

DPRI-VMGD joint survey
for Cyclone Pam damages

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1. Survey Overview

1.1. Purpose

This survey was conducted for the purpose to archive Cyclone Pam-induced damages to buildings as well as inundations along the coastlines, which is to be facilitated to understand wind-resistant performance of the buildings as well as vulnerability of its coastal areas, whereby identifying effective ways to improve the resilience of the built environment to future cyclones.

1.2. Items to survey

- Wind induced damages to buildings
- Qualitative assessment of distributions on wind speed
- Parameters related to wind-resistant performance
- Wave induced damages to buildings and natural environment
- Inundation heights
- Inundation areas
- Erosion of coasts

1.3. Survey areas

- Efate island
- Tanna island

1.4. Survey members

The survey was conducted jointly by Disaster Prevention Research Institute (DPRI), Kyoto University, and Vanuatu Meteorology and Geo-Hazards Department (VMGD). The members are listed up in Table 1.

Table 1. Survey members.

Name	Affiliation and expertise
Kazuyoshi Nishijima	Disaster Prevention Research Institute, Kyoto University, wind engineering
Nobuhito Mori	Disaster Prevention Research Institute, Kyoto University, coastal engineering
Tomohiro Yasuda	Disaster Prevention Research Institute, Kyoto University, coastal engineering
Tomoya Shimura	Researcher, Disaster Prevention Research Institute, Kyoto University, coastal climate modeling
Jerry Timothy Gogon	Vanuatu Meteorology and Geo-Hazards Department, forecasts

1.5. Survey itinerary

The survey was conducted between April 21 and 30, 2015. The itinerary is shown in Table 2 and the areas of the survey are shown in Figure 1.

Table 2. Itinerary.

Date	Activities
April 21	Depart Osaka, Japan, for Port Vila, Vanuatu, via Tokyo and Auckland.
April 22	Arrive at Port Vila. Briefing meeting with Mr. Gogon and JICA local staffs.
April 23	Visit to Vanuatu Meteorology and Geo-Hazards Department. Visit to Ministry of Climate Change and Natural Disaster. Survey in Port Vila and east coast of Efate Island (Eton, Epao, Onesua).
April 24	Visit to Ministry of Land. Visit to Public Works Department of Vanuatu. [Team Wind] Survey of buildings in Port Vila and south to east coast of Efate Island (Eton, Epao, Ekipe). [Team Coast] Survey in west to north coast of Efate Island (Pango road, Black sand, Takara (Baofatu), Ekipe).
April 25	Move to the Tanna Island. Survey in west coast of Tanna Island (Green point, Isangel, Kwataparen, Lenava).
April 26	Survey in east coast of Tanna island (Loutapunga, Waisisi, Natanu, Port Resolution).
April 27	[Team Wind] Survey in west coast and middle of Tanna Island (Lenakel, Yakel, Green Hill). [Team Coast] Survey in east coast of Tanna Island (Louniel, Epikel, Waisisi).
April 28	Survey in Green hill. Move to Efate Island.
April 29	Move to Auckland.
April 30	Return to Osaka via Tokyo.

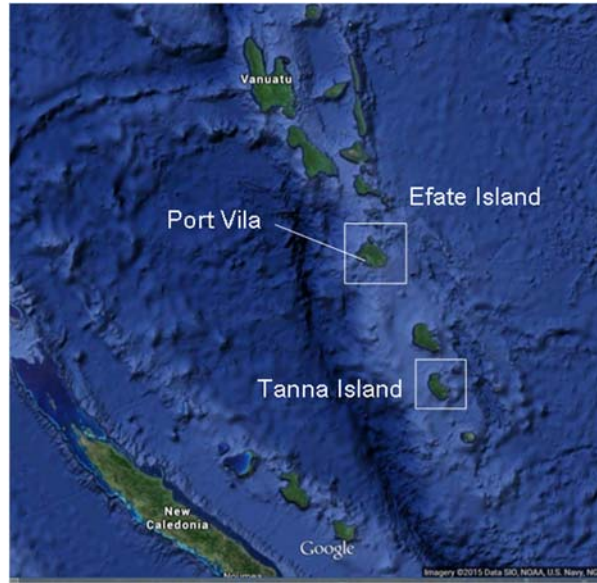


Figure 1. Areas of survey.



Figure 2. Locations of survey (left: Efate Island, right: Tanna Island).

