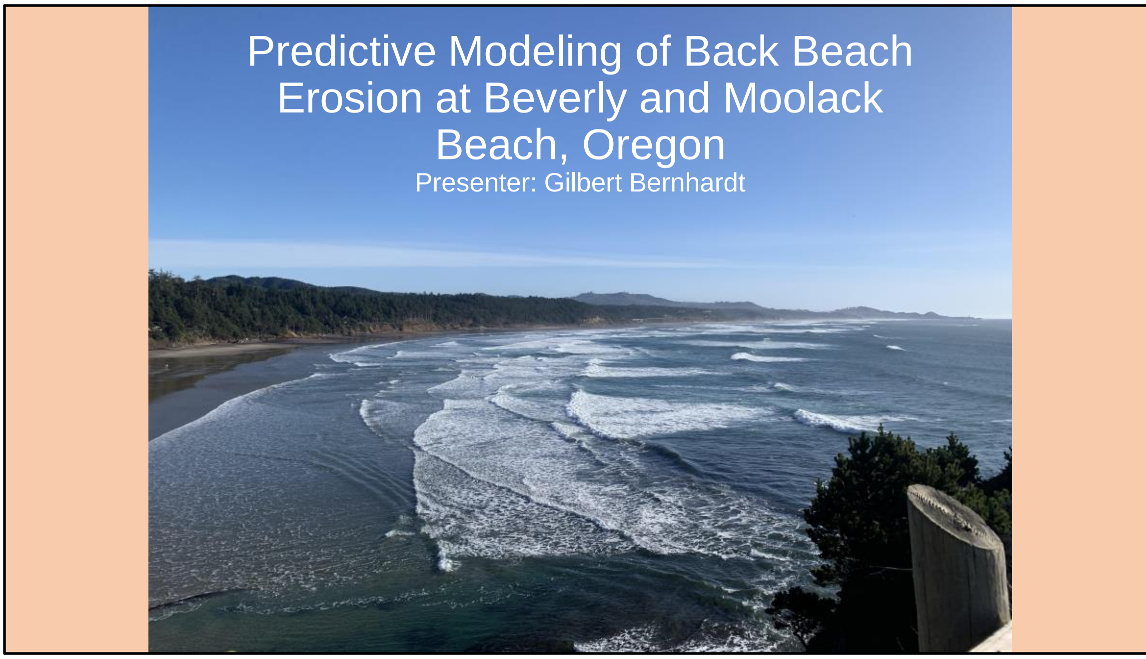
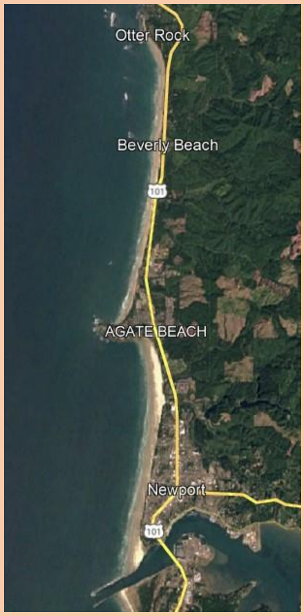
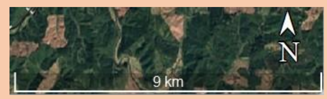


I am very excited to present this overview of our work on "Predictive Modeling of Back Beach Erosion at Beverly and Moolack Beach, Oregon". This study addresses the critical need to predict back beach erosion at Beverly Beach and Moolack Beach situated a few kilometers north of Newport, Oregon. To meet this need, we a robust mathematical model was developed using real-world data from the National Oceanic and Atmospheric Administration (NOAA) and the National Buoy Data Center (NBDC). This view is the study area looking south from Otter Crest along Beverly and Moolack Beaches to Yaquina Head.



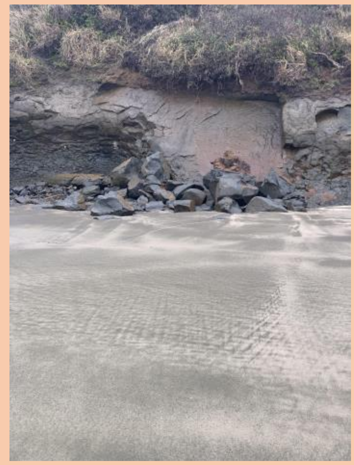
Location of Study Area



The study area is approximately 8 kilometers of arcuate sandy beaches protected by the headlands at Yaquina Head at Agate Beach to the south and Otter Rock to the North. The northern half of the beach is named Beverly Beach, and the southern half is named Moolack Beach. The beach experiences a mean tidal range of 2.5 meters. Ranging from a -1.356 meter Mean Lower-Low Water to 1.144 meter Mean Higher-High Water or tide. The tide data is based on mean sea level measurements collected between 1983 and 2001 measured at the NOAA station located at South Beach, Oregon. The northern beaches are wide and sandy, while the lower third features narrow sandy areas and wave-cut platforms.

