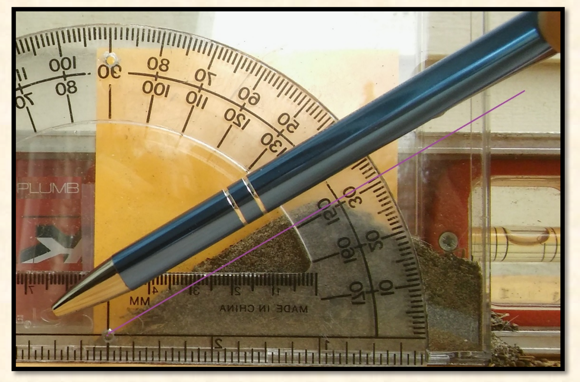

Actual vs. Predicted El Niño Induced Erosion Scarp Locations in northwest Oregon and southwest Washington

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Abstract

The El Niño event of 2015-2016 was one of the strongest El Niño's to occur in the last 33 years in the Pacific Northwest – second only to the 1983 and 1997 events. All three events were associated with elevated water levels along the northwest Oregon and southwest Washington coast resulting in increased erosion and scarping. In a study completed in 2016 we used sea surface temperature, precipitation anomalies, observed hourly tide levels and the Hedges and Mase (2004) Run-Up model (using Regional average parameters) to identify coastal beaches at risk to increased erosion by the El Niño event.

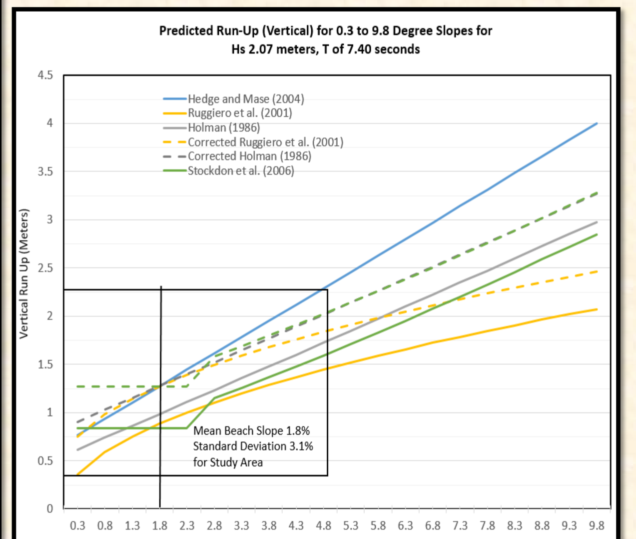
In this study LIDAR data published by NOAA's Ocean Service for July 2014 and April 2016 are used to identify beaches that actually experienced scarping during the 2014-2016 El Niño. To accomplish this I developed several GIS based models to extract scarps from the LIDAR data and compare them with the predicted 'at risk' locations and conducted an accuracy assessment. The risk analysis and run-up model were rerun using site specific mid-beach slopes extracted from the 2016 LIDAR for each transect. In general I found that the model based on Regional parameters provided a good first order estimate of risk, but that it under predicted the total number of transects that were subject to erosion from El Niño. The under prediction was primarily due to: (1) the use of a mean mid-beach slope of 3% vs. the generally lower site specific slopes derived from the LIDAR data, (2) not including the +0.093 m tide anomaly in the horizontal run-up calculations, and (3) an improved estimate off the deepwater significant wave height of 2.07 vs. 1.97 m. The new analysis obtained run-ups that were 10 to 30 m higher on transects with mid-beach slopes < 3% and run-ups that were lower than originally predicted when mid-beach slopes were > 3%.

Run-Up Model Selection

Most empirically derived wave run-up models developed over the past 50 years require beach slope (B), deepwater significant wave height (Hs), and deepwater wave period (Lo) or wave Period (T) (Shand et al. 2011). Four commonly used run-up equations were compared in this study: Holman (1986), Hedges and Mase (2004), Ruggiero et al. (2001), and Stockdon et al. (2006). The horizontal run-up calculations from these models were corrected based on factors derived from Shand et al. (2011). These factors (K1) apply when the "upper beach slope of the backshore" is used for ***B***, or as defined here, the mid-beach slope.