2. Weather conditions

2.1. Weather conditions

According to report by VMGD (2015), the tropical low system was christened “Pam” at 600 km northeast at 6:00 pm on the 9th of March 2015. Pam intensified into a CAT 4 at 11am, on 12 March 2015, and it became a CAT 5 system at 11am, on 13 March. Pam approached to 45 km east of Port Vila at the midnight on Friday, 13 March 2015. Pam moved to southwards, and then it passed 20 km west of Tanna at 8am on 14 March 2015

(see Figure 3). At 9am, on 11 March 2015, the first warning on Severe Tropical Cyclone Pam was issued for the Northern provinces as the system was 425 km northeast of Gaua. The Tropical Cyclone Warning Centre started to issue hourly warnings, from an original three hours of warnings at midday, on Friday, 13 March 2015.

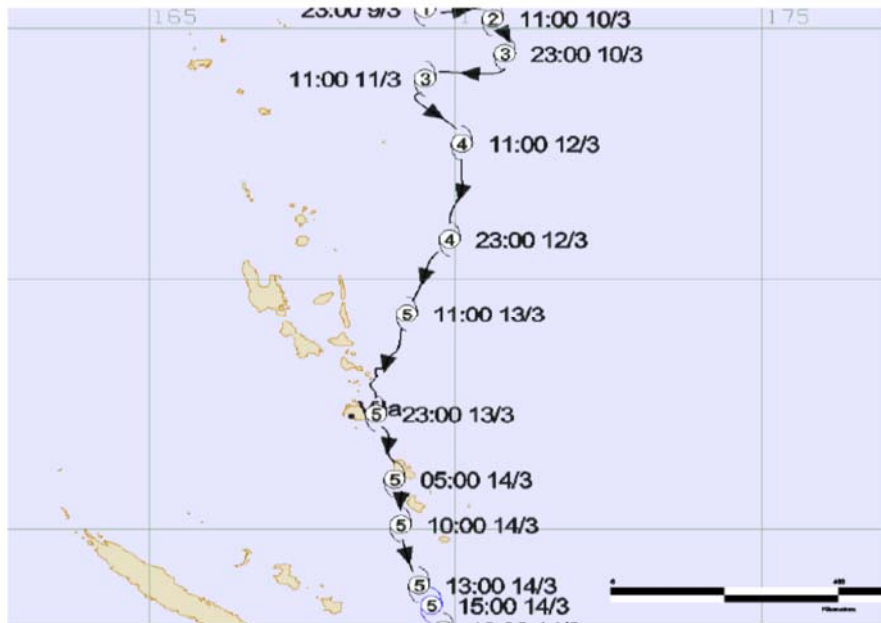


Figure 3. Track of TC Pam (VMGD, 2015).

Observed minimum central pressure was 986 hPa by satellite and 919 hPa by the ground station at Tanna airport. There is few available weather stations observed wind speed, atmospheric pressure and precipitation in Vanuatu. Therefore, it is important to use analysis data. Figure 4 shows maximum wind speed at 10 m height, U_{10} , by CFSR analysis. It is expected that CFSR wind underestimates because it uses 20 km resolution horizontally and it is too coarse to describe detail of topographic effects in the islands. Beside the accuracy of analysis data, the maximum U_{10} exceeds 40 m/s around Efate island. The measured maximum wind speed at the Tanna airport was 120 or 200 kt/h (62 or 103 m/s) at 10pm on 13 March and the instrument was broken after that.

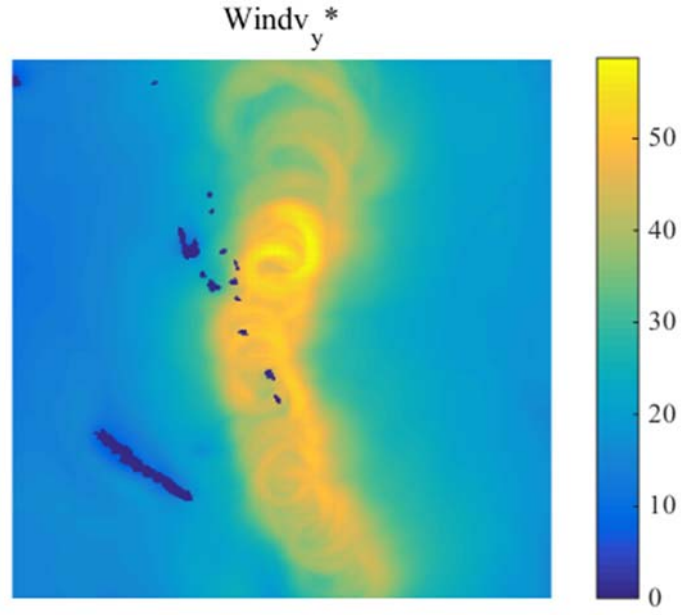


Figure 4. Maximum wind speed at height of 10 m by CFSR analysis.

