Study of coastal flooding in Kupang, East Nusa Tenggara due to Tropical Cyclone Frances (case study April 27th – 30th 2017)

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Abstract. Storm tide is one of the major natural hazard that can be endangered property and residents around the coastal region. A storm tide flooding has been occurred in Kupang, East Nusa Tenggara (NTT) on April 28th 2017 during the appearance of Tropical Cyclone Frances. The aim of this paper is to evaluate the coastal flooding events due to cyclone in order to develop the mitigation strategies in case of similar events in the future. The data from cyclone, such as the track and phase, were shown to see the cyclone stage and its impact to the changes of the waters on the coast of NTT. Three-hourly numerical hindcast of significant wave height ($H_s$) and primary swell from Indonesian Agency for Meteorology Climatology and Geophysics (BMKG) were used to analyze the waters condition of NTT area. The hindcast was modelled using GrADS with a resolution of 0.125° x 0.125° which has been operationalized by BMKG. Meanwhile, the sea level anomaly from AVISO Satellite Altimetry Data was used to examine the variation of regional sea level variation during the flooding occurrence. From the processing of several data and the analysis, we get that the significant wave and the swell have reaches 6 m high in on the peak of the cyclone event with the sea level anomaly is 10 – 15 cm. Thus, we conclude that this event was occurring because of the swell assisted with the strong steady wind, where the energy could transported the waters up into the mainland.

1. Introduction

Tropical cyclone is a form of extreme weather disturbance that begins with a low pressure center over the ocean which triggers the convection process and intensive cloud formation [1]. Tropical cyclone develops in convective areas and has at least 34 knots maximum wind speed of the region circling the center and at least lasts for six hours over warm waters. There are three conditions of cyclone formation according to Tjasyono.et.al (1983), namely: (1) there is convergence in the lower layers of the atmosphere that strong enough to raise the moist air bar, (2) there is divergence in certain layers to move air from the underlying layer and make the air fell. (3) the presence of sufficient energy to maintain the circulation [2]. Energy is obtained from the surface of the warm sea water because it contains a lot of water vapor as a fuel for cloud formation.

Cyclones are influenced by the Corioli force determined by the latitude position. Generally, the formation of tropical cyclones is effective in latitudes above 10° of north latitude and south latitude [3]. Therefore, tropical cyclone will be difficult formed in Indonesia because corioli force close to zero in
equatorial region. Tropical cyclones can have an impact on the weather in the lane and surrounding areas. The territory of Indonesia which is geographically adjacent to the cyclone formation region will indirectly be affected. Cyclones can cause strong winds, heavy rains, rising average sea levels over a period of time, leading to flooding. Coastal flooding events may changing the coastline, harming the infrastructure, causing contamination of freshwater reserves, and in the worst cases can causing the death of human life [4].

On April 28th, 2017, there was a coastal flooding on Kolbano beach due to Cyclone Frances. Residents from the three affected villages namely Kotolin, Kolbano and Boking villages must be evacuated (Figure 1) [5]. According to news of the Okezone dated April 28th, 2017, the waves are high enough that the water could flood the settlements [6].

On this research, we show the documentation and analysis of the coastal flooding that occurred in Kolbano Beach, Kupang. We use data of waves and swell modeling data from BMKG, and oceanographic observation data by satellite altimetry from AVISO. The purpose of this research is to know the effect of cyclone Frances that occur in western waters of Australia and moves to the waters in East Nusa Tenggara region. It is important to know the process that lead the flooding in order to cope the impact that will occur, especially for the island and maritime nation.

2. Methodology
2.1. Study area
The authors use a descriptive analysis for this coastal flooding case study in East Nusa Tenggara, April 28th, 2017. The incident location is Kolbano Beach, Timor Tengah Regency, Kupang (shown by the red dot). The eastern coastal area of East Nusa Tenggara is the study areas of this research (Figure 2). This beach area of East Nusa Tenggara is facing Timor Sea that separates Indonesia from Australia. This beach will take place on April 26th 2017 until May 1st 2017.
Figure 2. Map of study area, the red dot shows the location of coastal flooding during April 28th 2017.

2.2. Track of Cyclone
Track data of Cyclone Frances is obtained through the website of Unisys Weather (http://weather.unisys.com/hurricane/s_indian/2017/index.php) released by Joint Typhoon Warning Center (JTWC). The data is presented every 12 hours symbolized by line path. Time usage is in Universal Time Coordinate (UTC). The category of cyclone based on Saffir-Simpson Hurricane Wind Scale is shown in (Table 1).

Table 1. Saffir-Simpson Hurricane Wind Scale [Unisys Weather. 2017].

| Type          | Category | Pressure (mb) | Winds (kt) | Winds (mph) | Line Color |
|---------------|----------|---------------|------------|-------------|-------------|
| Depression    | td       | -----         | < 34       | <39         | Green       |
| Tropical Storm| TS       | -----         | 34 - 63    | 39 - 73     | Yellow      |
| Hurricane     | 1        | > 980         | 64 - 82    | 74-95       | Red         |
| Hurricane     | 2        | 965 - 980     | 83 - 95    | 96 - 110    | Light Red   |
| Hurricane     | 3        | 945 - 965     | 96 - 112   | 111 - 130   | Magenta     |
| Hurricane     | 4        | 920 - 945     | 113 - 135  | 131 - 155   | Light Magenta |
| Hurricane     | 5        | < 920         | > 135      | >155        | White       |

The Saffir-Simpson Hurricane Wind Scale (hereafter will be called as Saffir-Simpson Scale) is a scale for hurricane based the potential for property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous, and require preventative measures [8].

