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Overview of ST Shoreline Change Rate Calculation Method

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Coastal erosion studies by this group and others employ historical shoreline positions that are digitized from aerial photographs and survey charts (t-sheets) (Fletcher et al., 2003; National Academy of Sciences, 1990). Historical shorelines may be derived from several shoreline change reference features (SCRF's), such as, the vegetation line, high water line, or low water line. We utilize the low water line (indicated by the beach toe or base of the foreshore) as the SCRF for all photo and t-sheet years (Figure 1). The historical shorelines are displayed together on a map for comparison and their relative distances are measured along shore-perpendicular transects spaced 20 m apart (Figure 2).

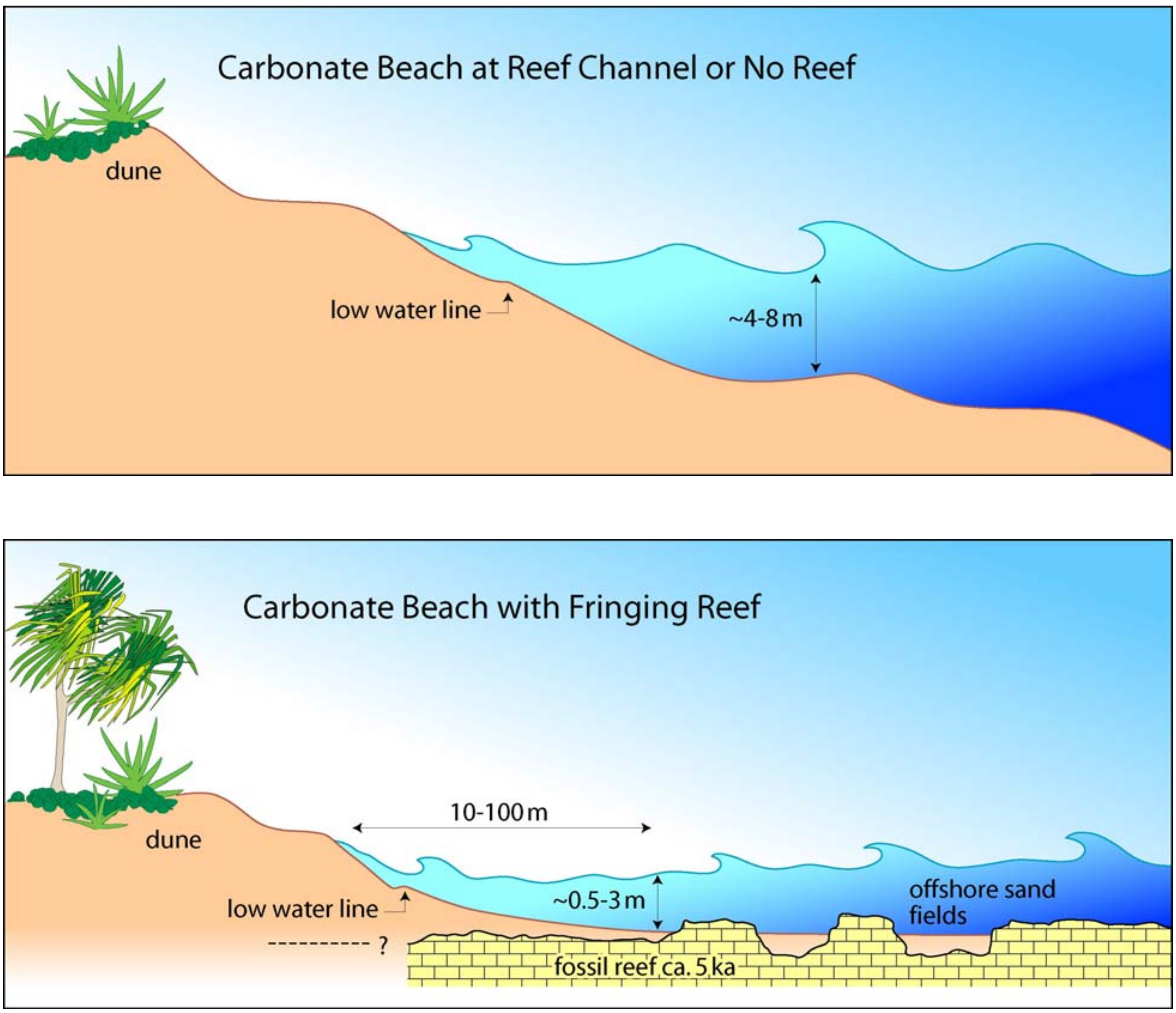

Figure 1. Typical cross-shore profiles of Hawaiian beaches. We utilize the low water line (indicated by the beach toe or base of the foreshore) as the shoreline change reference feature (SCRF).

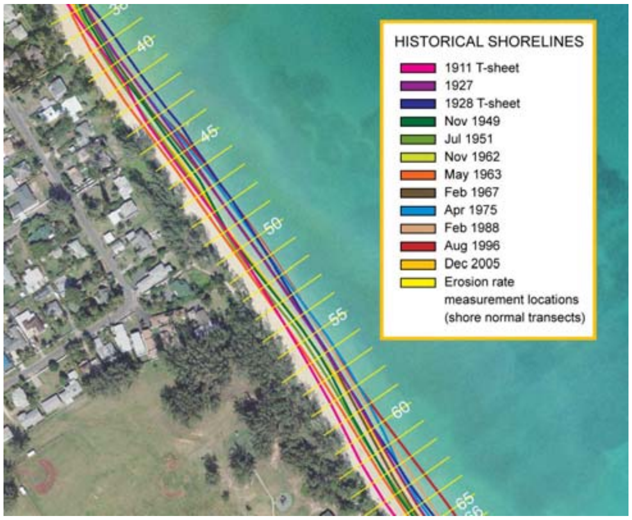

Figure 2. Historical shorelines and shore-perpendicular transects (spaced 20 m) for measuring relative shoreline change (displayed on recent aerial photograph, with transect number).

