TIDALLY-DRIVEN BEACH CHANGE:
INSIGHTS FROM LONG-TERM AND LiDAR MONITORINGS

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INTRODUCTION

Coastal erosion is caused by a variety of factors, including waves, currents and tides. Periodic rise and fall of sea level, the tide, is known to affect beach morphological changes through the processes: wave runup infiltration and groundwater exfiltration. For example, in Duncan (1964), during flood tides, waves run up to higher elevations, allowing seawater to infiltrate into the beach face, thus leaving sediment more likely to accumulate. During ebb tides, the groundwater level is relatively high and groundwater flows out of the beach face, strengthening the return flow and causing erosion.

However, the tidally-driven beach morphological change processes are not well observed and not quantitatively understood, and these processes are rarely considered in the prediction of beach morphological change and risk management in coastal areas. This study provides new insights into tidally-driven beach morphological change processes by analyzing 24 years of long-term beach monitoring data and one month of high-frequency observation data using LiDAR. This study focused on the processes in the upper swash zone, which is located above the mean water level (M.W.L.).

DATA AND METHOD

Monitoring of beach morphology at Hasaki coast, Japan facing the Pacific Ocean has been conducted since 1986 by measuring daily to weekly beach profiles at 5 m intervals in a 500 m cross-shore section along a pier (Banno et al., 2020; Figure 1). The beach has a longshore uniform morphology and about-0.2-mm fine sand.

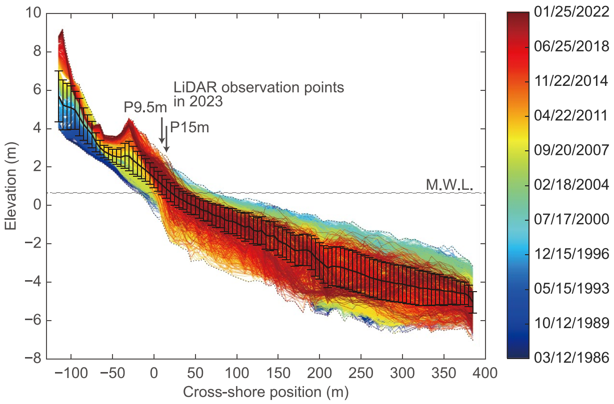

Figure 1 - Measured beach profile from 1986 to 2022.

The data used in the analysis were daily shoreline positions obtained from 1986 to 2010 (n = 9060). The shoreline position was defined by the cross-shore position with a specific elevation in the measured profile as a proxy for beach morphology. To investigate the cyclic changes in the beach morphology induced by tidal range variation, the spectra of the shoreline positions in the upper swash zone were obtained, especially focusing on the cycles of spring tide and king tide (Banno and Kuriyama, 2020). The peak powers of cycles related to spring tide and king tide, which were normalized by the overall average power in the frequency component, were calculated at the reference levels every 5 cm above M.W.L. (Figure 2).

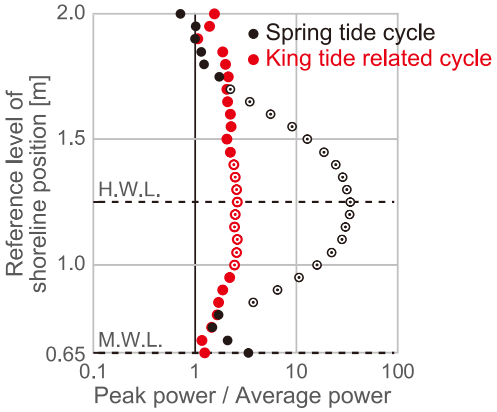

Figure 2 - Spectral peak power on cycles of spring tide and king tide. Open circle symbols mean that the peaks have statistical significance.

In addition to that data, we collected high-frequency data of beach morphology in the upper swash zone using LiDAR for one month in September 2023. We used a handy laser rangefinder to measure the elevations of the beach face at two fixed points (9.5-m and 15-m cross-shore points in Figure 1; P9.5m and P15m) at intervals of 1 to 10 seconds. After filtering out noise including captured waves, the elevation data obtained every minute were used to investigate the elevation changes during a single tide and compare the processes between flood and ebb tides.

TIDAL RANGE EFFECT

The narrow peaks corresponding to the cycles of spring tide and king tide were observed around H.W.L. (the upper swash zone) in the power spectra of the shoreline changes obtained from the long-term data (Figure 2). The phases of the changes in the upper swash zones (not shown in Figures here) showed that erosion in the upper swash zone is likely to occur when the tidal range increases in a spring tide and a king tide.

During high tide in the spring tide and king tide, the groundwater level rises larger due to wave runup to a higher level. The subsequent ebb tide would cause a larger difference between the seawater level and the groundwater level. Based on Duncan (1964), the possible mechanism for the erosion in the upper swash zone during spring tides and king tides would be caused by the larger water gap making exfiltration and erosion strong during ebb tide. However, the following beach morphological change during one tide using LiDAR provided new insights.