2.2. Ocean conditions

There are two tidal gauges in Vanuatu. The measured storm surge height at Port Vila was 0.6 m and was mainly due to pressure surge because of less wind surge effects by bathymetry around Port Vila. The estimation of wave field was conducted spectral wave model; SWAN model version 40.91 was used to simulate wave spectral evolution. A series of numerical experiments was performed to understand the characteristics of extreme wave condition for this event before conducting the post-event field survey. The source terms were given by the standard setup for S_{in} as Janssen's linear growth, DIA for nonlinear wave interactions and S_{ds} as Komen's dissipation, respectively.

Forcing of SWAN was the wind speed at 10 m height, U_{10} , atmospheric reanalysis data by CFSR by NOAA. The bathymetry was given by GEBCO 2014 Grid (a global 30 arc-second grid) with spatial linear interpolation. Three domains nesting scheme was applied from 0.50 degree (about 56 km) to 0.009 degree (about 1 km), horizontally. Storm surges were not considered in this analysis. The pressure surge was mainly occurred due to steep volcanic bathymetry in Vanuatu and it can be estimated by the atmospheric pressure.

Figure 5 shows the maximum significant wave height of domain 1 and 3. The estimated wave heights around Efate and Tanna were 10–15 m and 10–18 m, respectively. Although the estimated wave height is sensitive to track of Pam, the gradient of wave height along the coast is significant especially at Tanna island. It is expected that the severe wave effects can be expected at East coast of Tanna. The shading effect by Erromango was strong the similar effects can be found behind of small islands around

Tanna island. Based on SPC report, the simple empirical model suggest that wave higher than 10 m occurred between Efate and Tanna and waves as height as 16 m may have reached Erromango. The estimated extreme wave height of 100 years return period was 7.5 m in this area before Pam. The simulated wave heights by Pam reached twice as that estimation.

