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The long-term assessment of storm surge impact on Viti Levu Island, Fiji

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Introduction

Projection of storm surges and related inundation in the Pacific Islands is important for impact assessment and adaptation of coastal regions. The compounding effects of storm surges and sea level rise (SLR) are among the main hazards of flooding and extreme events [1]. The Oceanian region is dominated by island nations, which mostly rely on primary economic sectors, such as agriculture and fishery [2], and thus are particularly vulnerable to the rising sea levels.

The study focuses on Viti Levu, the biggest and most populous island in Fiji, estimating storm surge-induced impact due to climate change. In order to assess the impact, the simplified storm surge model with minimum dynamics is developed.

Methodology

Data is integrated in the Shuttle Radar Topography Mission (SRTM), Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG), General Bathymetric Chart of the Oceans (GEBCO) and Socioeconomic Data and Applications Center (SEDAC) Numerical modelling uses a non-linear shallow water equation (SWE) in the spherical coordinate system to model the interaction of storm surge and the island landmass.

Numerical SWE model test and application

The model for both ideal and actual bathymetry is based on the governing equation (1).

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\theta}\left[\frac{\partial P}{\partial \phi} + \frac{\partial \cos(\theta Q)}{\partial \theta}\right] = -\frac{\partial h}{\partial t},$$

$$\frac{\partial P}{\partial t} + \frac{gh}{R\cos\theta}\frac{\partial \eta}{\partial \phi} = -fQ - \frac{D}{\rho_w}\frac{\partial \rho_0}{\partial x} + \frac{\tau_{sx}-\tau_{bx}}{\rho_w},$$

$$\frac{\partial Q}{\partial t} + \frac{gh}{R}\frac{\partial \eta}{\partial \theta} = -fP - \frac{D}{\rho_w}\frac{\partial \rho_0}{\partial y} + \frac{\tau_{sy}-\tau_{by}}{\rho_w}$$

(1) SWE formula used for storm surge numerical modelling.

Here, P is the momentum flux in longitudinal direction, Q moment flux in latitudinal direction, θ and ϕ latitude and longitude, h water depth, R radius of the Earth, f Coriolis force (Ωsinθ), τ_s wind stress, and τ_b bottom stress. The x and y components of the stresses are represented by τ_{*x} and τ_{*y} respectively.

Assuming a 2D Gaussian with land idealized bathymetry in an idealized test case with an open boundary condition, the highest storm surge is observed in cases with wind blowing from the Western side. (Fig. 1).

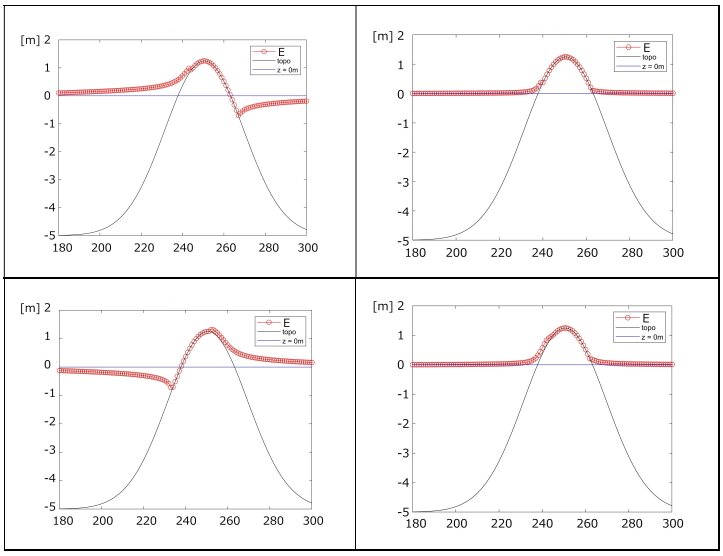

Figure 1. Storm surge heights on idealized bathymetry when U_{10} is 40 m/s and the wind direction (0°-270°) is from the a)West b)North c)East d)South

Simulated impact on an actual island

Numerical simulation predicts the storm surge as high as 1.5 m around Nadi and Lautoka, when U_{10} is 40 m/s and the wind is stable (Fig. 2)