2.3. Sea Level Anomaly
Along-track multi-mission altimeter satellite product for sea level anomaly (hereafter referred to as SLA) will be used to examine the variation of regional sea level variation during the flooding occurrence [9]. The data was taken from AVISO Satellite Altimetry Data (with resolution 1/4° x 1/4°) [10]. This satellite product is gridded sea level anomalies data which computed with respect to a twenty-year mean. The SLA displayed by Hovmöller diagram to show the spatial and time distribution of the anomaly in period of April 26th – May 1st 2017.
2.4. Wave, swell, and wind
Significant sea level ($H_s$) and primary swell will be used to know how the condition of the waters during the event. Data were obtained from BMKG from April 26th - May 1st, 2017 [11]. This data is the result of calculation because the observational data is not acquired at that location. In addition, we also used six-hourly wind speed and direction data to compare this to the wave direction. The numerical hindcast of $H_s$, primary swell, and the wind will be displayed with GrADS.

3. Result and Discussion
3.1. Tracking Analysis
Tropical Storm begins to grow on Northern Australia (Timor Sea close to Tiwi Island) on April 27th, 2017 and spread to the Southwest throughout the Timor Sea until finally dissipated on April 30th, 2017 in Northeast Australia. The propagation of the cyclone can be seen in Figure 3.

![Figure 3. The track of Tropical Cyclone Frances.](image)

Here is the life cycle stage of Cyclone Frances:

| Time       | Latitude | Longitude | Wind Speed (kt) | Status       |
|------------|----------|-----------|----------------|--------------|
| 04/27/00Z  | -9.60    | 130.20    | 35             | TROPICAL STORM|
| 04/27/12Z  | -10.90   | 128.40    | 45             | TROPICAL STORM|
| 04/28/00Z  | -11.60   | 126.30    | 55             | TROPICAL STORM|
| 04/28/12Z  | -12.10   | 125.00    | 70             | CYCLONE-1    |
| 04/29/00Z  | -12.80   | 123.80    | 70             | CYCLONE-1    |
| 04/29/12Z  | -13.60   | 122.90    | 60             | TROPICAL STORM|
| 04/30/00Z  | -13.40   | 122.10    | 35             | TROPICAL STORM|

The maximum speed of Cyclone Frances is 70 kt, so according to the Saffir-Simpson Scale, Cyclone Frances is included as Category 1 (Table 2). At this stage of cyclone, citizens, stockbreeding, and pets that flying or falling debris probably get hurted or killed. Some housing that it being built badly may have major damage, involving loss of the roof cover and disposal of patio coverings. Swimming pool hedge with aluminum material could be breakaged. Some roof top of the apartment buildings and shopping malls can be partially removed. Failure to unprotected windows will be common. Large branches of trees will snap and shallow rooted trees can be detached [12].
3.2. SLA Analysis
The condition of SLA in Kolbano Beach can be seen with Hovmöller Diagram (Figure 4). SLA height at the location of flooding events (inside yellow box) ranged between 10 - 15 cm. Based on diagram, the peak of SLA in the Kolbano Beach occured on April 26th, and gradually decreased. During the event, the anomaly is around 14.0 - 14.5 cm. The height of SLA of the location was relatively similair compared to the research that conducted in southern coast of Java, Bali, and West Nusa Tenggara that is <20 cm [13, 14].

![Hovmöller Diagram](image)

**Figure 4.** (a) Domain for Hovmöller Diagram, the red area is the main section (with 30 km width) (b) Hovmöller Diagram that shows the SLA from April 26th – May 1st 2017 (x axis shows the longitude, y axis is days, and color contour is the height of SLA in meter).

3.3. Wave and swell analysis
On April 26th 2017, a spin of the water begins to appear between the Saumlaki island and the Aru island with the highest wave height of about 2 - 2.5 m near the center of the seedling of the cell. On the next day, the cell moves closer to Australia and has grown further with a wave height of 4.0 meters around its center. Then, the cell of cyclone moves to the southwest throughout Timor Sea. The peak of the cyclone is on April 28th 2017, which Hs reaches 6 m high on the center (Figure 5). The propagation of the swell rather similar with Hs, which the height of swell reaches 6 m high on the center (Figure 6)

![Wave and swell analysis](image)

**Figure 5.** Spatial conditions of daily average of significant wave height (Hs) on April 26th – May 1st 2017. Waves are measured in meter.
Figure 6. Spatial conditions of daily average of primary swell on April 26th – May 1st 2017. Swell measured in meter.

Based on these pictures below, the circulation is already formed with speed 40 – 50 m/s and develops until it reaches more than 60 m/s on April 26th. The cyclone began to dissipate on April 30th.

Figure 7. Spatial conditions of wind direction and speed on April 26th – May 1st 2017.
The peak of the cyclone is on April 28th, 2017, where the peak of $H_1$ is as high as 2.0 - 2.5 m and 1.5 - 2.5 m for swell in the incident site. The propagation of $H_1$ and swell is relatively similar from April 26th to May 1st. The propagation of the cyclone moves from east to southwest. Reciprocally, the direction of the wind looks similar with the direction of $H_1$ and swell, which can be seen on Figure 7.

4. Conclusion

From the simulation of several data in this study, it shows that although the cyclones Frances in April 2017 did not generate a high anomaly along the eastern coast of East Nusa Tenggara on Kolbano Beach, which its surge high is < 20 cm, the coastal area remains susceptible to the coastal flooding. Sea level anomaly on the incident site reaches 10 – 15 cm with the highest significant wave and swell about 6 m. The condition of significant waves is influenced by swell and the wind.

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