Model	Equation	Correction Factor (K1)* Shand et al. (2011)	Adjustment Factor (K2)* this Study
Holman (1986)	$R_{2\%} = (5.2\tan\beta + 0.2)H_S$	1.31	+0.29 m
Ruggiero et al. (2001)	$R_{2\%} = 0.27(\tan\beta H_0 L_0)^{0.5}$	1.39	+0.39 m
Hedges and Mase (2004)	$R_{2\%} = (0.34 + 1.49\xi_0)H_S$	0.95	---
Stockdon et al. (2006)	$R_{2\%} = 0.043(H_0 L_0)^{0.5}$ for $\xi_0 < 0.3$; $R_{2\%} = 1.1(0.35\tan\beta_f (H_0 L_0)^{0.5} + \left(\frac{[H_0 L_0 (0.563\tan\beta_f^2 + 0.004)]^{0.5}}{2}\right)$ for $\xi_0 \geq 0.3$	1.47	+0.43 m

K1 is for a beach slope of 1.9% with mean sediment diameter of 0.16 mm.
K2 is for a beach slope of 1.8% with a mean sediment size of 0.2 mm.
H_0 and H_s is deepwater significant wave height; L_0 is the deepwater waver period; ξ_0 is the deepwater Iribarren number; and tan ***B*** is the beach slope.



Correlation analysis of the Hedges and Mase (2004) equation with three other popular models obtained a R^2 of 0.91 or better for beaches with slopes of 0.3% to 9.8%. This indicates that with a appropriate site-specific correction factor (e.g., K2) these models will produce similar results. Shand et al. (2011) found Hedges and Mase (2004) to be the most accurate model overall for low slope beaches; because of this the Hedges and Mase (2004) equation was selected for use in this study.

References

Carrigy, M.A. 1973. Experiments on the angles of repose of granular materials. Sedimentology (14) 4:147-158.

Cheng, N.S. and K. Zhao. 2017. Difference between static and dynamic angle of repose of uniform sediment grains. International Journal of Sediment Research (32) 2:149-154.

Daniels, R.C. 2016. Impacts of the 2015-2016 El Niño on Coastal Oregon and Washington. Annual Meeting of the Association of American Geographers. San Francisco, California.

Fiedler, J.W., Smit, P.B., Brodie, K.L., McNich, J. and R.T. Guza. 2018. Numerical modeling of wave runup on steep and mildly sloping natural beaches. Coastal Engineering (131) 1:106-113.

Hedges, T.S. and H. Mase. 2004. Modified Hunt's equation incorporating wave set-up. Journal of Waterways, Port, Coastal and Ocean Engineering (130) 3:109-113.

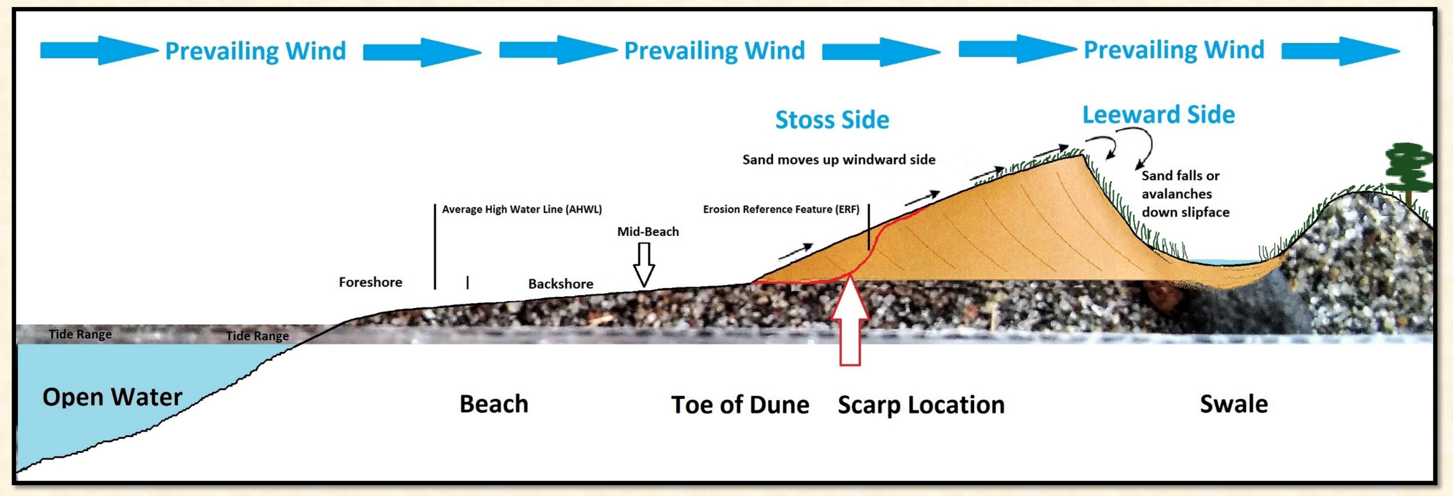
Holman, R.A. 1986. Extreme value statistics for wave run-up on a natural beach. Coastal Engineering (9) 6:527-544.

