Topographic change and sediment transport on Maeshima Tombolo tidal flat

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Abstract. For the management of the tidal flat environment and the preservation of several important functions of the tidal flat, the accurate topographic monitoring is indispensable. However, the appropriate measurement of the tidal flat topography is very difficult because water level changes every moment due to tidal oscillation, and the accountable time for the measurement is limited within several hours under low tide condition. In this study, topographic measurement of tidal flat using Unmanned Aerial Vehicle (UAV) was conducted 5 times over a year, and Digital Elevation Model (DEM) obtained by UAV photogrammetry (UAV-DEM) of the tidal flat was constructed in each measurement. The area of 400m in the land-island (L-I) direction and 100m in the west-east (W-E) direction was set on the developed UAV-DEM to analyze the short-term topographical changes (2 weeks including typhoon events, half year and year). By the influence of typhoon passing, sand on the tidal flat was transported from east to west obviously within typhoon event. However, after the topographic change due to the typhoon event, the sand moved opposite direction. By the estimation of the sand volume on the tidal flat using UAV-DEM, it was found that the change of the volume was quite small in one year. These results indicate that the sand volume on this tidal flat is mostly preserved although active sand transport occurs on the tidal flat.

1. Introduction
Tidal flat has several important functions, such as formation of fine biological environment, the water quality purification, and economic value creation [1], [2]. To manage the tidal flat environment, it is indispensable to carry out the accurate topographic measurement [3], [4], [5]. However, the topographic measurement on the tidal flat is difficult to conduct appropriately because water level changes from hour to hour by tidal condition, and the accountable time for the measurement is limited within two to three hours under low tide condition. On the other hand, case studies of UAV monitoring on coastal topography have been reported recently. Mancini et al. [6], Kuroiwa et al. [7], and Matsubayashi et al., [8] conducted topographic measurements by UAV in the beach area. They examined their UAV measurement accuracy and compared their accuracy with those of conventional methods. However, there are few examples of UAV topographic measurements on the tidal flats. Long et al. [9] showed that the tie points between photographs are smaller in white and relatively flat areas like tidal areas, making
it difficult to create a Digital Surface Model (DSM). To overcome this difficulty, Tabata et al. [10] utilized UAV to conduct short-time topographical measurements of a tidal flat. The UAV measurement result was compared with Real-Time Kinematic - Global Navigation Satellite System (RTK-GNSS) measurement result to verify the UAV measurement accuracy. The comparison demonstrated the possibility of topographical measurements during the low tide by UAV with a high accuracy within ± 5 cm of error. In this study, based on the outcomes by Tabata et al. [10], Digital Elevation Models by UAV (UAV-DEM) of the tidal flat were developed, and the short term topographic changes by about two weeks including typhoon event, half year and one year were investigated by UAV-DEMs.

2. Study area
The topographic measurement was conducted on a small tidal flat located at Nishio city, Aichi prefecture, Japan (figure 1). This tide flat appears between the offshore island (Maeshima) and the mainland at low tide. This tide flat forms a tombolo that connects the island to the mainland. Therefore, this tidal flat is called Maeshima Tombolo tidal flat. This tidal flat is famous as the place of shell gathering at low tide. Many people visit this tidal flat every year. However, local people, especially fishery persons, have been recognizing the changes in tidal flat topography and biological environment in recent years. It is hard to find the source of sediment supply to this tidal flat, such as big rivers, near this tidal flat. It means that it will be hard to restore the tidal flat environment once sediment on the tidal flat decreases and its topography changes, especially shrink, significantly.