ST Method

Shoreline change rates are calculated from the time series of historical shoreline positions using a variety of statistical methods. Our group and other coastal research groups (e.g., Theiler, et al., 2005) have utilized the single-transect (ST) method to calculate shoreline change rates. ST calculates a shoreline change rate and uncertainty at each shoreline transect. ST uses various methods (e.g., End Point Rate, Average of Rates, Least Squares) to fit a trend line to the time series of historical shoreline positions. We employ weighted least squares (WLS), which accounts for the uncertainty in each shoreline position when calculating a trend line (see: Fletcher et al., 2003; Genz et al., 2007). Shoreline positions with higher uncertainty will have less of an influence on the trend line than data points with smaller uncertainty. The slope of the line is the shoreline change rate (Figure 3).

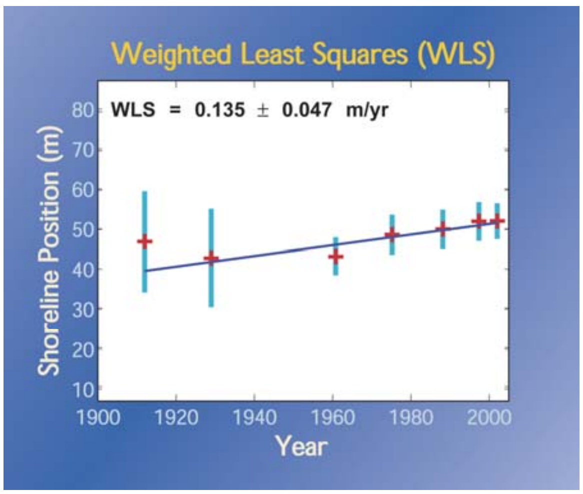

Figure 3. Example of single-transect (ST) rate calculation using weighted least squares. Each red cross is a historical shoreline position along a transect plotted in time and distance. Blue bars represent the positional and measurement uncertainty of each historical shoreline position. The slope of the line is the shoreline change rate.