Ruggiero, P., Komar, P.D., McDougal, W.G., Marra, J.J. and R.A. Beach. 2001. Wave run-up, extreme water levels and the erosion of properties backing beaches. Journal of Coastal Research (17) 2:407-419.

Shand, R.D., Shand, T.D., McComb, P.J. and D.L. Johnson. 2011. Evaluation of empirical predictors of extreme run-up using field data. In 20th Australasian Coastal and Ocean Engineering Conference. Perth Australia.

Stockdon, H.F., Holman, R.A., Howard, P.A. and A.H. Sallenger Jr. 2006. Empirical parameterization of setup, swash, and runup. Coastal Engineering (53) 7:573-588.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan. 2009 Digital Shoreline Analysis System (DSAS) version 4.0 — An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278. *updated for version 4.3.



Beach Width

Beach widths were derived from National Agriculture Imagery Program (NAIP) orthophotography flown on August 16, 2015 for Washington and June 22, 2014 for Oregon. The average high water line (AHWL) and erosion reference feature (ERF), represented by the transition zone where vegetation no longer covers more than 50% of the ground (in areas where the vegetation line is not visible the ERF will be the top edge of the cliff, bluff/scarp, or top center of the seaward most dune), were digitized and used to create an envelope or polygon. This envelope was used to clip the transects created in DSAS. The length attribute for each of the resulting transects was now the approximate width of the backshore –that portion of the beach only affected by waves during exceptional high tides or severe storms.

Mid-Beach Slopes and Scarps

The 1 x 1 meter bare earth LIDAR DEM's used for this study was obtained from by NOAA's Coastal Zone Mapping and Imaging Lidar (CZMIL) system. Horizontal accuracy is 1 m and vertical accuracy is 0.196 m or +/- 0.098 m at the 95% confidence level. LIDAR data for 2014 was collected between July 30-August 13, 2014 and data for 2016 was collected between April 28-May 28, 2016.

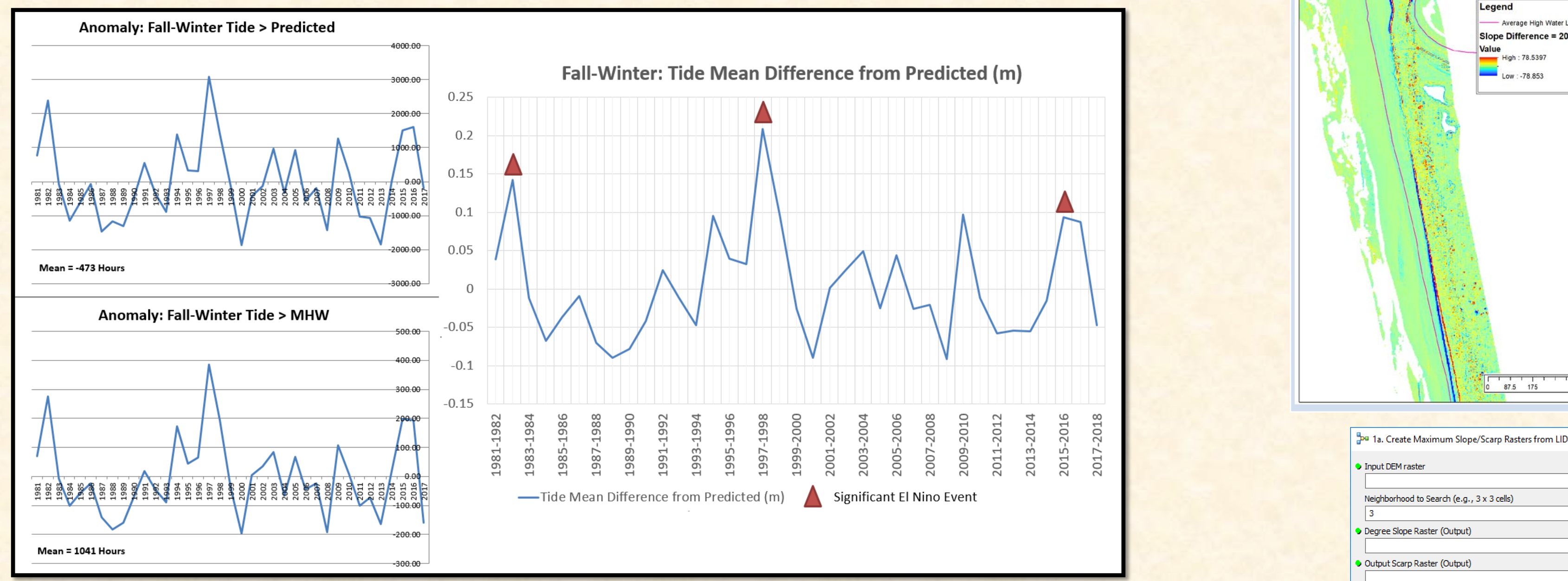
I derived scarp locations for 2014 and 2016 from LIDAR DEM's. Maximum Slope expressed in degrees was calculated for each cell as follows: the Range of Slope values was determined within a roving 3 x 3-cell window (i.e., 3 x 3 m). The Range was then divided by 3 meters to obtain the maximum slope found within each 3 x 3 m neighborhood. To determine if a specific cell represented the located at a scarp I used the concept of the lower Angel of Repose (AoR) and foredune formation. In the beach environment the seaward side of the foredune will be flattened by on-shore winds forming a ramp with an angle of 10 degrees to ½ the AofR (17 Degrees) for 0.2 mm sand (average sand size for the study area) in the dry condition. Based on this I have taken the presence of ocean facing slopes >= 20 Degrees that are present in 2016, but not in 2014, to indicate the presence of a "New Scarp".