Circular Slump

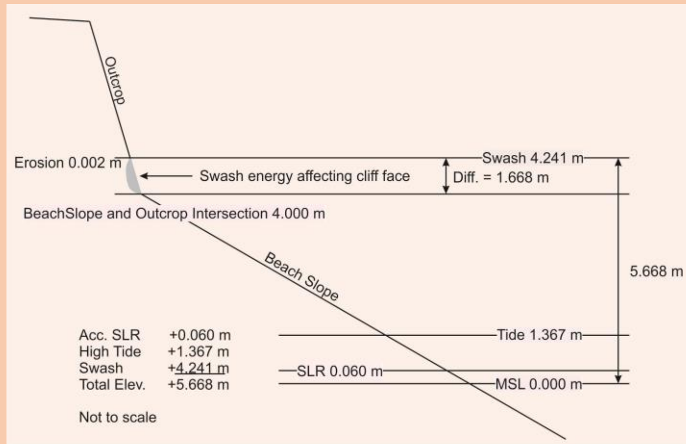
Rock Fall



The beaches are near Highway 101, homes, and businesses situated on terraces above the back beach seacliff. This geographical arrangement highlights the need for a reliable forecasting tool. The coastline in this area is susceptible to mass movements, including circular slumps and rockfalls. These natural events pose continuous safety risks to the highway, residential areas, and businesses. The scarps from circular slumps, visible in the left photograph, occur in Pleistocene terrace deposits.

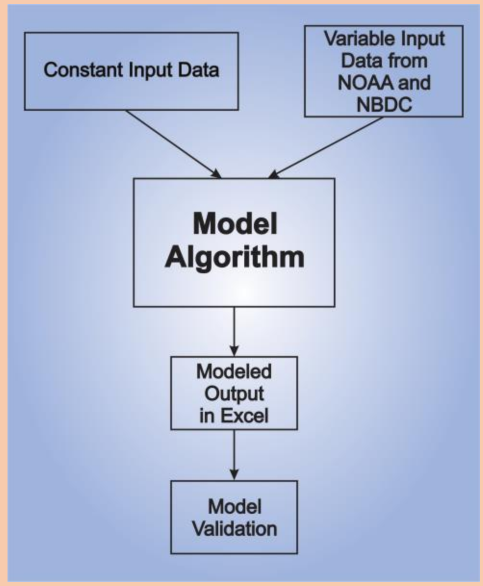
Rockfalls, often accompanied by soil and terrace debris, occur mostly in the Astoria formation. Four major active slumps directly impact Highway 101 along the northern half of the beach.

Create a model that determines the amount of erosion from swash energy.



Because of the danger of catastrophic damage due to the erosion of the sea cliffs occurring on the back beaches at Beverly and Moolach beaches and indeed along most of the west coast of the United States, a model was designed that would compute the amount of erosion occurring at the intersection of the back beach and the back beach escarpment, due to sea level rise, high tide, and swash.

Back Beach Erosion Model

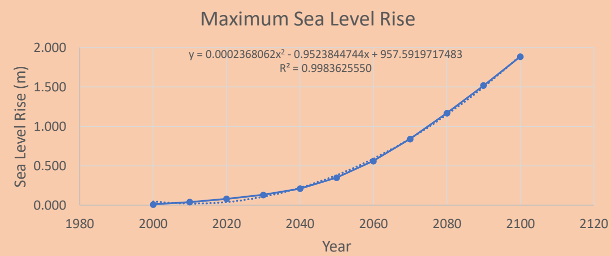


This is a simplified flow chart for the Back Beach Erosion Model. The next portion of the talk will discuss the inputs, the formulas used in the model algorithm, the model output, and, finally, model validation.

Constant Input Data

Input the computed maximum sea level rise, slr, for your area (Newport Oregon) since 2000 in meters.

NOAA | Coastal County Snapshots



compute projected		
Maximum sea level rise (polynomial)		
y = 0.0002368062x2 - 0.9523844744x + 957.5919717483		
year 2024	0.060391134	
Year 2025	0.066834963	
difference	0.0064438	
daily difference (dd)	0.0000088	
based on no. HT per yr.		

There are two sets of input data: constant input data and variable input data. Constant input data provides foundational context to the model, while variable input data captures dynamic changes within the model. Both types of features play crucial roles in building accurate and robust models. The next four slides will discuss input data for the model. The NOAA link shown in the figure provides the data for the maximum sea level rise since 2000 for any coastal county in the United States. The graph represents the maximum sea level rise per year from 2000 to 2100. It provides crucial information for long-term projects and structures. For structures with long lifespans (e.g., homes, roadways) or critical functions (power plants, ports, hospitals), NOAA recommends using the maximum sea level rise scenarios. Using the polynomial equation, we determine the annual maximum sea level rise for Lincoln County. A model sub-routine computes elevations at the study’s beginning and end. The difference between modeled periods (diff) calculates the sea level rise for specific years (e.g., 2025 minus 2024). Daily difference (dd) is derived by dividing this annual difference by 730 (number of high tides per year). The modeled calculations are shown in the slide using the polynomial equation shown in the graph for year 2024.

