Tropical Cyclone Storm Tides in Nadi Bay, Fiji

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SUMMARY FOR POLICYMAKERS

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Key Findings

- Currently rare tropical cyclone (TC) storm tide events will become more frequent in the future. For instance, storm tide heights of approximately 2 metres, currently associated with a 1-in-100 year event are projected to become more like a 1-in-50 year event by 2055 in the Nadi area. 1-in-100 year storm tide heights are estimated to be approximately 30 cm higher in 2055.

- These projected changes are linked primarily with sea level rise (SLR). Future changes in TC intensity and frequency in the Fiji region are unlikely to significantly change storm tide risks relative to SLR for 1-in-50 and 1-in-100 year events. High-resolution modelling of historical storm tides (TCs Mick and Evan) indicates water levels may differ by 30 cm or more along coastal distances as little as 5 km.

- Shallow embayments such as Nadi Bay and Vitogo Bay (north of the Lautoka tide gauge) appear much more susceptible to higher storm tide heights. Importantly, this means that storm tides observed at the Lautoka tide gauge may not be a good proxy for storm tide levels within Nadi Bay.

- The lack of available high-resolution bathymetry and coastal topography leads to low confidence in quantitative estimates of differences in storm tides risks at scales below approximately 5 km.

Background

The Government of Australia through its Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program is assisting Pacific island countries better understand and respond to climate change impacts, particularly in relation to infrastructure, coastal zone management and cross-sectoral planning.

In Fiji, PACCSAP is providing support to a World Bank-funded project to undertake detailed floodplain modelling of the Nadi floodplain, in order to inform flood risk mitigation measures for the township. This project aims to provide new information on coastal sea levels along the Nadi coastline during tropical cyclones (TCs) that can provide useful background information for the floodplain modelling.

Severe storms such as TCs can generate not only severe rainfall leading to riverine flooding, but also temporary increases in coastal water levels through storm surges. Combined with other variations due to tides and natural climate variability, the total coastal water level experienced during a storm is often referred to as a storm tide (Figure 1-foreground). These water levels may be still further elevated near shore due to the effects of breaking waves, all of which can cause coastal inundation. Storm tides also slow the rate at which rivers can drain leading to backwater effects and enhanced upstream flooding (Figure 1-background).

Sea levels can also vary on seasonal or interannual time scales due to changes in atmospheric wind and pressure and ocean heat and currents that can vary on these time scales. In Fiji, sea levels are, on average, about three centimetres lower during El Niño and three centimetres higher during La Niña.

Climate change may affect coastal flooding in a number of ways. Warming of the atmosphere and oceans will cause sea level rise (SLR) due to a combination of the melting of icesheets and glaciers and the thermal expansion of the oceans. This warming may also cause severe storms to become more intense, leading to heavier rainfall and stronger winds. Heavier rainfall may worsen riverine flooding while stronger winds may increase coastal water levels due to storm surge and waves.