3. Summary of topographic measurement
The topographic measurement was conducted five times from September 2017 to August 2018 (table 1) at low tide. Since a wide area of the tidal flat dries out at the lowest tide, the aerial photographs of the tidal flat were taken about one hour before and after the lowest tide time to survey the topography. During our monitoring period, Typhoon 18 in 2017, which is cited as “TY1718” (Talim), from 17th to 18th September 2017, TY1812 (Jongdari) from 18th to 19th July 2018 and TY1820 (Cimaron) from 23rd to 24th August 2018 passed near the research fields (figure 2). These atmospheric impacts resulted in the apparent topographic changes on this tidal flat. Network type RTK-GNSS survey was carried out simultaneously with aerial photographing by UAV to obtain the cross-sectional (East-West and Land-Island) profiles of the tidal flat (figure 3) and positional information (X,Y,Z) of Ground Control Points (GCPs) placed on the tidal flat. The results of RTK-GNSS survey were used to evaluate the accuracy of UAV-DEM.
Table 1. List of UAV measurements.

| Measurement | Date               | Period |
|-------------|--------------------|--------|
| Meas-1      | 5\textsuperscript{th}, September, 2017 | Prd-1  |
| Meas-2      | 20\textsuperscript{th}, September, 2017 | Prd-2  |
| Meas-3      | 3\textsuperscript{rd}, February, 2018   | Prd-3  |
| Meas-4      | 11\textsuperscript{th}, August, 2018    | Prd-4  |
| Meas-5      | 28\textsuperscript{th}, August, 2018    |        |

DJI Phantom 4 Pro was used to conduct the aerial photography in all measurements of this study. Because a manual operation of UAV photographing needs high manipulation skills and its operation has a high possibility to cause the unevenness of overlapping of UAV pictures [11], the automatic navigation system, DJI-GS-Pro, was used to perform aerial photographing appropriately in this study. An altitude
of UAV flight was demonstrated at 50m over the tidal flat, in order to obtain a high spatial resolution in a picture. The 50m flight could take a picture of the tidal flat surface of about 90m by 60m with using 5472×3648 pixels, and realized a spatial resolution of about 1.7cm/pixel. In the standard aerial photography condition given in the manual for public survey using UAV by Geospatial Information Authority of Japan (GSI) [12], three or more outside GCPs, which are located outside the target area and are within 100 m of each other, are recommended. It is also recommended to place at least one GCP in the target area and keep the distance from the surrounding GCPs to 100m or less. However, it is difficult to set an outside GCP on the tidal flat because the area is surrounded by the sea. In addition, Rehak et al. [13] have found that the error increases when there is a bias in a GCP arrangement. In our measurement, only the inside GCPs are arranged at the interval of 30m to reduce the disadvantage of the lack of the outside GCPs. The ratios of over-lap (OL) and side-lap (SL) are set to 90% and 65% in the aerial photography although 80% and 60% are proposed in the manual by GSI as the general setting. The photos obtained by UAV are analyzed by Structure from Motion (SfM) processing using Photoscan Professional (Agisoft), and the Digital Elevation Model (DEM) of the tidal flat was developed. These conditions are same as Tabata et al. [10].

4. Results

4.1. Verification of accuracy

Figure 4 demonstrated the comparison of the results of UAV-DEM with RTK-GNSS data obtained on the survey lines (W-E line and L-I line) shown in figure 3. The UAV-DEM data on the RTK-GNSS survey lines are selected. On the whole, the UAV-DEM data indicate good agreement with the results of the RTK-GNSS survey. The root-mean-squared error (RMSE) was evaluated by about 5cm. However, some points indicate a large difference (error) between UAV-DEM and RTK-GNSS. Figure 5 shows the comparison of the elevation along the W-E survey line (cross section) and L-I survey line (longitudinal section) on February 3rd, 2018. The error, a value of UAV-DEM minus RTK-GNSS, is also indicated in this figure. It is identified that large errors occur at both ends of the W-E survey line. The height of the lowest water level on the survey date, February 3rd, 2018, was around 70cm below the mean water surface, which height was estimated using water elevation data at a tide station near this tidal flat because the water level was not measured on this tidal flat. Then, the areas indicating a large difference would be submersible areas when the photos were taken by UAV. On the other hand, a large difference occurred at the right-hand side, which is close to a mainland, in the figure 5(b) and (c). This area was the end of aerial shooting range (figure 3). Number of overlapped photo for SfM procedure in this area is less than in other areas. It caused low accuracy of UAV-DEM. These large errors correspond to the data greatly deviating from the 1:1 line in figure 4.

