THE EFFECT OF MANGROVES ON STORM SURGE FLOODING

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ABSTRACT

By analysis of numerical simulations validated with abundant field measurements, we show that the 6-30 km wide mangrove forest along the Gulf coast of South Florida effectively attenuated storm surges from a category 3 hurricane, Wilma, and protected the inland wetland by reducing an inundation area of 1,700 km2. The average surge amplitude decay rates are about 40-50 cm/km across dense mangrove forests and about 20 cm/km for areas with a mixture of mangrove islands with open water. The forest cannot fully attenuate storm surges from a category 5 hurricane with a forward speed of 2.2 m/s (5 mph) and reduced surges can still affect the wetland behind the mangrove zone.

1. INTRODUCTION

One of the ecological services provided by mangroves is to buffer the impacts of waves, storm surges, and tsunamis on coastal property and infrastructure by dissipating incoming wave energy. The role of mangroves in attenuating short-period wave energy has been well documented by theoretical analysis and field observations; however, conclusions regarding mangrove effects on long waves including storm surges and tsunamis are controversial [1]. There is a 200 km long mangrove belt with widths of 6-30 km along the Gulf coast of South Florida and the Florida Bay coast. The mangrove forest is comprised primarily of 4-18 high Rhizophora mangle, Laguncularia racemosa, and Avicennia germinans with varying abundance in space. Hurricane Wilma made landfall as a Category 3 at the mangrove coast of South Florida, providing an ideal case to examine the interaction between storm surges and the mangrove forest.

2. OBJECTIVE

The objective of this study was to examine the role of mangrove in reducing storm surge flooding by analysis of numerical simulations validated with abundant field measurements.

3. METHODS

High-quality digital elevation models from airborne light detection and ranging data and airborne height finder measurements allow numerical simulations of surge inundation over the nearly flat coastal area with mangroves. The coastal and estuarine storm tide model in a depth-integrated, 2D form was employed to simulate Wilma's surge [1]. The model grid with about 110,000 cells extends from 78.7°W to 83.4°W in longitude and from 24.2°N to 27.2°N in latitude with resolutions ranging from 700×850 m along the coast to 1,300×1,600 m in the open ocean. The following assumptions were made to approximate the first-order effect of mangroves on storm surges: (1) effect of trees on surface wind is incorporated into the simulation by adjusting wind speed based on the ratio of the water depth to the tree height, (2) drag force to water flow induced by mangroves is estimated by adding the drag coefficient into the Manning's bottom friction coefficient, (3) tidal components are ignored due to a small tide range of 0.3-0.6 m in the study area, and (4) the effect of small tidal creeks on overall surge propagation pattern is negligible.

4. RESULTS

Comparison of computed and observed storm surges shows that the simulations well reproduced observed surge heights and inundation [1]. The simulation incorporating the effects of land cover (including mangroves) produces a 2,500 km2 inundation area within the mangrove zone, while the simulation excluding the effects of land cover by setting Manning coefficients inside the mangrove zone as 0.02 (i.e., bare ground) and tree heights for wind field computation as zero generates an additional 1,700 km2 inundation area within and behind the mangrove zone (Fig. 1). These results indicate a substantial reduction of surge inundation across the mangrove zone during Wilma. Without mangroves, surge amplitudes decay gradually in an almost linear fashion with rates of 6-10 cm/km, while with mangroves, surge amplitudes decay with much large rates. The surge amplitude decay rate across the areas with a mixture of mangrove islands with open water is relatively low with a value of 20 cm/km because the Manning coefficient is reduced due to numerous open water areas in the Ten Thousand Island area. The decay rates range from 40 to 50 cm/km across the mangrove forest where there are few open water areas. These rates are almost one order of magnitude higher than a previous estimate for the same location [2]; however, they are still much lower than the short-period wave decay rate of 200 cm/km [3]. Numerical experiments also show that storm surges from a category 5 hurricane with a slow forward speed of 2.2 m/s (5 mph) cannot be fully attenuated and can affect the wetland behind the mangrove zone.

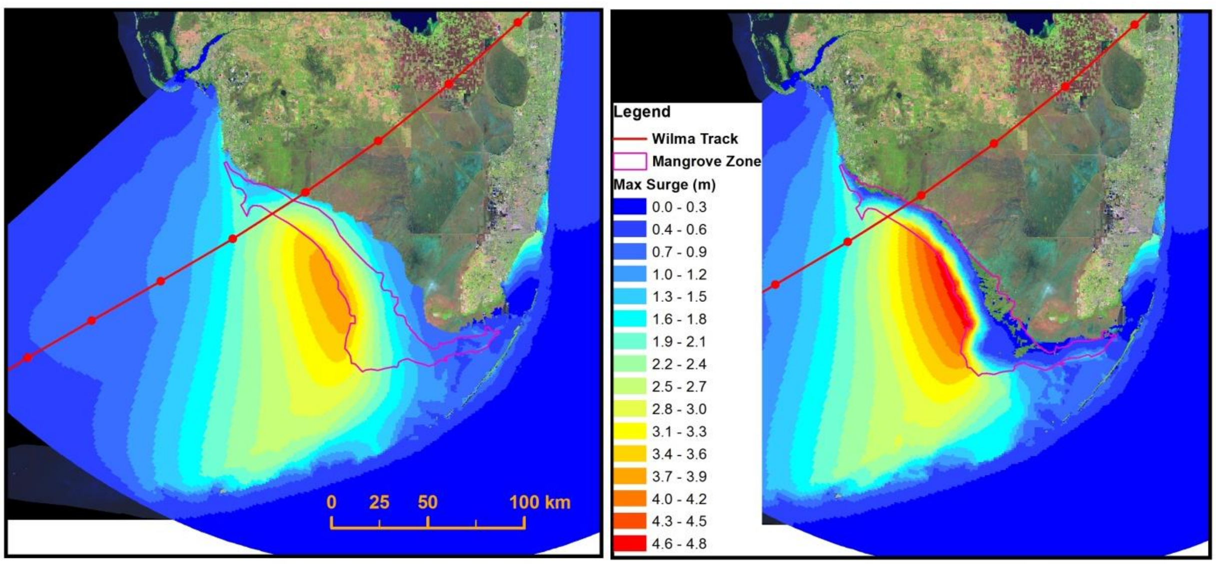

Fig. 1. Computed peak surge heights above NAVD88 using observed HWind and constant Manning coefficients of 0.02 (left), and using HWind and Manning coefficients based on the 2001 national land cover dataset (right).

5. CONCLUSIONS

The inundation area by Wilma would extend more than 70% further inland without the mangrove zone, causing severe inundation of the wetlands behind the mangrove zone. The amplitude of storm surges at the front of the mangrove zone increase by 10%-30% because of the "blockage" of mangroves to surge water, while the amplitudes decay across mangroves at rates of 20-50 cm/km. Without the mangrove zone, surge amplitudes would decrease gradually landward in almost a linear fashion with rates of 6-10 cm/km.

6. ACKNOWLEDGEMENTS
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7. REFERENCES

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