An area search was then run that compared the "New Scarp" locations with the clipped transects (note - the transects were clipped by the average high water line and erosion reference feature in 2015, so the transect length approximated the width of the backshore); the search distance used was 49 m or about 1/2 the transect spacing. If a "New" scarp is located within 49 m of a transect it can be said that significant scarping and foredune erosion occurred near the transect in the period between Summer 2014 and Spring 2016 (i.e., large enough that it was not repaired by onshore sediment transport between the end-of-winter, defined as March 31, and May 28, 2016).

Scarp Recovery after five days with Sun, no rain, and onshore winds (10-15 mph) in Ocean Shores, WA
(Photo location 1 mile north of Grays Harbor North Jetty; scarps 1.8 to 2 m high)

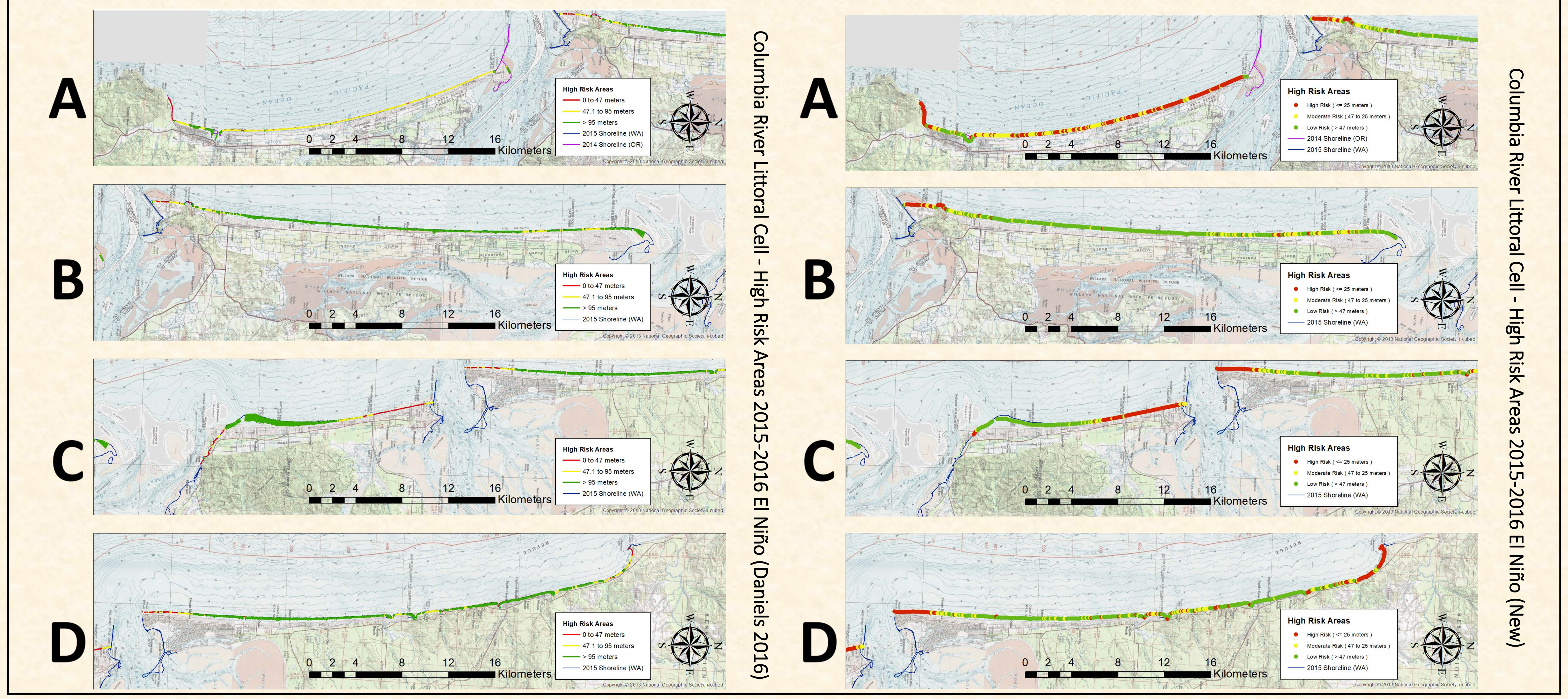
Tides and Water Levels

Hourly Tide elevation data from NOAAs National Ocean Services Station 9440910 Toke Point, WA were analyzed for the period 1981 to 2018. This station was selected because of its long period of continues record and its located at the approximate center of the study area. Missing data points in the station record were estimated based on linear correlation equations derived for adjacent gauges (9439040 Astoria, OR and 9439011 Hammond, OR).

