

CALIBRATION OF SHORELINE PREDICTION MODEL USING ENSEMBLE KALMAN FILTER

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INTRODUCTION

The increasing greenhouse gas emissions induce global warming, leading to sea-level rise (SLR). In particular, climate change has already been becoming apparent in the coastal environment. The most significant variation due to SLR is shoreline change. A proper model that could predict the shoreline change on a large scale and a long-term is urgently needed. Models in different aggregation levels have been developed to study shoreline morphology in various spatial and temporal scales (e.g., Yates et al., 2011; Splinter et al., 2014). This study aims to discover the drivers of shoreline behavior and especially understand the wave climate's impact on shoreline to reduce the uncertainty of shoreline in the long-term forecast.

METHODOLOGY

Hasaki Beach is an open coast located on the east coast of Japan. The bathymetry data was collected at HORS, which is a pier perpendicular to the beach extending 270m in offshore. The shoreline data has been recorded from 1985 to the present once per day (once per week after 2012), and its uncertainty is around one meter, which is much more accurate than the image recognition technique. Wave data was collected at the Kashima Port (Figure 1) and long-term wave hindcast data is used based on the atmospheric reanalysis model JRA-55 (1979 to present).

The reduced complexity model, ShoreFor (Splinter et al., 2014), is applied to the Hasaki beach to hindcast and forecast the morphodynamic behavior.

$$dx/dt = c^a F^+ + c^e F^- + b \quad (1)$$

$$F = p^{0.5} \frac{\Delta\Omega}{\sigma_{\Delta\Omega}} \quad (2)$$

$$\Omega = \frac{H_s}{\omega T_p} \quad (3)$$

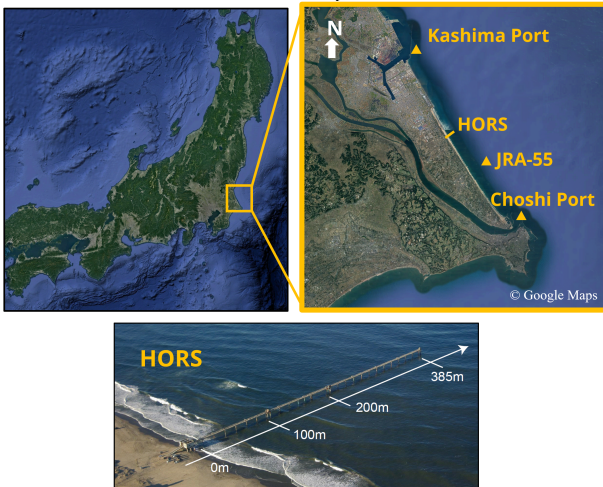


Figure 1 - Study area: The Hasaki Beach and HORS (Banno

and Kuriyama, 2014)

$$\Delta\Omega = \left[\sum_{i=1}^{2\phi} 10^{-i/\phi} \right]^{-1} \sum_{i=1}^{2\phi} \Omega_i 10^{-i/\phi} - \Omega_{i=1} \quad (4)$$

where x represents the shoreline position, c^a and c^e are the efficiency factor of accretion and erosion, F is the forcing term, b is the linear term, Ω is the dimensionless settling velocity composed by significant wave height H_s , settling velocity ω , and peak wave period T_p . $\Delta\Omega$ is the disequilibrium, and ϕ is the number of days prior to the present time.

Ensemble Kalman Filter (EnKF, Evensen, 2003), a data assimilation method, is applied to the ShoreFor model. An ensemble with the size at 1000 is initialized at the beginning and in each ensemble member, the free parameters' initial values are generated randomly following the given mean value and variation. In the model, the free parameters c^a and c^e are no longer constant for all the periods but are time-variant. The simulated shoreline and free parameters will be updated when shoreline data is available according to the covariance and Kalman gain. EnKF is an effective tool used to track the change of those free parameters and find the correlation between free parameters and wave climate.

RESULTS

By setting the shoreline position at mean sea level as the proxy of the shoreline, the accumulation of shoreline accretion and erosion are extracted in Figure 2. Shoreline shows a seasonally cyclic behavior, significantly eroding in September, October, and March, corresponding to the months with the stormy wave climate. In summer, from April to August, the significant wave height decreases; meanwhile, the shoreline is restored. During that period, even though the wave climate is generally getting milder, the shoreline is becoming more active and erosion is superinsignificantly increasing. This is because when wave climate is calm, the shoreline change is dominated by other processes, resulting in small variations at a short time scale.

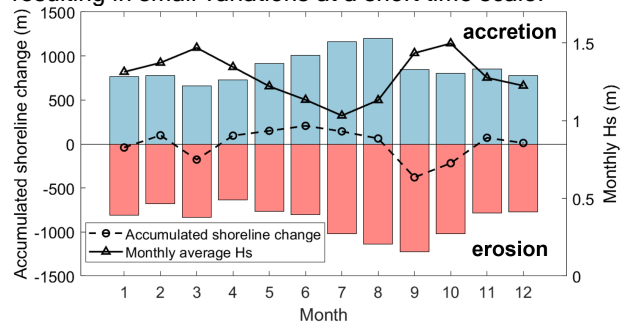


Figure 2 - Accumulated monthly shoreline change from 1989

to 2011 (left axis) and monthly averaged significant wave height extracted from JRA-55 wave hindcasts (right axis) (solid line: monthly averaged H_s , dashed line: accumulated shoreline change, bar: above the axis the accumulated accretion and below the erosion).