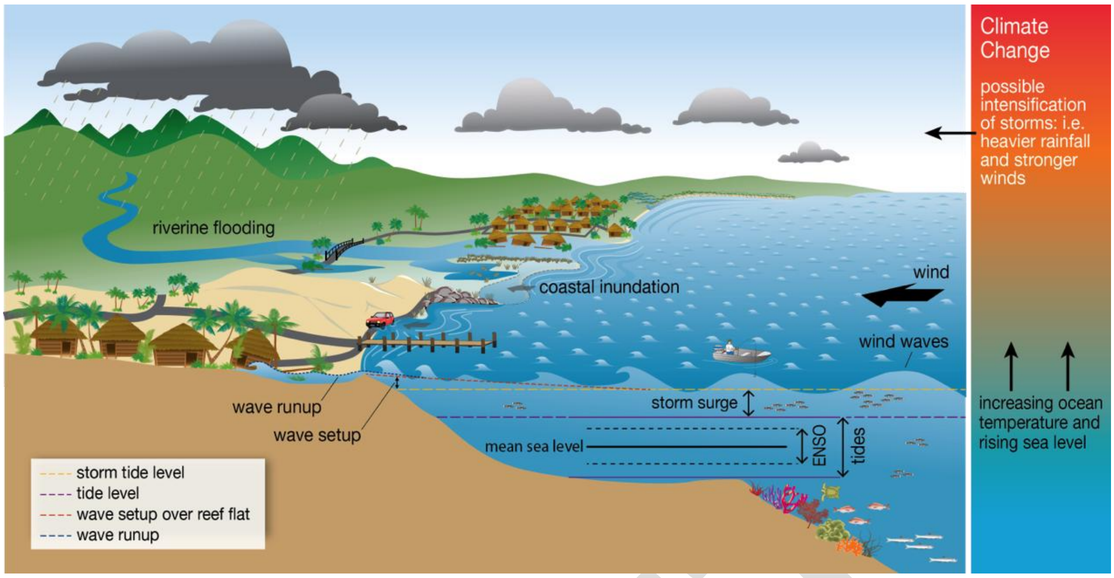

Figure 1 - Foreground: the different processes that vary sea levels on daily, fortnightly and longer time scales due to tides and interannual variability such as ENSO. During storms, wind and falling pressure elevate sea levels to produce a storm surge, while wind-waves breaking at the shore further elevate sea levels due to wave setup and wave runup. Background: elevated coastal sea levels can reduce river drainage and backed up water can worsen upstream flooding. Right panel: Climate change may impact coastal flooding in the future through rising sea levels and possible intensification of storm systems which may increase storm surge height and rainfall during storms.

Resent research suggests that climate change may lead to a decrease in the overall frequency of TCs (i.e. fewer TCs, on average, per season) but an increase in the mean intensity of TCs in the south Pacific (see Walsh et al. [2012] for a review). For instance, in Fiji, the intensity TC winds are projected to increase by 10% while TC frequency is projected to decrease by 25%, although there is still considerable uncertainty around these changes (McInnes et al. 2014). In addition, SLR in Fiji is projected to be in the range of 0.1 m and 0.3 m by 2055 and 0.16 m to 0.62 m by 2090. Both the range of possible SLR and the uncertainty around changes in TC intensity and frequency are largely due to the uncertainty in the amount of greenhouse gases that will be emitted in the future and also because of uncertainty around how the Earth will respond to these greenhouse gases as a system.

Research Methodology

Both present and future TC-related storm tide risk levels were assessed for the entire Fiji archipelago. Both the projected SLR and TC intensity and frequency changes were considered, as well as changes in seasonal and interannual sea level associated with El Niño/Southern Oscillation (ENSO). These storm tide risks can, in part, be understood through return interval (RI) statistics. A 100-year RI storm tide is the maximum water level (due to any combination of storm surge, tides and sea level variability) expected to occur (in the statistical sense) once in 100 years. These RIs are plotted in Figure 2 for Lautoka and Nadi: at both locations the 100-year RI storm tide level is approximately 2.0 m under current (baseline scenario) conditions. At the upper range of projected SLR in 2055, the 100-year RI storm tide level is approximately 2.3 m and the 50-year RI is approximately 2.0. Thus, under the upper range of SLR scenarios, the current 1-in-100 year event becomes approximately the 1-in-50 year event, indicating roughly a doubling in the frequency of current 1-in-100 year events. When the effect of future changes in TC intensity and frequency are considered along with SLR, the projected increase in TC intensity (%10) cause long RI events (>100 year) to be even more extreme, while the decrease in frequency (25%) tends to reduce the storm tide heights with RI<50 years. SLR however, tends to cancel out any reductions in storm tide heights this decrease in frequency would otherwise cause (see Figure 2). More details of this analysis are reported in McInnes et al. (2014).

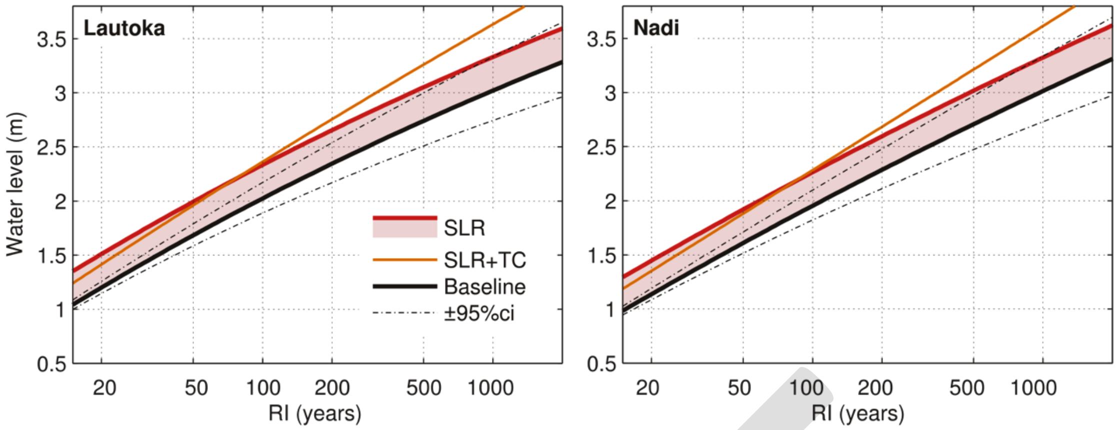

Figure 2 - Return period (RI) curves for Lautoka and Nadi for current (baseline) conditions (black line), the upper range of future SLR (year 2055) conditions (red lines) and the combination of future SLR and projected changes in TC intensity and frequency (orange lines). The shaded band represents the projected range of possible SLR for 2055. 95% confidence intervals for the baseline scenario are also indicated with dashed lines.