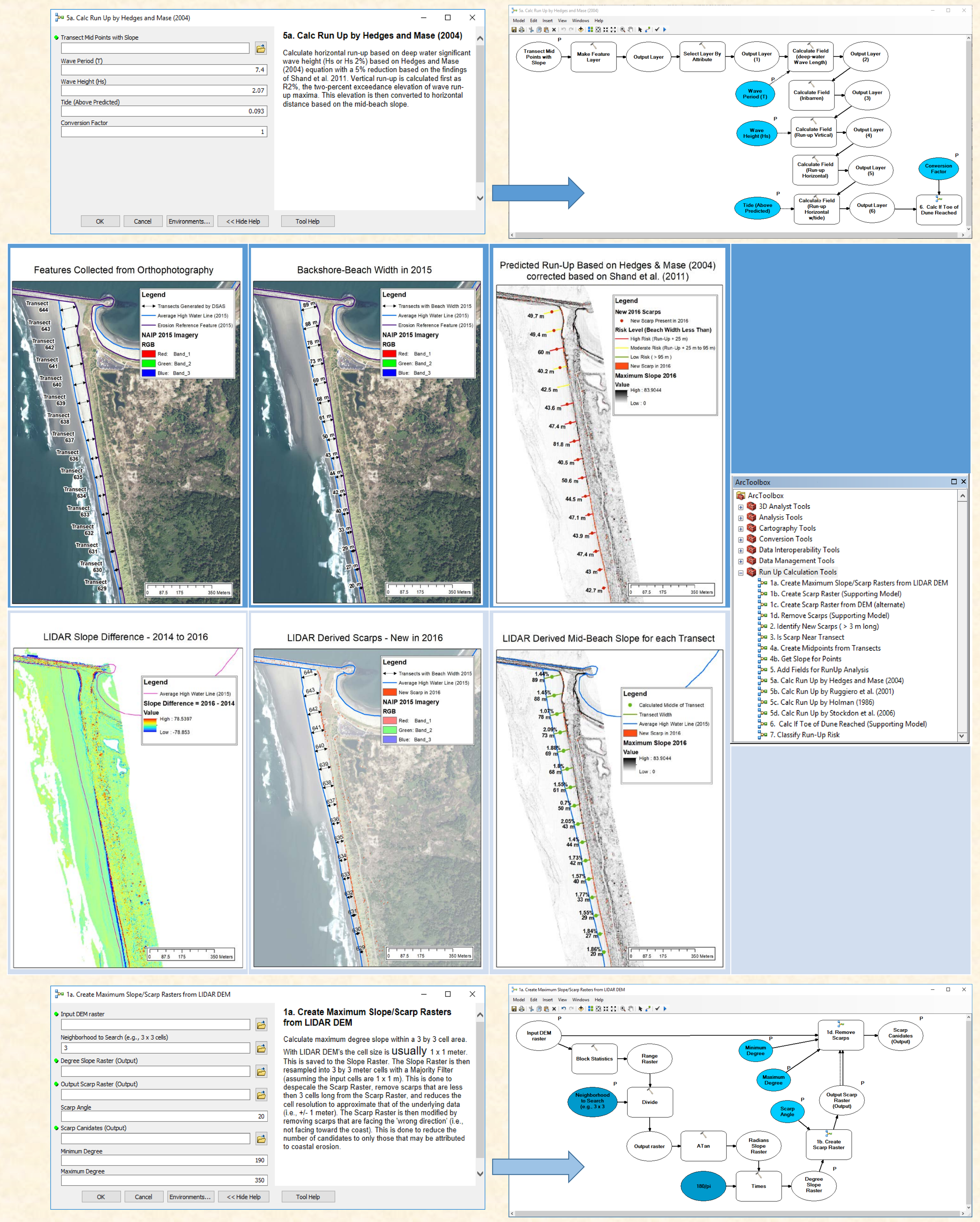


Based on an analysis of hourly tide gage data NOAA's Toke Point, WA I found that during the 2015-2016 winter season (October 1 to March 31) the measured tide heights averaged +0.093 m above predicted; resulting in the beach being impact by an additional 1,239 hours (51 days) with water levels above predicted levels. Prior to calculating the horizontal run-up for each transect this El Nino induced elevation anomaly was added to the calculated vertical run-up.

Shoreline Erosion Risk Mapping



Run-Up Calculation and Scarp Identification Modeling



Accuracy Assessment: Risk vs. Scarp Locations

New Analysis	High Risk	Moderate Risk	Low Risk
Number of Transects	398	287	694
Number with Scarps	253	94	113
% of Transects with Scarps	64%	33%	16%
Daniels (2016) Analysis	**High Risk**	**Moderate Risk**	**Low Risk**
Number of Transects	134	462	797
Number with Scarps	107	312	476
% of Transects with Scarps	80%	68%	60%

Conclusions

This analysis found that empirical run-up models such as Hedges and Mase (2004) can be used to predict the site of 'future' erosion when appropriate site specific values are available and that these models produce comparable results when correction factors are used. In the United States LIDAR derived 1 x 1 m DEMs are now available for most of our Nations open coast. As such the use of "Regional Average" beach slopes should be discouraged and actual slope measurements derived from LIDAR used. This enhancement resulted in significantly improved erosion risk mapping for our study area (e.g., only 16% of the transects identified as being at 'Low Risk' in the new analysis showed evidence of scarping, down from 60% for the 'Low Risk' category in the previous analysis).

Results

