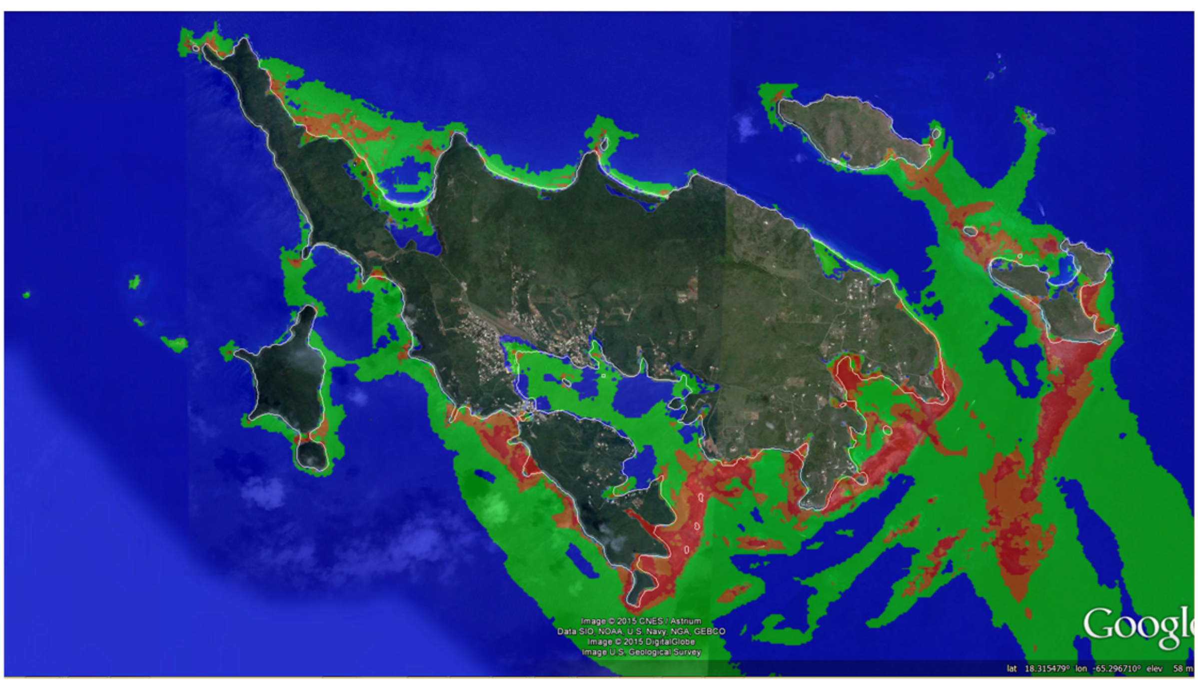


Figure 29 – Maximum speed. Regional tsunamis. Culebra Island.

