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CALCULATING SHORELINE CHANGE RATES: APPLYING THE NEW PX AND PXT METHODS

Bradley M. Romine, Ayesha Genz, Charles H. Fletcher, L. Neil Frazer, Matthew M. Barbee, Siang-Chyn Lim, and Matthew Dyer

University of Hawaii Coastal Geology Group, School of Ocean and Earth Science and Technology 1680 East West Road Honolulu, HI 96822 U.S.A
contact: romine@hawaii.edu, agenz@hawaii.edu, fletcher@soest.hawaii.edu

ABSTRACT

It is important that coastal erosion studies produce valid erosion rates to aid in the development of public policy. Currently, the Single-Transect (ST) method is the most common shoreline change model, which calculates a rate at each shore-normal transect without regard to influences of data from adjacent transects along a beach. Improving on ST, we have developed the PX (Polynomial in alongshore X) and PXT (Polynomial in X and Time) calculation methods, which model all shoreline positions on a beach simultaneously using polynomial techniques. PXT lets the rate change with time (acceleration) as well as alongshore. This is an important advance, as beaches may not erode or accrete at a constant (linear) rate. These methods are an improvement on previous methods as they produce more meaningful, i.e., statistically significant rates. In companion with the work presented by Ayesha Genz on the PX and PXT rate methods, we present results from the Southeast Oahu Shoreline Study.

HISTORICAL SHORELINES

Historical shorelines are digitized from 0.5 m orthorectified aerial photo mosaics and NOAA NOS topographic maps (t-sheets). Relative distances of the historical shorelines are measured along shore-normal transects spaced 20m apart.

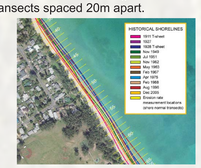


Figure 2. Historical shorelines and shore-normal transects.

Seven sources of error are calculated for each historical shoreline. The total positional error, *Et*, is the root sum of squares of the individual errors.

Source	Magnitude Range
Ed, Digitizing Error	± 0.54 - 5.73 m
Ep, Pixel Error, air photos	± 0.50 m
Ep, Pixel Error, t-sheets	± 3.00 m
Es, Seasonal Error	± 3.59 - 6.23 m
Er, Rectification Error	± 0.55 - 3.01 m
Etd, Tidal Error	± 2.54 - 3.42 m
Ets, T-Sheet Plotting Error	± 5.00 m
Ec, T-Sheet Conversion Error	± 3.40 - 5.70 m
Et, TOTAL POSITIONAL ERROR (root sum of squares)	± 4.49 - 10.78 m

Table 1. Range of positional and measurement errors for historical shorelines, Southeast Oahu, Hawaii.

SHORELINE CHANGE RATES

Single-Transect Method (ST)

Previous studies utilize ST, which employs linear regression to calculate shoreline change rates from the time series of historical shoreline positions at individual transects.

Problems with ST:

1. Unparsimonious models (over-fitting).
2. Many rates are not statistically significant.
3. Short-term fluctuations and poor sampling can mask the long-term trend.
4. Shoreline data from adjacent transects are assumed independent.

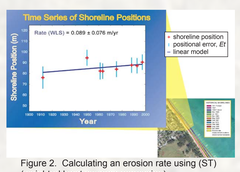


Figure 2. Calculating an erosion rate using (ST) (weighted least squares regression).

- Significant and defensible erosion rates are vital to plan for erosion hazards.
- Adjacent sections of a beach share sand along the shore.
- Many beaches do not erode or accrete at a constant (linear) rate.

New Polynomial Methods

The PX (Polynomial in alongshore distance X) and PXT (Polynomial in alongshore distance X and Time) shoreline change rate methods combine data from all transects along a beach and model shoreline change for the entire length of the beach using polynomial regression.

- PX and PXT produce more statistically significant shoreline change rates than ST.
- PXT can find acceleration in the shoreline change rate with time.

To find the best model to describe the change occurring at a beach, a range of possible models are tested, which vary in number of parameters and mathematical basis function type:

- Legendre polynomials (LX and LXT)
- Trigonometric functions (sins and cosines) (RX and RXT)
- Principal components (eigenvectors) of the beach data (EX and EXT).

An objective information criterion (IC) is used to find the "best", i.e., most parsimonious model to describe change at a beach. The model with the lowest IC score is the best among the models tested.