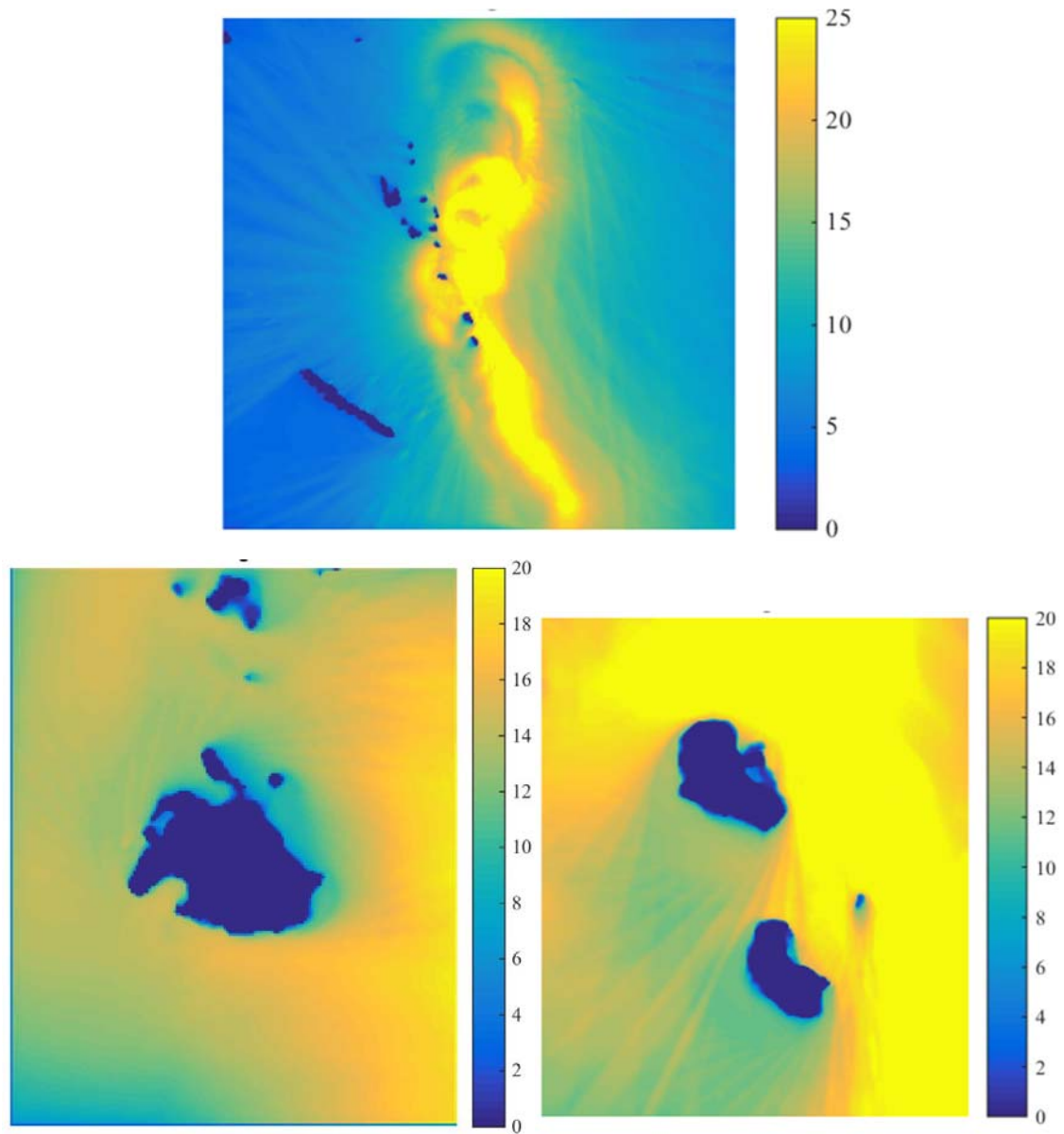


Figure 5. Maximum significant wave height (unit: m). Top: Largest domain (D1), Bottom left: Efate island (D3), Bottom right: Tanna island (D3).

3. Reported damages summary

According to the document by UNOCHA, 166,600 people were affected and 11 people are dead by the Cyclone Pam, and 75,000 people in need of shelter. It also reports that Shefa and Tafea were the most affected provinces – Efate Island is located in Shefa and Tanna Island is located in Tafea. In Tanna Island 50 percent of shelters has been destroyed.

The following information sources provide overview on the impacts of Cyclone Pam:

The Pacific by OCHA:

<http://www.unocha.org/rop/>

Cyclone PAM portal by SPC:

<http://www.spc.int/cyclone-pam-response/>

Damage Assessment by UNITAR:

<http://www.unitar.org/unosat/>

4. Reporting of the survey

4.1. Wind-induced damages to buildings

4.1.1. Overview of wind damages to buildings

Damages to buildings in Efate and Tanna Islands are reported here for traditional buildings and modern buildings. Traditional buildings refer to buildings made of materials locally available such as woods, canes and leaves. Sometimes, nails and screws are used. On the other hand, modern buildings refer to non-traditional buildings, ranging from engineered structures such as reinforced concrete structures, over concrete block structures, and non-engineered structures made of timbers, galvanized iron sheets, etc.. Typical occupancy types of modern buildings are commercial, governmental, school and church. Those of traditional buildings are residential and cyclone shelters.

Most of the damages to RC structures seem limited to non-structural components such as envelopes and interiors. The building in Figure 6 is a commercial building located in Port Villa, Efate Island. As seen, the damages are limited to its envelop, part of which is believed damaged due to lack of shutters. Significant damages are also observed to interior such as ceilings and partitions. It should be noted that many commercial buildings in Port Vila are equipped with shutters, many of which seem undamaged.

Generally speaking, quality of construction work is good; however, several buildings with low quality construction were observed.

Collapses of concrete block structures were also observed. The totally collapsed building seen in Figure 7 is located in Tanna Island. The mortar joints seem relatively weak, and amount of rebar few and it lacks stiffness. It had been used as church and in the event of the Cyclone Pam several people in the village first evacuated to the church.

Significant deterioration of components were identified in many modern buildings that were damaged, see Figure 8. Steel connections are often rusted and un-treated timber products were deteriorated in those buildings.



Figure 6. Damages to envelop of commercial building in Efate Island.



Figure 7. Totally collapsed church in Green Hill in Tanna Island.



Figure 8. Deteriorated component of damaged school building.