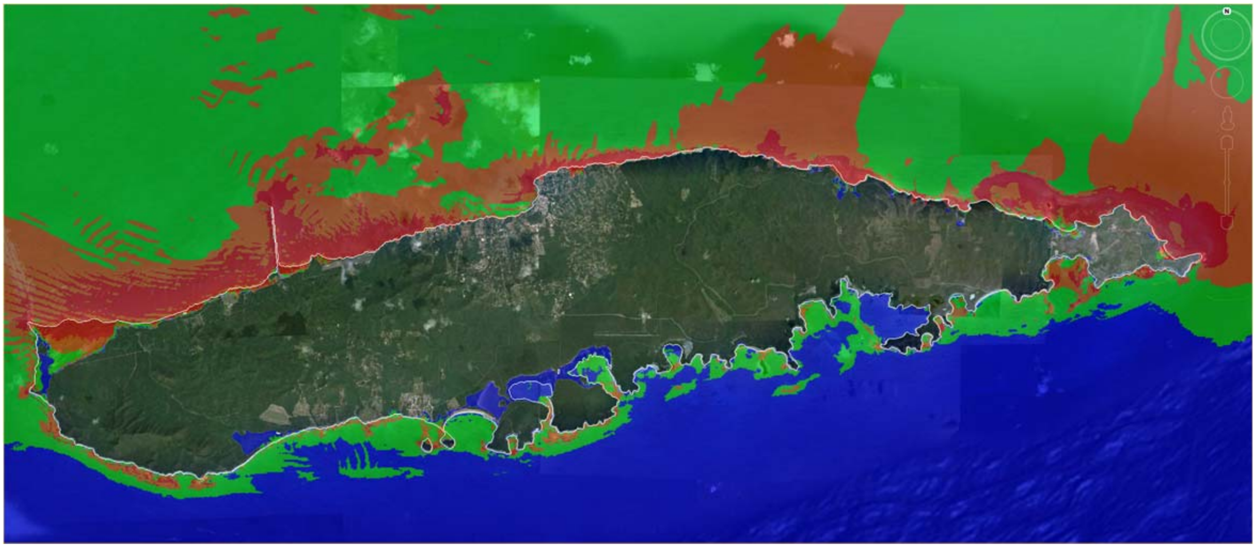
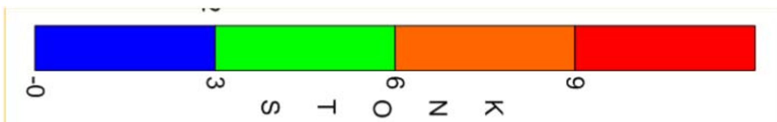


Figure 23 – Maximum speed. Local tsunamis. Vieques Island.



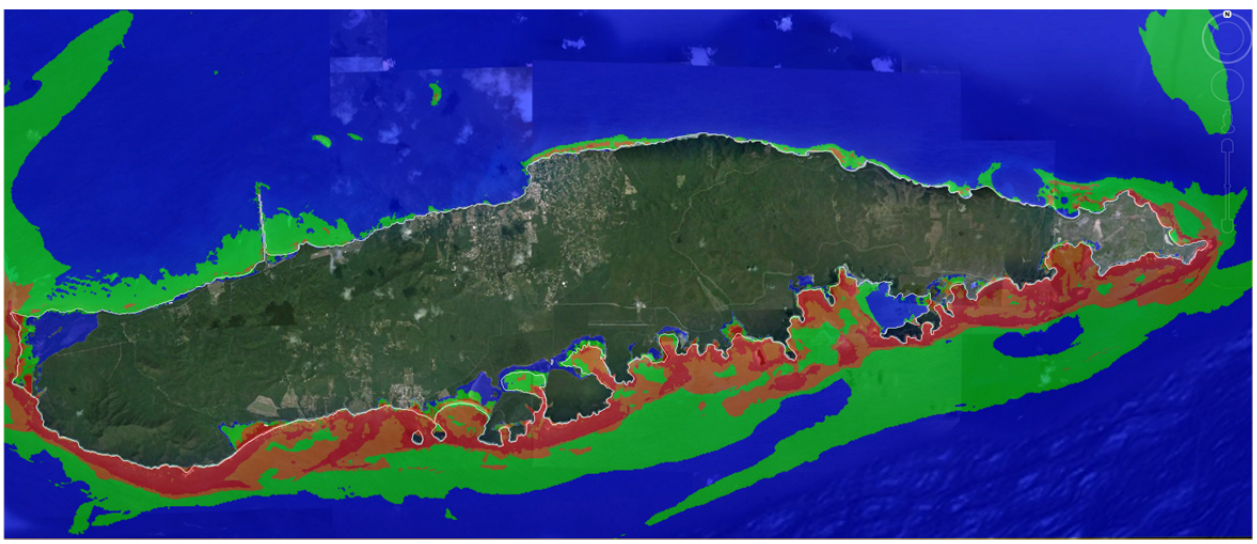


Figure 24 – Maximum speed. Regional tsunamis. Vieques Island.