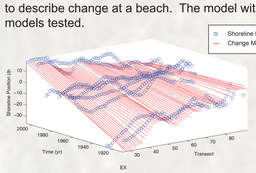


Figure 3. PX (EX) shoreline change model for North Bellows Beach. Shoreline change rates vary continuously in the alongshore direction.

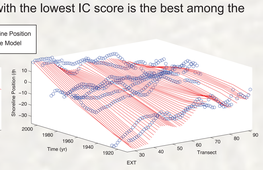
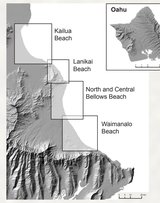


Figure 4. PXT (EXT) shoreline change model for North Bellows Beach. Shoreline change rates vary continuously in the alongshore direction and with time (acceleration).



Study Area

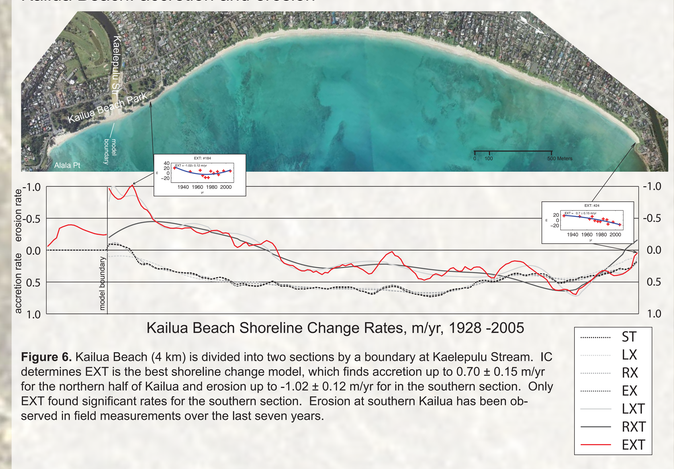
The SE coastline of Oahu, Hawaii, features a range of beach morphologies and littoral dynamics well suited for further testing of the PX and PXT methods.

Figure 5. Beach study sites.

Shoreline Change Rate Plots

- The shoreline change model determined by IC is depicted in red for each study site.
- Other model types are depicted in gray scale for comparison.
- Plots of the shoreline change models sampled at a single transect are shown to illustrate acceleration in the change rate with time.

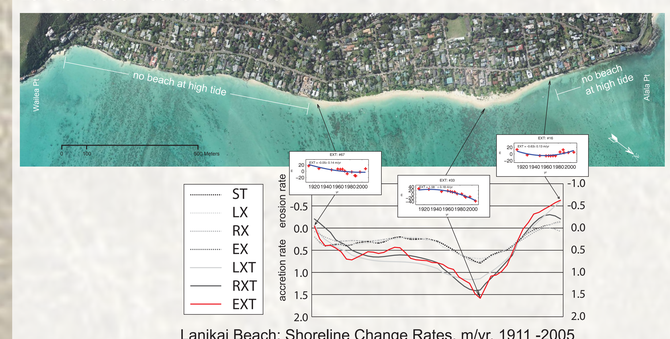
Kailua Beach: accretion and erosion



Kailua Beach Shoreline Change Rates, m/yr, 1928 -2005

Figure 6. Kailua Beach (4 km) is divided into two sections by a boundary at Kaelepulu Stream. IC determines EXT is the best shoreline change model, which finds accretion up to 0.70 ± 0.15 m/yr for the northern half of Kailua and erosion up to -1.02 ± 0.12 m/yr for in the southern section. Only EXT found significant rates for the southern section. Erosion at southern Kailua has been observed in field measurements over the last seven years.

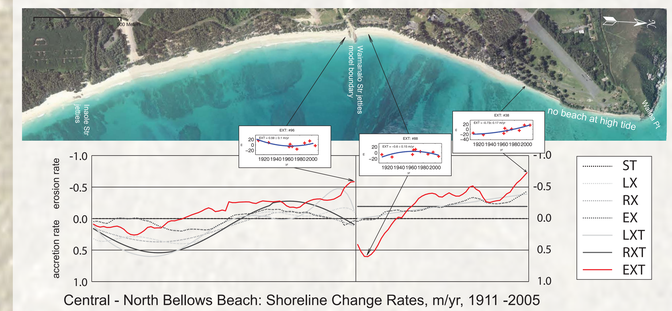
Lanikai: beach loss and accretion



Lanikai Beach: Shoreline Change Rates, m/yr, 1911 -2005

Figure 7. Lanikai has a narrow 800 m beach. The beach to the north and south was lost entirely to erosion by the late 1980's. Seawalls protect many oceanfront homes. IC determines EXT is the best shoreline model to describe shoreline change at Lanikai Beach. EXT finds most of Lanikai Beach is presently accreting as much as 1.58 ± 0.18 m/yr near the center of the beach. Erosion is encroaching from the north and south, indicating beach loss is continuing to expand with some of the eroded sand apparently collecting near the center of the beach.