Input the unconfined rock strength of the rock where the wave impact occurs in kg/m^3.

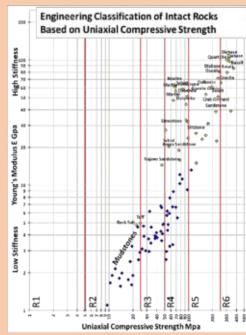


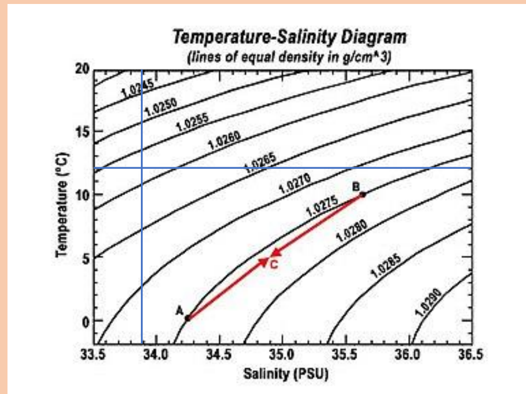
Table 4-3 National Engineering Handbook Part 631: Engineering Classification of Rock Materials (NEH, 2017)

Range of Unconfined Compresssive Strength (Mpa)	Rock Class	Hardness Category	Field Character	Typical Rock Types
>250	R6	Extremely Hard Rock	Can't be broken with rock pick	Granite, Basalt, Quartzite
100 to 250	R5	Very Hard Rock	Breaks only after repeated heavy blows	Cemented Sand, Chert
50 to 100	R4	Hard Rock	Hand sample requires repeated hammer blows to break.	Dolostone, Limestone, Compacted Shale
12.5 to 50	R3	Moderately Hard Rock	Indurated, breaks with a single hammer blow	Siltstone, Mudstone, Coal, Concrete
5 to 12.5	R2	Moderately Soft Rock	Dents when hit with a rock pick	Gypsum, Anhydrite, Rock Salt, Mudstone, Chalk
1 to 5	R1	Soft Rock	Can be crushed between fingers	Diatomite, Tuff,
<1	R0	Soil	Unindurated	Mud, Soil

rocktype	silty mudstone				
density	2650.000	kg/m^3			
unconfined compressive rock strength(ucrs)	12.5	Mpa	127.465	kg/cm^2	1274650.000	kg/m^2

The Astoria Formation outcrop shown in this photo pinches out at Yaquina Head at the southern end of our study area. Rocks assigned to the Astoria Formation typically consist of yellow to gray, massive to cross-bedded, medium- to fine- grained, feldspathic, locally tuffaceous or micaceous sandstone interbedded with varying amount of silty shale. The rock affected in the study area is a silty mudstone. We used an estimated uniaxial compressive strength of 12.5 Mega pascals or about 1.27 million kg/m^3. This information is sourced from Table 4-3 of the National Engineering Handbook's Engineering Classification of Rock Materials.

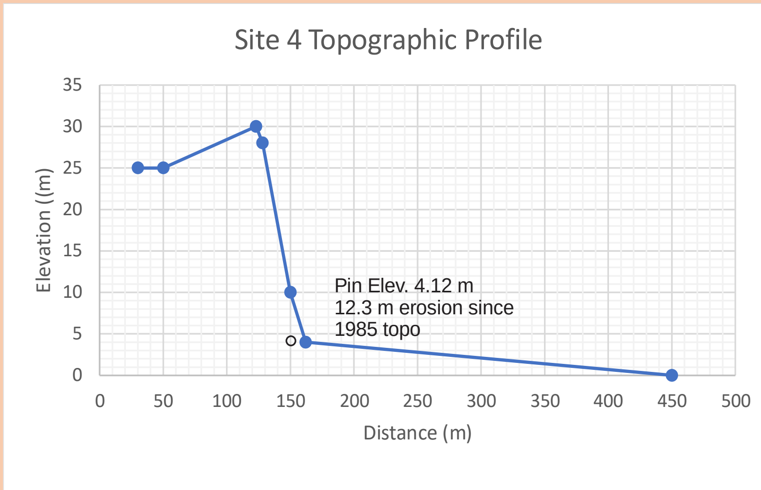
Input the density of the seawater in kg/m^3 by estimating it from this chart.



*NASA **public domain** in the United States*

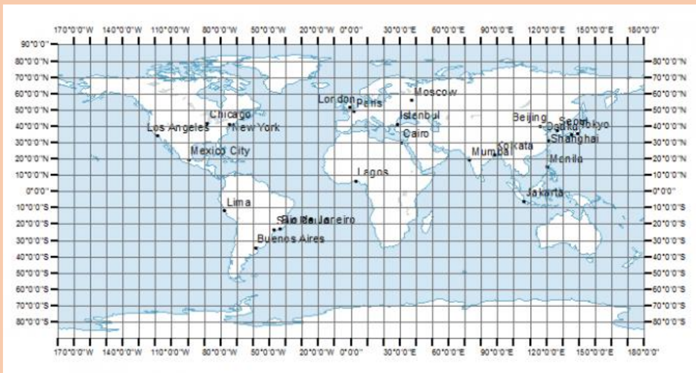
NBDC data from buoy no. 46050, Stonewall Bank was used to determine the average water temperature for the year 2023. The mean water temperature was 12.09^{o} C. The estimated water density from the Temperature-Salinity Diagram for that temperature is about 1.0258 g/cm^3 which is equivalent to 1025.8 kg/m^3.