The vulnerability of the northwest Oregon and southwest Washington ocean coast to coastal erosion was calculated for 1,420 shore perpendicular transects located 100 m apart for the 2015-2016 Niño event. The transects were created using the USGS Digital Shoreline Analysis System (Thieler et al. 2009). In this region major El Niño events are associated with region-wide beach recession, dune scarping, and episodic coastal flooding during the weeks leading up to and after the Winter Solstice.

- During Fall-Winter of the 2015-2016 El Niño the number of hours were the observed tide exceeded the predicted tide and mean high water was 197 hours (276 hours 1982-1983;387 hours 1996-1997); the mean tide elevation was +0.093 m above predicted.
- Analysis of Wave Height and Period data for 2009-2017 from the Grays Harbor, WA and Astoria, OR CDIP Buoy obtained a Significant Wave Height (Hs) of 2.07 m and Deep Water period of 7.40 sec. This is higher than the previously accepted Regional average of 1.97 m and 7.44 sec. (Daniels 2016).
- The mean beach slope for the study area, derived from the 2016 LIDAR slope raster, was 1.8% with a standard deviation of 3.12%. This is lower than the previously used Regional average of 3%.
- Analysis of the 2014 and 2016 LIDAR data derived a location dataset of "New Scarps", were "New" means a scarp was present in 2016 but not in 2014. Of the 1420 transects in the study area 905 (64%) had identifiable scarping.

Using site specific information resulted in improved run-up calculations. On average, this resulted in horizontal run-up's that were 20 m higher than originally predicted at transects with mid-beach slopes < 3% and run-ups 10 m lower than originally estimated on transects with mid-beach slopes > 3%.

DSAS DIGITAL SHORELINE ANALYSIS SYSTEM   GIS @ WSDOT