Uncertainties and Errors

In order to apply WLS, it is necessary to accurately estimate the errors and uncertainties associated with each shoreline. Several sources of error impact the accuracy of historical shoreline positions and final shoreline change rates. We define two types of uncertainty: positional uncertainty and measurement uncertainty. We quantify 7 different sources of error in identifying shoreline positions on aerial photographs and T-sheets (3 positional and 4 measurement errors). The 7 different sources of errors are summed in quadrature (the square root of the sum of the squares) to get a total positional uncertainty (U_t).

Positional uncertainty is related to all features and phenomena that reduce the precision and accuracy of defining a representative shoreline position in a given year. These uncertainties mostly center on the nature of the shoreline position at the time an aerial photo is collected. Influences on position include the seasonal state of the beach, stage of tide, and the conversion from HWL to LWM in T-sheets.

Seasonal error (E_s) is quantified by using summer and winter beach profiles (or seasonal shoreline positions from aerial photographs). Many beaches have seasonal cycles where they accrete in summer and erode in winter (or vice versa). Because high resolution aerial photographs are limited for the Hawaiian Islands, aerial photographs cannot be selected on seasonal time frames. To account for shifts in shoreline position due to seasons, the seasonal error is the standard deviation of a randomly generated uniform distribution with minimum and maximum values equal to the mean plus two times the standard deviation of the difference in the seasonal shoreline positions.

Tidal fluctuation error (E_{td}) is only calculated for aerial photographs. The aerial photographs were obtained without regard to tidal cycles, which can result in inaccuracies on the digitized shoreline. The horizontal movement of the LWM during a spring tidal cycle is monitored on several beaches to assess this error. Because the tides are cyclical fluctuating between low and high, there is an equal chance of taking a photograph of the shoreline at different stages of the tides. Therefore, the tidal error is the standard deviation of a randomly generated uniform distribution with minimum and maximum values equal to two times the horizontal movement of the LWM.

Conversion error (E_c) is only calculated for T-sheets. The surveyed shoreline on T-sheets is the HWL. To compare shorelines from aerial photographs that use the LWM with shorelines from T-sheets that use HWL, we migrate the HWL from T-sheets to the LWM using an offset calculated from beach profiles. The error associated with this migration is the standard deviation of the difference between the offset and the difference between HWL and LWM.

The measurement uncertainty is related to analyst manipulation of the map and photo products. For photos, measurement uncertainty is related to the orthorectification process and onscreen delineation of the shoreline reference feature. For T-sheets, we adopt National Map Accuracy Standards that provide a measure of both position and measurement uncertainties.

Digitizing error (E_d) is the error associated with digitizing the shoreline. Only one analyst digitizes the shorelines for all photographs and T-sheets to minimize different interpretations from multiple analysts. The error is the standard deviation of the differences between repeat digitization measurements. The error is calculated for photos/T-sheets at different resolutions.

Pixel error (E_p) is the pixel size of the image. The pixel size in orthorectified images is 0.5 m, which means anything within 0.5 m cannot be resolved.

Rectification error (E_r) is calculated from the orthorectification process. Aerial photographs are corrected, or rectified, to reduce displacements caused by lens distortions, Earth curvature, refraction, camera tilt, and terrain relief using remote sensing software. The RMS values calculated by the software are measures of the misfit between points on a photo and established ground control points (GCP). The rectification error is the RMS value.

T-sheet plotting error (E_{ts}) is only calculated for T-sheets. The error is based on Shalowitz (1964) thorough analysis of topographic surveys. There are three major errors involved in the accuracy of T-sheet surveys: (1) measuring distances has an accuracy of 1 m, (2) planetable position has an accuracy of 3 m, and (3) delineation of the actual high water line has an accuracy of 4 m. The three errors are summed in quadrature to get the plotting error.