Most of traditional houses had been destroyed or damaged, according to the testimonies of local people; however, many of them were already reconstructed when the survey was conducted. Typical houses are made of woods for columns, beams and roof structures; roofs are covered with dried leaves, grasses, wild canes and sometimes with support of bamboos. Simple industrial construction materials such as nails and screws and construction instruments such as chain saw are available in some cases. Figure 9 and Figure 10 show traditional houses under reconstruction in two villages in Efate Island.

The house in Figure 10 has the dimension of 3140 mm in width, 2720 mm in height and 5270 mm in depth. It has narrow eaves. The columns are made of Mango tree. The diameter of the columns is around 120 mm and the columns are casted into the soil by around 500 mm. The rafters are made of Oak tree. The diameter of the rafters is around 60 mm. The ridgepole is made of a kind of nut tree. These trees were cut in the forest nearby, brought to the site and cut with a chain saw. For the connections nails are used.



Figure 9. Traditional house under reconstruction at Eton, Efate Island.



Figure 10. Traditional house under reconstruction at Epao, Efate Island.

4.1.2. Traditional cyclone shelters

There are several testimonies that people in villages in Tanna Island evacuated to traditional cyclone shelters and those shelters did not fail during the cyclone. Figure 11 shows an example of the traditional cyclone shelter in Tanna Island and Figure 12 shows a traditional cyclone shelter that are being built after Cyclone Pam. Although the dimensions and details are diverse, there is a common characteristics in the traditional cyclone shelter. That is, the roof is extended to the ground. The shape seems empirically optimized to best resist against strong wind.

It is remarkable that people in those villages take the warning messages serious and evacuated to the traditional cyclone shelters, which are specially constructed for the purpose to protect human lives in the events of cyclones – and it worked.



Figure 11. Traditional cyclone shelter at Yakel in Tanna Island.



Figure 12. Newly constructed traditional cyclone shelter at Loutapunga in Tanna Island.