4.2. Morphological changes

To investigate the morphological changes during the UAV monitoring period, from September 2017 to August 2018, an analyzed area of 100m in the East-West (E-W) direction and 400m in the Land-Island (L-I) direction was set on UAV-DEM (figure 6). The mean elevation at 5m interval in the W-E direction and 10m interval in the L-I direction was obtained in this area (figure 6(a)) from UAV-DEM with higher resolution. In the mean elevation dataset, there were the data which seems to be too deep (much lower than the mean level). It is expected that these data are in submersible area mentioned in figure 5(a) and they have a slightly large error. Therefore, the elevation of -1.5m was set as the minimum value (lowest elevation) in this dataset. In addition, this mean elevation distribution was divided into small areas of 25m in the E-W direction and 50m in the L-I direction, so that the total small blocks are 32 (figure 6(b)). The volumetric changes were estimated in each small area, and the feature of the change of tidal flat morphology was investigated by the distribution of the sediment volume and its change.
(a) Comparison and error on W-E (cross-sectional) survey line.

(b) Comparison of RTK-GNSS and UAV-DEM on L-I (longitudinal) survey line.

(c) Error between RTK-GNSS and UAV-DEM of (b).

Figure 5. Verification of UAV-DEM accuracy on 3rd, February, 2018 (Meas-3 in table 1).

4.2.1. Total volume of sediment on tidal flat. Figure 7 shows the time series of the total amount of sediment volume on the tidal flat. The sediment volume in each small block was estimated by multiplying a mean elevation by an area of a small block (50m by 100m). And the total volume of sediment within the analyzed area was calculated by adding the sediment volumes of all the small blocks. The red broken line in the figure represents the average of the estimated sediment volumes during the measurement period, and the solid blue lines indicate the sand volume of ± 5.0% from the average. From this figure, it can be confirmed that the total sand volume in the analyzed area has not changed substantially. In Tabata et al. [10], the occurrence of the topographic change of this tidal flat in about 6 months was confirmed. It is known that there is no source of sediment supply, such as a river, near the tidal flat. However, figure 7 indicated that no significant sediment volume changes occurred in one year.
These results would conclude that sediment transport occurs only in the tide flat (the analyzed area) and total sediment volume on the tidal flat is almost conserved.

Figure 6. Analysis area of sediment volume in UAV-DEM.

(a) Mean elevation point. (b) Small block for sediment volume estimation.

Figure 7. Change of sand volume in one year.

4.2.2. Topographic changes in short term due to typhoons. Tabata et al. [10] demonstrated that the deposition on the western area of the tidal flat and the erosion on the eastern area was caused by TY1718. The analyzed area (32 small blocks) estimating the sediment volume is divided into 4 longitudinal sections, (A) westernmost, (B) western, (C) eastern and (D) easternmost, as shown in figure 6(b), to investigate the spatial characteristics of the volume changes. Figure 8 shows the volume changes in Prd-
1 (2017/9/20-2017/9/5) and Prd-4 (2018/8/28-2018/8/11) to identify the influence of typhoon on the topographic changes. The volume changes of sediment due to a typhoon along the longitudinal sections, (A), (B), (C) and (D), are compared separately. The same tendency was displayed in (A), (B) and (C). However, the opposite one was shown in (D). The decrease of sediment volume (erosion) occurred in the island side (block of 4, 5, 6 and 7) although the increase of sand volume (deposition) occurred in the same area. The distinct difference between TY1718 and TY1820 was found in the trajectory of typhoon. The typical track of a typhoon around the main island of Japan was from west to east, and TY1718 followed that route. However, TY1812 approached the main island from east to west. That track was in the opposite direction. It was the extraordinary event in Japan and it was very difficult to estimate the influence of this typhoon on the topographic condition in the research area. It is inferred that the reverse trend on volume changes results from this rare phenomenon. It is also indicated the necessity of further monitoring of tidal flat topography to reveal the characteristics of topographic change and sediment dynamics due to a typhoon on this tidal flat.