Input the elevation of intersection of beach slope with cliff face in meters



The profiles for each validation site were based on Google Earth 1985 datum and adjusted according to the location and time of the tide line, the beach slope, the distance to tide line, the height of tide at that time, the swale height computation and sea level rise calculation. The average percent slope is 1.39%. The actual erosion pin elevation at each site used for model validation, presented later in the talk, was always above the slope intersection with the back beach sea cliff. For our example, the intersection of beach slope with cliff face was 4.12 m.

Input Gravity Constant



The force of gravity varies with latitude and increases from about 9.780 m/s^2 at the Equator to about 9.832 m/s^2 at the poles.

Boynton, Richard (2001). "*Precise Measurement of Mass*" (PDF). *Sawe Paper No. 3147*. Arlington, Texas: S.A.W.E., Inc.

Gravity is slightly weaker at the equator compared to the poles due to the Earth's shape and its rotation. Therefor, force of gravity varies with latitude and increases from about 9.780 m/s^2 at the Equator to about 9.832 m/s^2 at the poles. The study area is at latitude 44^{o} 43’ 25”N and the force of gravity used in the model is approximately 9. 806 m/s^2.

Input NOAA and NBDC Variable Data

- The data is cleaned from information acquired from current and historic tide data obtained from NOAA and current and historic swell data obtained from NBDC at the following url's: https://tidesandcurrents.noaa.gov/
- and https://www.ndbc.noaa.gov/

16			
17	Date	APD	High Tide (HT)
18		sec	m
19	1/1/2024	8.909	1.056
20	1/1/2024	8.909	1.056
21	1/2/2024	7.335	1.126
22	1/2/2024	7.335	0.863
23	1/3/2024	7.860	1.265
24	1/3/2024	7.860	0.573
25	1/4/2024	8.252	1.172
26	1/4/2024	8.252	0.393
27	1/5/2024	10.119	1.134
28	1/5/2024	10.119	0.468
29	1/6/2024	9.429	1.367
30	1/6/2024	9.429	0.491
31	1/7/2024	8.910	1.273

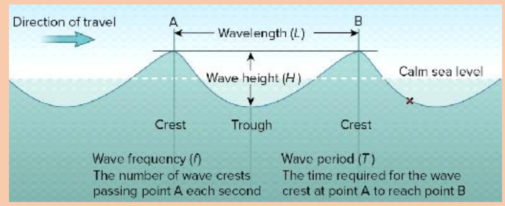
Next the average wave period, APD, and high tide, HT, data per day are the variable input data sets. The APD is measured in seconds for all waves during a 20-minute period. This data is then presented by NBDC in 6-minute intervals per hour for each day. Then for the model, the daily 6-minute APD was averaged for a daily APD. The APD data is derived from Stonewall Bank Buoy station located 37 kilometers west of Newport, Oregon. On the central coast of Oregon, we have semidiurnal mixed tides and only the high tides effect the model. At the South Beach tide sstation we generally have two high tides daily. This is a massive amount of data that has to be cleaned and processed for the model input. It is hand processed in the excel model and will be automated when converted to Python. An example of the cleaned data is shown on the right in the slide.

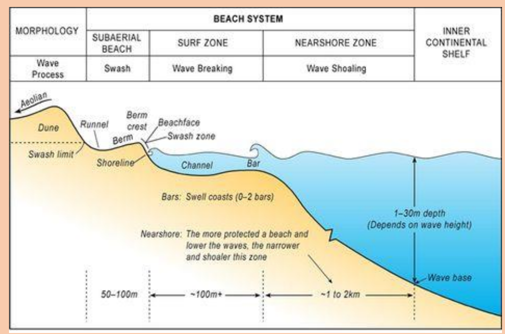
Model Algorithm

Inner Continental Shelf (Wavelength L_d)

$L_d = (g * APD^2/(2\pi))$

APD = average T in the upper figure





The formulas for the model algorithm have been separated into five separate oceanic morphological zones for this discussion: inner continental shelf, near shore zone, surf zone, swash zone, and back beach. The **Inner Continental Shelf** is characterized by a relatively **gentle, shallow, and submerged** extension of the continental landmass, typically extending from the shoreline to a depth of approximately **200 meters** or less. The only deep-water information needed is wavelength. The wavelength L_d is calculated from the empirical formula shown. APD is the average time required for the wave crest at point A to reach point B. The formula is used as we transition through the nearshore zone to the surf zone to determine shallow water wave depth.