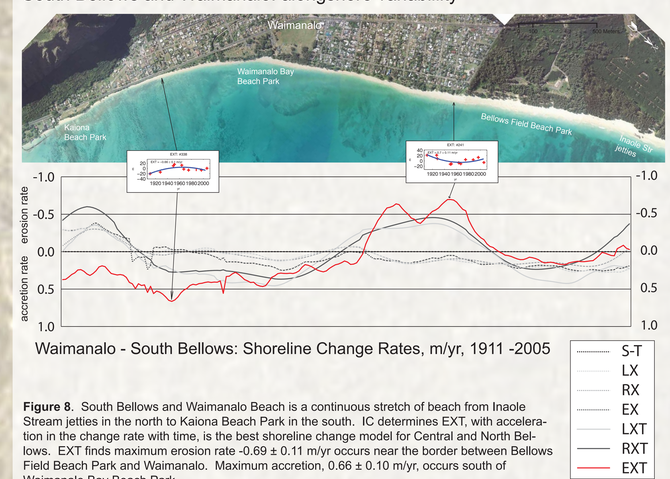
Central and North Bellows Beach: localized effects of shoreline structures



Central - North Bellows Beach: Shoreline Change Rates, m/yr, 1911 -2005

Figure 8. Central and North Bellows Beaches are divided into two study sections by a boundary at Waimanalo Stream jetties. Remains of a similar structure at Inaole Stream separate Central Bellows beach from Waimanalo Beach to the south. The beach at northern Bellows has been lost to erosion over the past few decades and the shoreline has been armored with stone rubble revetments. IC determines EXT is the best shoreline change model for Central and North Bellows. EXT finds maximum erosion, -0.73 ± 0.17 m/yr, and maximum accretion, 0.60 ± 0.15 m/yr, occur adjacent to man-made structures at Bellows. Other models do not suggest such a strong localized effect of shoreline structures.

South Bellows and Waimanalo: alongshore variabillity



Waimanalo - South Bellows: Shoreline Change Rates, m/yr, 1911 -2005

Figure 8. South Bellows and Waimanalo Beach is a continuous stretch of beach from Inaole Stream jetties in the north to Kaiona Beach Park in the south. IC determines EXT, with acceleration in the change rate with time, is the best shoreline change model for Central and North Bellows. EXT finds maximum erosion rate -0.69 ± 0.11 m/yr occurs near the border between Bellows Field Beach Park and Waimanalo. Maximum accretion, 0.66 ± 0.10 m/yr, occurs south of Waimanalo Bay Beach Park.

% of Transects with Significant Rates

rate method	Kailua	Lanikai	Bellows and Waimanalo	Totals
ST	81%	66%	13%	42%
LX	85%	91%	71%	78%
RX	90%	91%	74%	81%
EX	89%	94%	85%	87%
LXT	65%	89%	71%	70%
RXT	74%	87%	72%	74%
EXT	90%	94%	88%	89%

Table 2. Percentage of statistically significant rates for individual study sites and totals for the southeast Oahu study area. An insignificant rate is statistically indistinguishable from a rate of 0 m/yr (95% C.I.).

CONCLUSIONS

1. The PX and PXT shoreline change rate methods produce parsimonious shoreline change models by utilizing all the shoreline data from a beach and employing Objective Information Criterion (IC) to find the model that best describes shoreline trends with the fewest parameters.

2. PXT can model acceleration in the shoreline change rate with time, an important advance as many beaches may not change in a constant (linear) manner.

3. PX and PXT produce more statistically significant and defensible shoreline change rates than the ST method.

FUTURE WORK

The Oahu Shoreline Study is utilizing new methods to map historical shorelines and analyze shoreline change for all beaches on Oahu, Hawaii. Similar projects are studying the beaches of Maui and Kauai, Hawaii.

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MAHALO

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