The above present and future TC-related storm tide assessment used both statistical and hydrodynamic modelling techniques. The hydrodynamic model incorporated the entire Fijian archipelago at a spatial resolution of 1 km. Such a resolution cannot be expected to resolve small-scale coastal differences in storm tide along the west coast of Viti Levu, e.g. between the mouth of the Nadi River, Nadi Bay and the site of the Lautoka tide gauge. To investigate such small-scale differences in storm tides, a high-resolution hydrodynamic model (the 'Nadi model') was implemented and storm tides associated with two recent TCs (Mick in 2009 and Evan in 2012) were simulated with both the lower-resolution Archipelago model and the Nadi Model. TC Mick crossed the coast near Lautoka from the northwest, whereas TC Evan tracked along a path approximately perpendicular to TC Mick offshore of the west coast of Fiji (Figure 3). The Archipelago model provided currents, sea levels, surface winds and sea-level pressure to the boundaries of the Nadi model.

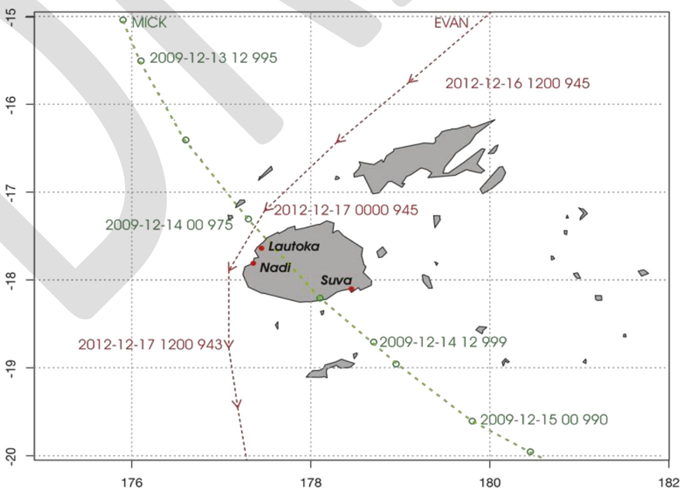

Figure 3 - Best track data for cyclone Mick (source: IBTrACS) and Evan (source: Australian Bureau of Meteorology).

Results and Discussion

Maximum water levels (storm tide heights) simulated by both the Archipelago model and Nadi model differ from those observed at the Lautoka tide gauge by less than 7 cm, indicating excellent overall agreement between the two models and the tide gauge. Larger differences between simulated and observed water levels (up to 30 cm) occur in the lead up to the storm tide peak in both Evan and Mick. These differences are likely due to the wind fields used to force the hydrodynamic models, which does not resolve the influences of local terrain (e.g. hills) on wind speed and direction. This likely has little effect on maximum storm tide heights at most locations, since maximum storm tide heights should occur during onshore winds, which would be much less affected by coastal terrain.

Simulated maximum storm tide heights from both the Archipelago model and the Nadi model were in the range of 0.92 to 1.41 m for both TCs Mick and Evan. These levels are close to the 20-year RI storm tides at these locations (Figure 2). For the Archipelago simulations, the maximum water levels were higher at Lautoka than at Nadi for both TC Mick and TC Evan. However the Nadi model results show much more variation in storm tide heights associated with coastal morphology (Figure 4). For instance, the maximum water levels for TC Mick were significantly lower at the mouth of the Nadi River than at the Lautoka tide gauge. During TC Evan, however, the difference in maximum water levels between these two locations was much less pronounced. These differences are partially related to the tracks of the two cyclones. TC Mick crossed to the north of Lautoka on a relatively shore-normal track, meaning that winds remained largely offshore particularly south of Lautoka. This led to lower wind setup in the Nadi area relative to Lautoka. TC Evan, with its more shore-parallel track, caused onshore winds along the entire western side of Viti Levu, leading to generally more consistent storm tide levels along the coast (evident in the Nadi model results).

In both of the historical cases, though, small geographical features also lead to localized 'hotspots' in storm tide heights. The Nadi model simulations produce differences in storm tides heights of up to 30 cm between Nadi Bay and the mouth of the Nadi River, and similar differences between the location of the Lautoka tide gauge and other locations along the coastline. In the two historical TCs simulated, shallow embayments such as Nadi Bay and Vitogo Bay (north of the Lautoka tide gauge) appeared to be much more susceptible to higher storm tide heights.