These errors are random and uncorrelated and may be represented by a single measure calculated by summing in quadrature (the square root of the sum of the squares). The total positional uncertainty (U_t) is:

$$U_t = \pm\sqrt{E_s^2 + E_{td}^2 + E_c^2 + E_d^2 + E_p^2 + E_r^2 + E_{ts}^2} \qquad \text{Equation (1)}$$

For aerial photographs, E_c and E_{ts} are omitted. For T-sheets, E_r and E_{td} are omitted.

U_t is used as the uncertainty value (blue bars in Figure 3) for each shoreline year. These uncertainty values are propagated into the shoreline change result using WLS. The resulting uncertainty of the rate will incorporate the uncertainty of each shoreline and the uncertainty of the model.

Smoothing

The ST method treats each transect independently. This can lead to big jumps in rates between adjacent transects. To reduce variability in the alongshore direction, we apply a smoothing technique to the rates. Rates are smoothed using a center-weighted five-point moving average (Rooney et al., 2003). The weighting scheme is 1,3,5,3,1 for each set of transects. We present the smoothed ST rates on our posters.

Transect Plot

Individual transect plots illustrate the shoreline change model at each transect. The horizontal axis is time (historical shoreline date) and the vertical axis is relative distance of the historical shorelines along the transect. The shoreline positions are depicted as red crosses and the shoreline change model (unsmoothed rate) is depicted with a blue line. The light blue bars represent the total uncertainty of each shoreline position. A negative slope is equal to erosion and a positive slope is equal to accretion (Figure 4). The smoothed ST rate is reported as a value in the figure.

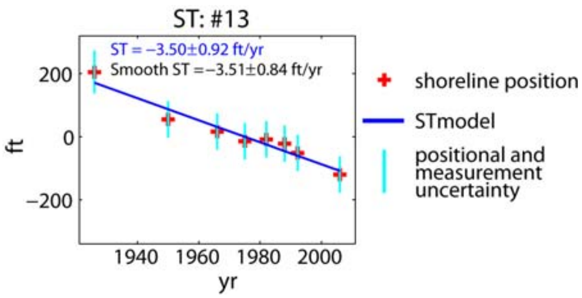

Figure 4. Individual ST transect plot showing erosion (negative rate). Historical shoreline time is shown on the horizontal axis and relative shoreline distance is shown on the vertical axis.

LITERATURE CITED

Fletcher, C.H., Rooney, J.J.B., Barbee, M., Lim, S.-C. and Richmond, B.M., 2003. Mapping Shoreline Change Using Digital Orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, Special Issue 38: 106-124.

Genz, A.S., Fletcher, C.H., Dunn, R.A., Frazer, L.N. and Rooney, J.J., 2007. The Predictive Accuracy of Shoreline Change Rate Methods and Alongshore Beach Variation on Maui, Hawaii. Journal of Coastal Research, 23(1): 87-105.

National Academy of Sciences, 1990. Managing Coastal Erosion. National Research Council, Committee on Coastal Erosion Zone Management, National Academy Press, Washington D.C., 182 pp.

Rooney, J.J.B., Fletcher, C.H., Barbee, M., Eversole, D., Lim, S.-C., Richmond, B.M., and Gibbs, A., 2003. Dynamics of Sandy Shorelines in Maui, Hawaii: Consequences and Causes, in Coastal Sediments '03 Proceedings, Clearwater Beach, Florida.

Shalowitz, A.L., 1964. Shore and Sea Boundaries: Washington D.C., Publication 10-1, U.S. Department of Commerce, 2 v., v. 2.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Miller, T.L., 2005. Digital Shoreline Analysis System (DSAS), http://woodshole.er.usgs.gov/project-pages/dsas/.