Model Algorithm Surf Zone

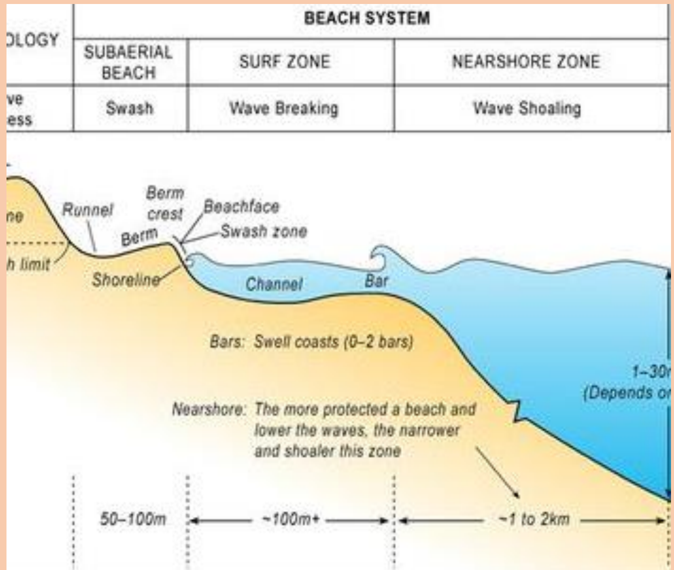
Formulas used to measure conditions in the surf zone for wave depth, wavelength, celerity, and breaker height are as follows:

2. Shallow water wave depth, S_d=L_d/20 in meters,

3. Shallow water wavelength, L_s = APD$(gS_d)^{0.5}$ in meters,

4. Celerity. C = $\sqrt{gS_d}$ in m/s^2, and

5. Breaker height, H_b = L_s/7 in meters.



The **surf zone** is a dynamic coastal area where **breaking waves** interact with the shoreline, shaping features such as sandbars, troughs, and longshore currents. As the swell approaches the surf zone and transitions from deep water to the surf zone, the shallow water wave depth S_d is calculated using formula 2: S_d=L_d/20. Deep water wavelength Ld was obtained from formula 1 on the previous slide. The shallow water wavelength L_s is calculated from formula 3. The celerity or velocity, C, of the breaking wave is given in formula 4, and the breaking wave height H_b is derived from formula 5. The results from the preceding formulas are used in the next set of formulas used to model wave action in the swash zone.

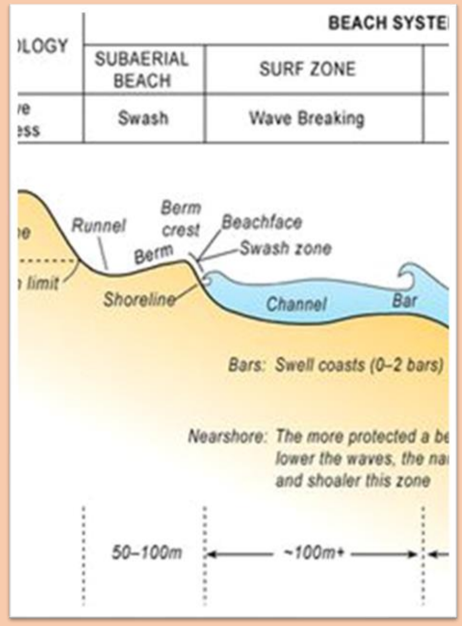
Model Algorithm Swash Zone

The formulas used to model conditions in the Swash Zone for height of Swash Zone, cumulative sea level rise and accumulated water levels are as follows:

6.Swash height $Z = 0.125\ H_b^{0.625}\ (g*APD^2)^{0.375}$ in meters,,

7. Sea level rise slr = yb + dd in meters, for each high tide, and

8. Water height $W_h = Z+HT+slr$ in meters



The **swash zone** is the area of the beach where **waves rush up the shore after breaking**, resulting in back-and-forth water movement and sediment deposition. Once the wave breaks, the depth of the swash zone, Z, is determined from formula 6. Then the cumulative predicted sea level rise for each high tide cycle is computed for the study period using formula 7. Finally, the water height W_h or elevation of water reaching the back beach which includes swash height, high tide elevation, and the sea level rise is derived using formula 8. This is the water that may affect the sea cliffs in the back beach.

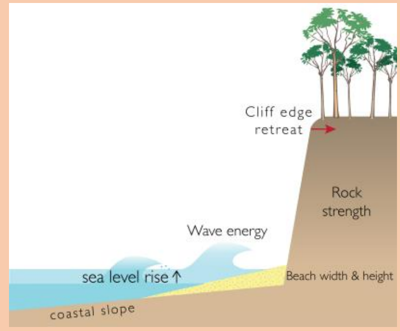
Model Algorithm Back Beach

The formulas used solve for elevation difference between the max. water ht. (E_d) and the beach slope intersection (S_i) with the back beach outcrop, wave energy, and depth of erosion on the back beach sea cliffs are as follows:

9.Elevation difference, $E_d = W_l - S_i$ in meters,

10. Wave energy, $Epw = (1/8) \cdot \rho \cdot g \cdot E_d$ in kg/m^2,

11. Erosion, E = Epw / ucrs in meters



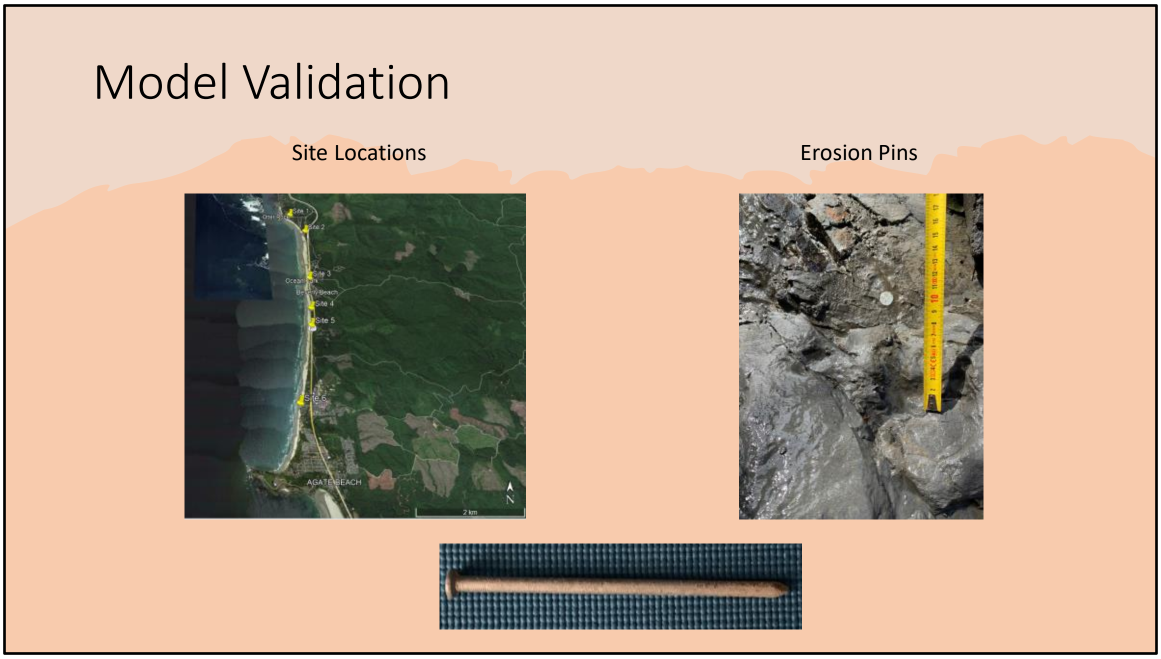
To determine the surf that will impact the back beach sea cliff or outcrop, the elevation difference (E_d) between the water height and the slope intersection with the back beach outcrop is determined using formula 9. Only positive computed values will impact the escarpment. Then the energy or the power of the surf's impact on the outcrop (Epw) is computed with formula 10. Finally, the amount of erosion (E) for each daily high tide is computed using formula 11. The results are in kg/m^2 . UCRS used in the formula, is the constant input for rock strength of the outcrop and is in kg/m^3. When Epw is divided by ucrs the units balance to meters giving linear erosion in the outcrop.

The photograph was taken during a king tide on Christmas day in 2022 to illustrate the waves breaking against the back beach sea cliffs.