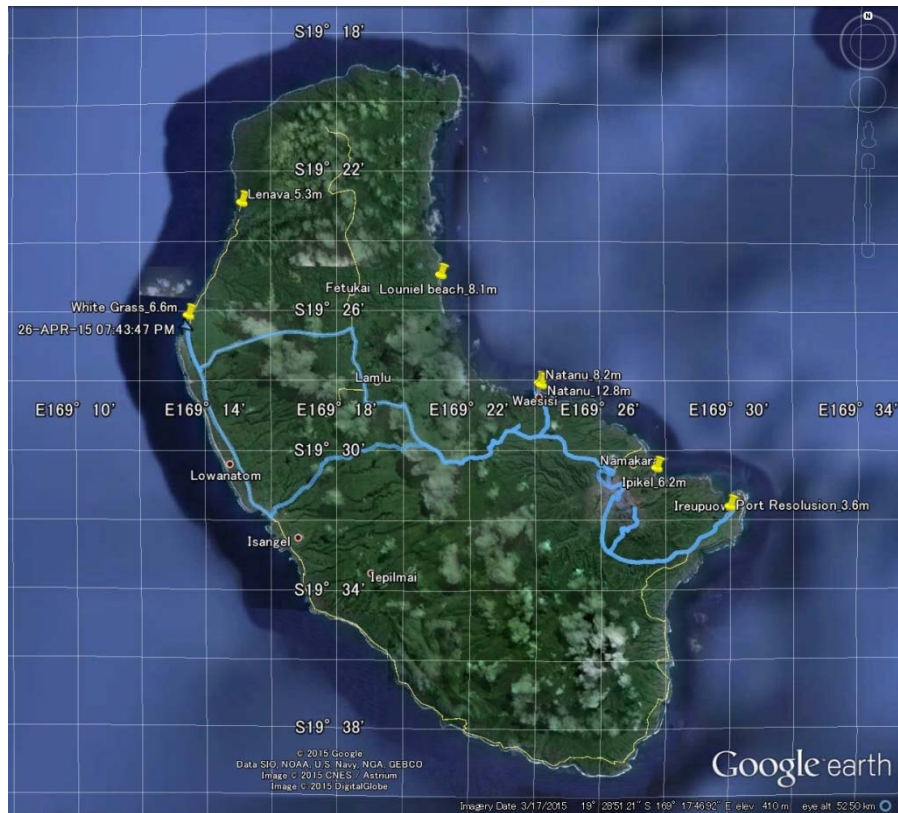
4.2. Coastal damages

4.2.1. Overview of run-up and inundation height

Wave run-up and inundation heights were measured according to interview to local residents by an auto-level and a laser range finder. The survey follows protocol of the post-tsunami survey field guide by IOC. Figure 13 displays the survey results in Efate Island and Tanna Island. In Efate Island, coastal inundation was mainly observed along the east coasts, e.g. Eton, Epao, and Onesua, and the maximum run-up heights were about 5 m from the mean sea level (MSL) excluding tidal effects. In Tanna Island, inundation heights were larger than that of Efate due to larger offshore wave height shown in Figure 4. Along northwest coast of Tanna where the distance is close to the cyclone eye, 5–6 m run-up above MSL was observed at Lanava and White Grass. On the other hand, in the northeast coast of the island, large inundation which is 8 m was observed where the fetch was the longest without shading effects of islands. Severe beach cliff erosion was observed at Louniel beach, which height was about 6 m as shown in Figure 14. Several ships made of FRP were flown and run-up at Natanu, Waisisi. Inundation heights gradually decrease to south in the east coast due to shading of peninsula. At Ipikel facing the Sulfur bay, inundation height was about 6 m, and at the Port Resolution run-up height becomes less than 4 m. SPC report summarized that the satellite image of the North East of Erromango shows major coastal erosion and inundation. We observed similar phenomena by extreme waves in Tanna Island visually.



(a) Efate Island.



(b) Tanna Island.

Figure 13. Measured run-up and inundation height from MWL (unit: m).

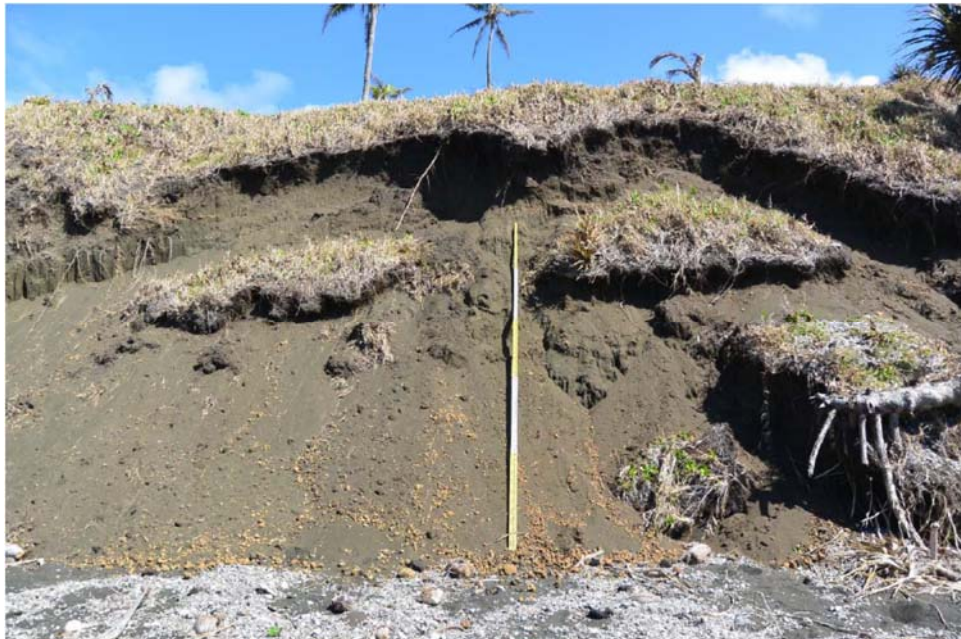


Figure 14. Sevier coastal cliff erosion at Louniel beach in Tanna Island.

4.2.2. Detail of specific damaged area

The long distance inundations were observed several locations. One example is Baofatu beach (Takara hot spring) at the northeast coast of Efate island. Figure 15 (a) shows aerial snapshot of observed coastal inundation by a drone. There are many boulders of coral rocks from the reef and concrete blocks from coastal walls until 100 m along the coast. The maximum distance of inundation is 300 m and it was remained more than 2 days according to witness evidence by local residence. The highest run-up of coastal flooding was observed at Waisisi village in southeast coast of Tanna Island (Figure 15 (c)). The maximum run-up height was about 12 m and propagated up to 300 m from the coast line. The severe coastal inundations are measured east coast of Tanna island that feature is matched with numerical hindcast shown in Figure 5.



(a) Baofatu (Takara hot spring) in Efate Island.



(b) Waisisi village in Tanna Island.

Figure 15. Snapshot of observed coastal wave inundation by drone.

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