This is an important indication that storm tide levels in Nadi Bay and elsewhere along the western coast of Viti Levu cannot be assumed to be the same as those at the Lautoka tide gauge for a given cyclone event. This is because (1) the track, forward speed and radius of winds of the TC's leads to local variations in the timing and magnitude of storm surge along the coast and (2) local bathymetry and topography interact with the TC's wind field, changing both the wind field itself (topographic effects) and coastal currents (bathymetric effects) which redistributes wind setup along the coast. This second reason highlights the importance of small scale features such as peninsulas, islets and reefs to local inundation risk.

The sensitivity of the Nadi model to small scale coastal features leads to an important caveat. Since very little high-resolution bathymetry and topography was available, values used in the Nadi model were interpolated from low-resolution bathymetry data. This lowers confidence in the quantitative details of the simulated stormtides along the coast.

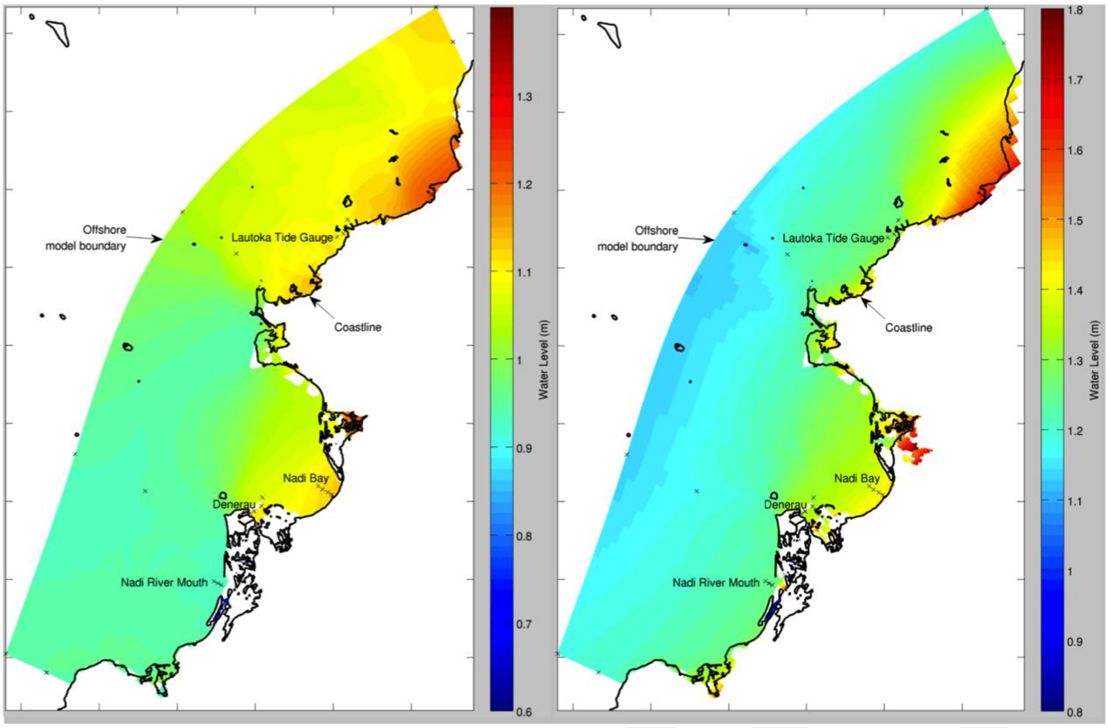

Figure 4 – Maximum storm tide heights simulated by the Nadi model, for Cyclone Mick (left) and Cyclone Evan (right). Note the colour scale of the two plots is different.

Further stormtide risk analysis for the Nadi Bay region (or elsewhere in Fiji) should include effort to collate existing sources of bathymetry and topography, identify where such data is absent or insufficient, and prioritise efforts to collect data in missing areas. Such data would allow higher resolution wind fields models which can take into account the influence of topographic effects and also enable the modelling of waves, which can further increase coastal sea levels. Validation of storm tide heights at locations other than the Lautoka tide gauge would also greatly improve model accuracy. This could be implemented with a relatively low-cost network of pressure sensors. The accuracy of both coastal and terrestrial (fluvial) inundation risk is predicated by the quality of underlying geophysical data. Investment in the collection of topographic and bathymetric datasets and physical observations (e.g. water levels, waves, winds and precipitation) provides greater confidence in the findings of risk assessments and the design of adaptation responses.

References

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