Modeled Output in Excel

Date	APD	High Tide (HT)	Swell length (L_o) L_o =(g*APD^2/(2π))	Shallow water wave depth S_d=L_o/20	Shallow water wave length (L_s) L_s = APD (gS_d)$^{0.5}$	Shallow water Celerity C = √gS_d	Breaker Height H_b (H_b) = Ls/7	swash zone (Z) ht see above	cumulative sea level rise rise (slr)	water level (W_l) Z+HT+slr	slope intersection (S_i) with outcrop E_d=W_l-S_i	Epw = (1/8) · ρ · g · E_d	depth of erosion E_d=Epw/UCRS	
	sec	m	m	m	m	m/sec	m	m	m	(m)	m	kg/m^2	m	
1/1/2024	8.909	1.056	123.871	6.194	69.430	7.793	9.919	3.786	0.22488	5.067	0.967	1215.202	0.000953	
1/1/2024	8.909	1.056	123.871	6.194	69.430	7.793	9.919	3.786	0.22488	5.067	0.967	1215.202	0.000953	
1/2/2024	7.335	1.126	83.977	4.199	47.069	6.417	6.724	2.567	0.22490	3.917	-0.183	-229.424	-0.000180	
1/2/2024	7.335	0.863	83.977	4.199	47.069	6.417	6.724	2.567	0.22491	3.654	-0.446	-560.001	-0.000439	
1/3/2024	7.860	1.265	96.428	4.821	54.048	6.876	7.721	2.947	0.22492	4.437	0.337	423.662	0.000332	
1/3/2024	7.860	0.573	96.428	4.821	54.048	6.876	7.721	2.947	0.22493	3.745	-0.355	-446.171	-0.000350	
1/4/2024	8.252	1.172	106.277	5.314	59.568	7.219	8.510	3.248	0.22495	4.645	0.545	685.168	0.000538	
1/4/2024	8.252	0.393	106.277	5.314	59.568	7.219	8.510	3.248	0.22496	3.866	-0.234	-294.024	-0.000231	
1/5/2024	10.119	1.134	159.796	7.990	89.565	8.851	12.795	4.884	0.22497	6.243	2.143	2693.512	0.002113	
1/5/2024	10.119	0.468	159.796	7.990	89.565	8.851	12.795	4.884	0.22498	5.577	1.477	1856.361	0.001456	
1/6/2024	9.429	1.367	138.758	6.938	77.774	8.248	11.111	4.241	0.22500	5.833	1.733	2178.203	0.001709	
1/6/2024	9.429	0.491	138.758	6.938	77.774	8.248	11.111	4.241	0.22501	4.957	0.857	1077.081	0.000845	
1/7/2024	8.910	1.273	123.910	6.196	69.452	7.794	9.922	3.787	0.22502	5.285	1.185	1489.660	0.001169	
1/7/2024	8.910	0.226	123.910	6.196	69.452	7.794	9.922	3.787	0.22503	4.238	0.138	173.590	0.000136	
1/8/2024	7.858	1.497	96.377	4.819	54.019	6.874	7.717	2.946	0.22505	4.668	0.568	713.482	0.000560	
1/8/2024	7.858	0.980	96.377	4.819	54.019	6.874	7.717	2.946	0.22506	4.151	0.051	63.625	0.000050	
1/9/2024	7.960	1.710	98.897	4.945	55.432	6.963	7.919	3.023	0.22507	4.958	0.858	1078.077	0.000846	
1/10/2024	9.581	1.115	143.270	7.164	80.303	8.381	11.472	4.379	0.22509	5.719	1.619	2034.895	0.001596	
1/10/2024	9.581	1.731	143.270	7.164	80.303	8.381	11.472	4.379	0.22510	6.335	2.235	2809.227	0.002204	
1/11/2024	8.138	0.973	103.366	5.168	57.937	7.119	8.277	3.159	0.22511	4.357	0.257	323.409	0.000254	
1/11/2024	8.138	1.759	103.366	5.168	57.937	7.119	8.277	3.159	0.22512	5.143	1.043	1311.432	0.001029	
1/19/2024	6.719	1.539	70.451	3.523	39.488	5.877	5.641	2.153	0.22531	3.918	-0.182	-229.396	-0.000180	
1/19/2024	6.719	0.661	70.451	3.523	39.488	5.877	5.641	2.153	0.22532	3.040	-1.060	-1333.032	-0.001046	
1/20/2024	7.342	1.584	84.120	4.206	47.149	6.422	6.736	2.571	0.22534	4.380	0.280	352.338	0.000276	
1/20/2024	7.342	0.831	84.120	4.206	47.149	6.422	6.736	2.571	0.22535	3.627	-0.473	-594.172	-0.000466	
1/21/2024	7.075	1.719	78.120	3.906	43.786	6.189	6.255	2.388	0.22536	4.332	0.232	291.562	0.000229	
1/21/2024	7.075	1.032	78.120	3.906	43.786	6.189	6.255	2.388	0.22537	3.645	-0.455	-571.986	-0.000449	
1/22/2024	6.756	1.746	71.240	3.562	39.930	5.910	5.704	2.177	0.22539	4.149	0.049	61.197	0.000048	
1/22/2024	6.756	1.095	71.240	3.562	39.930	5.910	5.704	2.177	0.22540	3.498	-0.602	-757.099	-0.000594	
1/23/2024	6.642	1.477	68.844	3.442	38.587	5.810	5.512	2.104	0.22541	3.806	-0.294	-368.952	-0.000289	
1/24/2024	6.800	1.166	72.166	3.608	40.449	5.948	5.778	2.206	0.22542	3.597	-0.503	-632.260	-0.000496	
1/24/2024	6.800	1.737	72.166	3.608	40.449	5.948	5.778	2.206	0.22544	4.168	0.068	85.507	0.000067	
1/25/2024	7.940	1.184	98.380	4.919	55.142	6.945	7.877	3.007	0.22545	4.416	0.316	397.504	0.000312	
1/25/2024	7.940	1.569	98.380	4.919	55.142	6.945	7.877	3.007	0.22546	4.801	0.701	881.468	0.000692	
1/26/2024	7.521	1.155	88.276	4.414	49.479	6.579	7.068	2.698	0.22547	4.078	-0.022	-27.086	-0.000021	
1/26/2024	7.521	1.475	88.276	4.414	49.479	6.579	7.068	2.698	0.22549	4.398	0.298	375.172	0.000294	
1/27/2024	6.808	1.318	72.343	3.617	40.548	5.956	5.793	2.211	0.22550	3.754	-0.346	-434.301	-0.000341	
1/27/2024	6.808	1.570	72.343	3.617	40.548	5.956	5.793	2.211	0.22551	4.007	-0.093	-117.519	-0.000092	
1/28/2024	7.456	1.260	86.767	4.338	48.633	6.522	6.948	2.652	0.22552	4.137	0.037	46.968	0.000037	
1/28/2024	7.456	1.387	86.767	4.338	48.633	6.522	6.948	2.652	0.22554	4.264	0.164	206.624	0.000162	
1/29/2024	8.035	1.198	100.769	5.038	56.481	7.029	8.069	3.080	0.22555	4.503	0.403	507.020	0.000398	
1/29/2024	8.035	1.242	100.769	5.038	56.481	7.029	8.069	3.080	0.22556	4.547	0.447	562.344	0.000441	
1/30/2024	8.646	1.249	116.661	5.833	65.388	7.563	9.341	3.565	0.22557	5.040	0.940	1181.678	0.000927	
1/30/2024	8.646	1.098	116.661	5.833	65.388	7.563	9.341	3.565	0.22559	4.889	0.789	991.885	0.000778	
1/31/2024	7.956	1.502	98.794	4.940	55.374	6.960	7.911	3.019	0.22560	4.747	0.647	813.306	0.000638	monthly erosion
1/31/2024	7.956	1.082	98.794	4.940	55.374	6.960	7.911	3.019	0.22561	4.327	0.227	285.379	0.000224	0.024 m
February			0.000											
2/1/2024	8.213	1.501	105.260	5.263	58.998	7.184	8.428	3.217	0.22563	4.944	0.844	1060.500	0.000832	