The correlation between shoreline and 2-weekly averaged significant wave height is calculated by month (Figure 3). Apart from November, the median correlation remains negative, which illustrates that shoreline restores when wave climate is getting milder, and vice versa. August and November have a similar historical change of shoreline, but November has a smaller shoreline variation with a higher H_s compared to August, which is opposite to the previous study that the shoreline is generally eroded under strong waves.

The ShoreFor model with time-independent free parameters can capture the seasonal variance, but the peak value is underestimated (Figure 4). The Hasaki beach may have a more rapid response to storm and restore more fastly right after storm. Therefore, the constant free parameters possibly limit the predictability of the model. EnKF is applied to the model to update the simulated shoreline and time series of time-variant free parameters and its deviation (Figure 5). The high sampling frequency and low measuring uncertainty at Hasaki Beach make data assimilation more effective in tracking changing free parameters.

Since the linear term in governing Eq.(1) is eliminated in the simulation, a long-term accreting trend of shoreline from 1989 to 1999 is reflected in the increasing of accretion efficiency factors in the same period. The erosion efficiency factor (c^e) remains stable for the whole period, but the accretion factor (c^a) shows an obvious intra-annual variation, which may relate to the wave climate and sediment supply. The long and continuous Hasaki beach shoreline makes it possible to interpret the physical meaning behind the free parameters in the model, which can significantly decrease the uncertainty in shoreline forecasts. The recent study shows that efficiency factors negatively correlate with mean wave height, but the wave average period is in the order of years (Ibaceta et al., 2022). Therefore, the correlation between free parameters and wave or other processes is still unclear, and more analysis should be conducted.

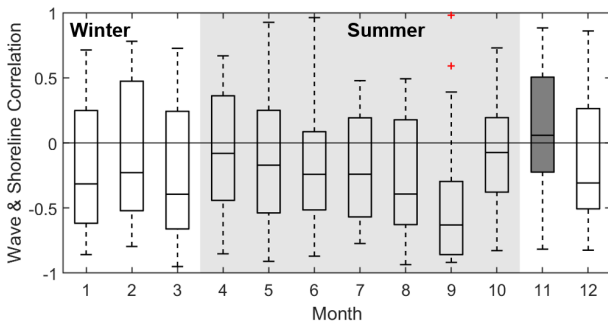


Figure 3 - Correlation between bi-weekly averaged wave height and shoreline location. (Dark bar: positive median correlation; white bar: negative median correlation)

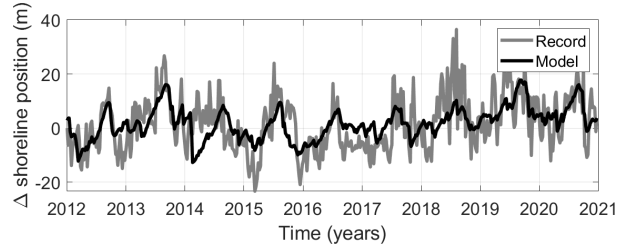


Figure 4 - Shoreline hindcast by the ShoreFor model with constant free parameters (solid line: model, gray: weekly observation).

CONCLUSION

The shoreline change shows a genuinely negative correlation with 2-weekly averaged significant wave height, and the reduced complexity model, ShoreFor, can capture the seasonal variance based on the wave climate. The long-recorded bathymetry data at Hasaki Beach with a high sampling resolution provides could in-depth relationship between the wave climate and shoreline change. The data assimilation method could also track the change of free parameters in the model. The detail relationship and understanding physics between the free parameters and wave climate is to be studied in the future.

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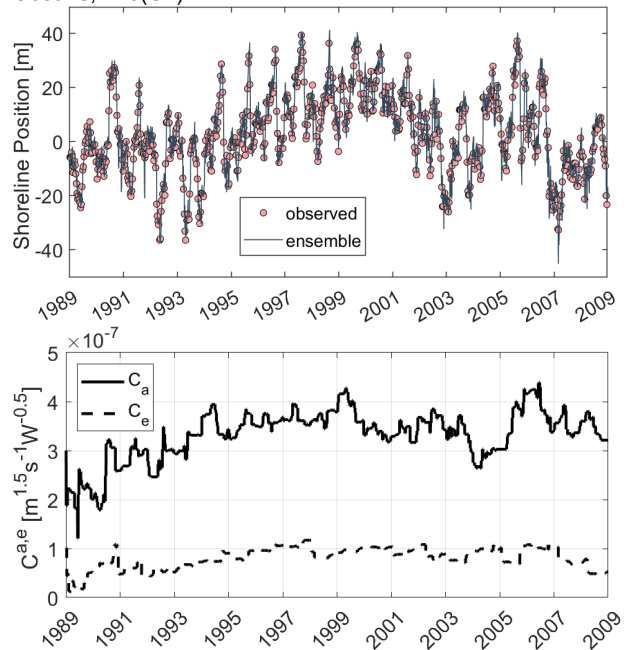


Figure 5 - Ensemble mean shoreline hindcast from 1989 to 2009 and the observation from HORS (upper, dots the shoreline records and line the simulated mean value); The variation of efficiency factors tracked by EnKF from 1989 to 2009 (bottom, solid line: c^a and dash line: c^e).