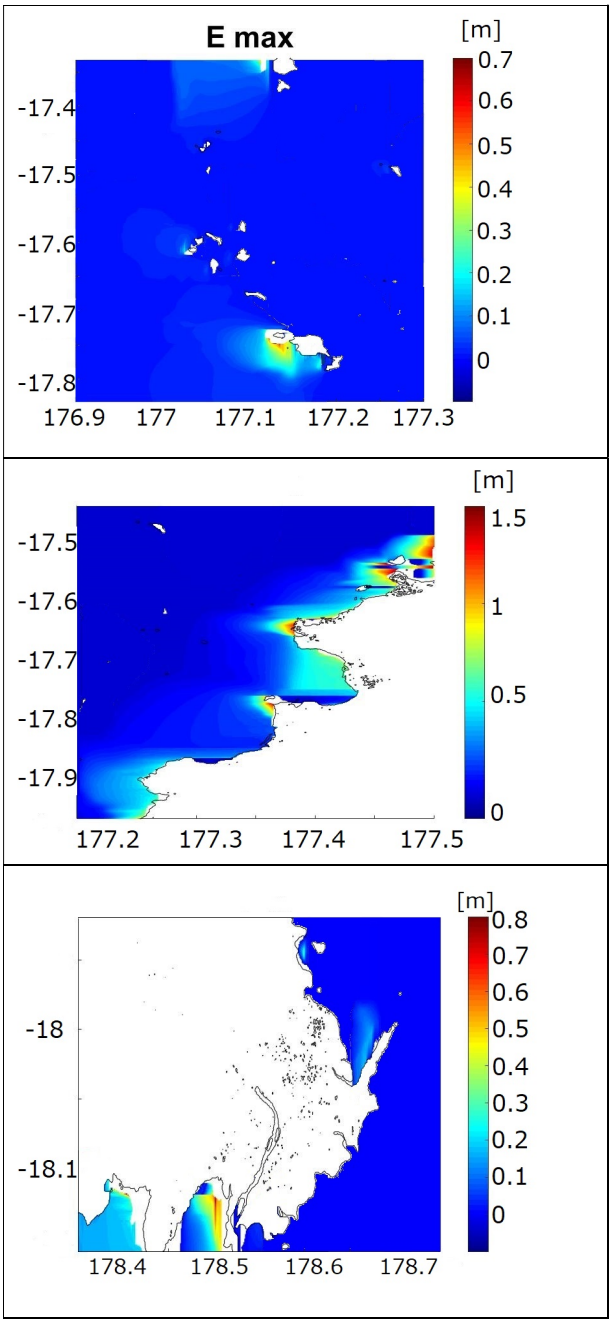

Figure 2. Storm surge in a)Mamanuca islands b) Nadi and Lautoka c) Suva area, with the optimal wind direction.

Population density in Fiji

Even though the population in Fiji is relatively sparse (48.4 inhabitants/sq. km^2) [3], many coastal areas exceed the average density more than two times (Fig. 3), thus exacerbating the storm surge impact.

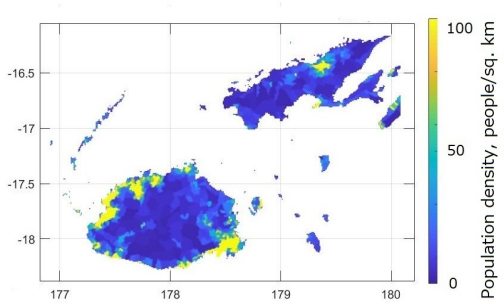

Figure 3. Population density in two main islands of Fiji.

Conclusions

The results that remain largely incomplete at this stage in Viti Levu case show that a number of coastal areas, including the populous Suva, Nadi, and Lautoka, are under threat of the rising sea levels aggravating by the storm surge phenomenon. In the case of Lautoka the storm surge reaching 1.5 m is estimated when U_{10} is 40 m/s. Other observed areas, namely the Eastern coast of Suva and Malolo (Mamanuca Islands) anticipate storm surges up to 0.8 m under the same conditions. The areas where the hazards of storm surge exceed 0.5 m harbours more than 40,000 permanent inhabitants. Other than providing home for the inhabitants these areas frequently serve as economic hubs of the country.

A more detailed study is needed to estimate the exact vulnerable locations, as well as the scope of the population to be potentially displaced by rising sea levels.

References

[1] Little, C.M. et al., "Joint projections of US East Coast sea level and storm surge," *Nature Climate Change,* vol. 5, pp. 1114-1120, 2015.

[2] "Pacific Strategic Plan For Agricultural and Fisheries Statistics," Pacific Community, Suva, Fiji, 2017.

[3] "Fiji Population & Housing Census," Fiji Bureau of Statistics, Suva, Fiji, 2018.