![Figure 8. Distribution of volume change caused by typhoon passing along the L-I direction (Land: 1, Island: 8).](image)

### 4.2.3. Topographic change of tidal flats in half a year.

Figure 9 shows the volume changes of sediment in the period of Prd-1&2 (2018/2/3-2017/9/5), and Prd-3&4 (2018/8/28-2018/2/3). Each period is almost half a year. Accumulation on the east-side area (C, D) and very small changes in the west-side area (A, B) in Prd-1&2 (red line) were confirmed. In the study by Tabata et al. [10], it was confirmed that the westward sediment transport occurred due to a typhoon, and the sediment transport in the opposite direction was generated after the typhoon. In this study, TY1718 passed close to the study area before Prd-2 (figure 2) and caused the topographic changes on the tidal flat. Then, it can be considered that the topographic change in Prd-1&2 included the recovery process from the changes caused the typhoon. This topographic recovery seems to continue further in Prd-3 after Prd-2. However, two typhoons passed
near the research area and the opposite trend was demonstrated at the end of Prd-4. Significant erosion in the east-side area and slight deposition in the west-side area were found. As mentioned above, the track of TY1821 was opposite direction to the normal track. It is supposed that the eastward sediment transport was generated due to TY1812 before the end of Prd-3. About one month later, next typhoon TY1820 approached Japan and landed in Prd-4. The strength of TY1820, the lowest central pressure and the maximum wind speed, was greater than that of TY1812. But the track of TY1820 was far from this tidal flat compared to the track of TY1812. Therefore it is suggested that the influence of TY1812 which was the eastward sediment transport remained at the end of Prd-4. However, the same characteristics that the volume changes of sediment in both periods were larger on the island side than on the land side, especially in east-side area.

![Figure 9](image)

**Figure 9.** Distribution of volume change in half a year along the L-I direction (Area 8 to 1).

4.2.4. Morphological change during the investigation period (1 year). Figure 10 shows the annual change of tidal flat morphology derived from Meas-1 (2017/9/5) to Meas-5 (2018/8/28). This Figure shows erosion in the east-side area and deposition on the west-side area. This feature is the same as the volume change after the typical typhoon passing. However, as mentioned in 4.2.1, the total amount of sediment on the tidal flat has hardly changed in one year. These results indicate that the existence of this tidal flat is maintained although active sand movement on the tidal flat causing the topographic changes are generated by natural phenomena.

About 1000m³ increase of total sediment volume in one year was estimated. The analyzed area is 40,000m² (= 400m x 100m). And the mean increase of the tidal flat topography is calculated to be 0.025m. On the other hand, the accuracy of UAV-DEM is about 5cm (section 4.1). Then the mean topographic change is less than the accuracy (limitation) of UAV-DEM. Figure 11 shows the change of the cross-sectional profiles in the analyzed area on the tidal flat. These profiles changed more than 5cm apparently. In terms of the total sediment volume, no significant change can be confirmed in the sediment volume of this tidal flat, but the cross-sectional profile has clearly changed and it has been confirmed that active sediment movement has occurred on this tidal flat.
Figure 10. Distribution of volume in one year along the L-I direction.

(a) Area A (Westernmost area)
(b) Area B (Western area)
(c) Area C (Eastern area)
(d) Area D (Easternmost area)

Figure 11. Change of cross-sectional profiles on the tidal flat.