FLOOD AND EBB TIDE EFFECT

During the one-month LiDAR observation in 2023 (Figure 3), accretion continued due to low waves initially, increasing the elevations by 50 to 60 cm. High waves after September 23 caused rapid erosion, decreasing the elevations by up to 80-90 cm. Thereafter, accretion and erosion were observed over time.

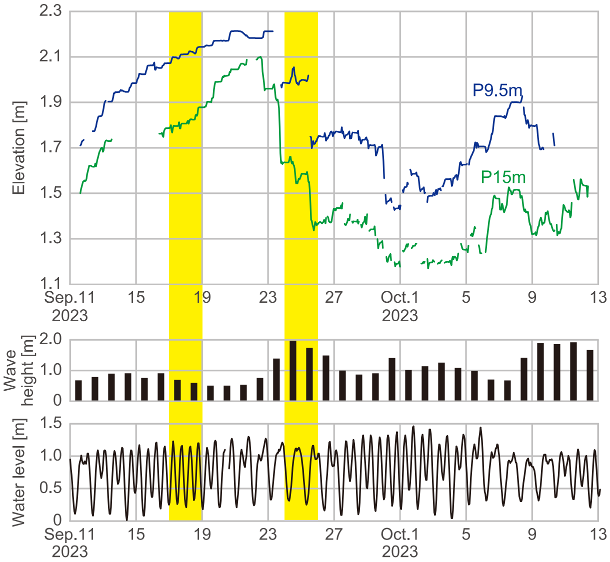

Figure 3 - Elevation measured by LiDAR, daily mean wave height and hourly water level. Yellow ranges are shown in Figure 4.

The changes in the elevations during a single tide (flood tide and ebb tide) are noteworthy. Although the wave regime governs the trend of the morphological change, the following new insights were obtained from the overview of the observation result. The highly-resolution changes in the elevations (Figure 4) show that accretion occurs first when the tide rises and the wave runup reaches the elevation of the point. This is consistent with the results of Duncan (1964). Then, as the tide level rises further, it turns to erosion. As the tide reaches high tide and is about to decrease, accretion occurs again. This means that erosion occurs when the groundwater level rises sufficiently even during flood tide, and accretion also occurs during the ebb tide when the groundwater level falls. In other words, total morphological change in one tidal cycle is determined by the changes of three processes, which are two accretion and one erosion in between. In existing numerical models, they basically are not possible to express the accretion and erosion individually during one tide. The findings in this study would lead to the improvement of the beach morphological change models. However, as mentioned above, wave regime is the main force for beach morphological change, so the mechanism should be further investigated, including the influence of waves.

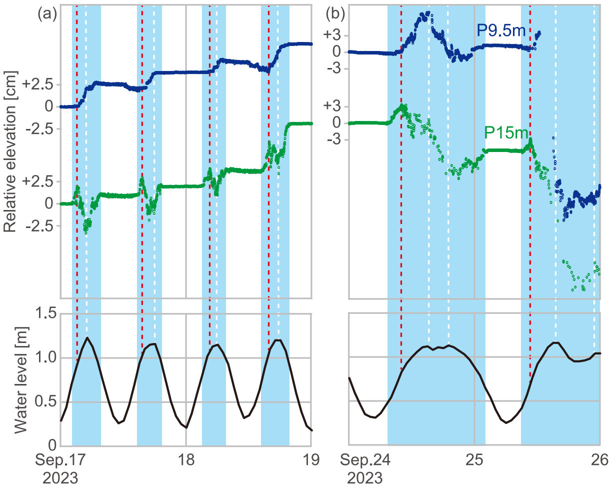

Figure 4 - Zoom in (a) accretion event and (b) erosion event. Water blue ranges indicate the period during which the beach morphology was subjected to wave action. Red dashed lines indicate the times of the transition from accretion to erosion mode at P15m. White dashed lines indicate the high tides.

CONCLUSION

The long-term data showed that the beach morphological changes in the swash zone have cycles with the tidal range, with erosion in the upper swash zone during spring tides and king tides. The high-frequency observation data also showed that the beach morphological changes in the swash zone are likely to occur in the order of accretion, erosion, and accretion during a single tide.

These findings provide new insights into the tidally-driven beach morphological change processes, which can lead to the improvement of the prediction of beach morphological change and coastal management.

REFERENCES

Banno, M., Nakamura, S., Kosako, T., Nakagawa, Y., Yanagishima, S. and Kuriyama, Y. (2020): Long-Term Observations of Beach Variability at Hasaki, Japan. Journal of Marine Science and Engineering, 8(11), 871.

Banno, M. and Kuriyama, Y. (2020): Supermoon drives beach morphological changes in the swash zone. Geophysical Research Letters, 47, e2020GL089745.

Duncan, U. S. (1964): The effect of water table and tide cycle on swash-backwash sediment distribution and beach profile development. Marine Geology, 2, 117-130.