Once the model has been coded into Python, the output for the model will go into another excel output file and will appear like the image shown. All the positive depth of erosion values E_d are summed for any time interval needed (yearly, monthly, or days).

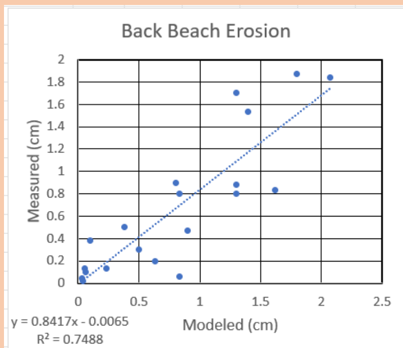


The model was validated by setting 20 cm long, zinc coated, steel spikes at six locations approximately 1 kilometer apart along Beverly and Moolack Beaches. Slightly smaller holes were drilled horizontally and vertically into the rock, Then the nails were coated with Gorilla glue and hammered into the outcrop to minimize fracturing the rock. The pins were set in early January 2024.

Model Validation

1 cm / 0.75 cm measured = X (erosion cm) / 0.38 cm measured

In addition to the periodic physical measurement obtained at the erosion site, a photograph was taken for further analysis and comparison. The photographic analysis was more accurate and consistent than field measurements. The ratio shown on the slide (1 cm (real world) / 0.75 cm measured = X cm (erosion real world) / 0.38 cm measured) was used to determine the amount of erosion.



Site	Date	Measured (cm)	Modeled (cm)
1	2/4/2024	0.9	0.8
	3/7/2024	0.02	0.04
	3/29/2024	0.1	0.06
2	2/4/2024	0.3	0.5
	3/7/2024	0.04	0.03
3	2/1/2024	1.7	1.3
	2/15/2024	0.5	0.38
	3/7/2024	0.2	0.63
	3/16 to 3/29/24	0.38	0.1
3B	4/17/2024	0.13	0.23
4	1/21 to 2/15/2024	0.83	1.62
	3/6 to 3/13/24	0.06	0.83
4B	3/29/2024	0.8	1.3
	4/1724	0.8	0.83
5	1/21 to 2/1/2024	1.53	1.4
	2/2 to 2/15	1.87	1.8
5B	03/13 to 03/29/24	0.47	0.9
	03/29/24 to 04/16/24	0.88	1.3
6	2/15/2024	1.84	2.07
	3/6/2024	0.13	0.05

Model Validation

The amount of erosion was measured at each pin location on numerous occasions. The time between measurements varies at each location depending on weather, tides and accessibility. In some cases, several pins were temporarily inaccessible because they were covered either by sand or rock debris. This slide shows the data acquired and the graph of the data for the 20 measurements obtained from the six sites. Measured erosion data is the dependent variable Y-axis and modeled data is the independent data X-axis. Overall, the data had a correlation coefficient of 0.865 and the best fit linear trendline had an R-squared of 0.7488. This indicates a strong positive linear relationship between the measured and modeled data, suggesting that the model is doing a good job of predicting the measured values.

Thanks

This was a self-funded project, and I could not have performed the field work without the assistance of Frances Lombardi, my citizen scientist associate and friend. We could improve the validation of the model by 1. acquiring accurate profiles for slope intersection and elevation of horizontal erosion pin at each site location, 2. determine the extent of surface erosion on overall erosion due to wet/dry cycle of the siltstone and 3. having uniaxial compression tests run on rock samples for each site. The next phase of the model will predict when rockfall should occur. I think that by using the methods discussed, we have more than validated the functionality of this model. Thank you for giving me the opportunity to present this talk to you. Time permitting, I will now respond to any questions you may have.