(a) 2017/09/05
(b) 2017/09/20
5. Conclusions
In this research, the detailed topography of tidal flat was measured using UAV, and the measurement was conducted 5 times in one year. The topographic changes were investigated by analysis of UAV-DEM in some periods.

From the estimation of total sand volume on the tidal flat, it was demonstrated that sediment transport occurs only in the tideland and total sand on the tidal flat is almost conserved although topographic changes were caused by natural phenomena, such as typhoon.

By the influence of typhoon, sand on the tidal flat was transported from east to west in case of typical typhoon tracks. However, during the monitoring period of this research, the extraordinary event which typhoon moved in the opposite direction occurred. The different trend of topographic change and sand transport was resulted from two typhoon events in one year. Further monitoring of the tidal flat topography is necessary to grasp the characteristics of its change.

The morphological change of this tidal flat will occur continuously in the future. However, if the amount of sand does not change (does not decrease), the existence of this tidal flat will be maintained in the future. Therefore, in order to maintain and preserve the quality of the tidal flat, it is indispensable for investigating its topography in detail.

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References
[1] Mitsch W J and Gosselink J G 2000 The value of wetlands: importance of scale and landscape setting *Gosselink : Ecological Economics* **35** 25-33
[2] Bridges T, Henn R, Komlos S, Scerno D, Wamsley T and White K 2013 Coastal risk reduction and resilience *US Army Corps of Engineers*
[3] Thom B G, Wright L D and Coleman J M 1975 Mangrove ecology and deltaic-estuarine geomorphology: Cambridge Gulf-ord river, western Australia *The J. of Ecology* **63** 1 203-32
[4] Wilson C A, Hughes Z J, FitzGerald, D M, Hopkinson C S, Valentine V and Kolker A S 2014 Saltmarsh pool and tidal creek morphodynamics: dynamic equilibrium of northern latitude saltmarshes? *Geomorphology* **213** 99-115
[5] Marsooli R, Orton P M, Georgas N and Blumberg A F 2016 Three-dimensional hydrodynamic modeling of coastal flood mitigation by wetlands *Coastal Engineering* **111** 83-94
[6] Mancini F, Dubbini M, Gattelli M, Stecchi F, Fabbri S and Gabbianelli G 2013 Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: The structure from motion approach on coastal environments *Remote Sensing* **5** 12 6880-98
[7] Kuroiwa M, Sueyoshi R, Ichimura Y and Fukuoka K 2016 Study on coastal topographic change analyz using UAV *J. of Japan Society of Civ. Eng. Ser. B3 (Ocean Engineering)* **72** 2 I_1627-32 (in Japanese)
[8] Matsubayashi Y, Komatsu H and Ogasawara T 2017 Simplified method for coastal topography measurement with UAV *Journal of Japan Society of Civil Engineers Ser. B2 (Coastal Engineering)* **73** 2 I_1627-32 (in Japanese)
[9] Long N, Millescamps B, Guillot B, Pouget F and Bertin X 2016 Monitoring the topography of a dynamic tidal inlet using UAV imagery *Remote Sensing* **8** 5 387
[10] Tabata T, Kato S, Nakamura R, Oda T, Nishizono H and Okabe T 2018 Verification of measurement accuracy of tidal flat topography by UAV and applicability to continuous monitoring of tidal flat *Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)* **12** 2 I_961-6 (in Japanese)
[11] El Meouche R, Hijazi I, Poncet P A, Abunemeh M and Rezoug M 2016 UAV Photogrammetry
Implementation to Enhance Land Surveying, Comparisons and Possibilities International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences 42

[12] Geospatial Information Authority of Japan (GSI) 2017 Manual for public survey using UAV (draft) revised in March, 2017 (in Japanese)

[13] Rehak M and Skaloud J 2015 Fixed-wing micro aerial vehicle for accurate corridor mapping ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences 10.5194/isprsannals-II-1-W1-23-2015