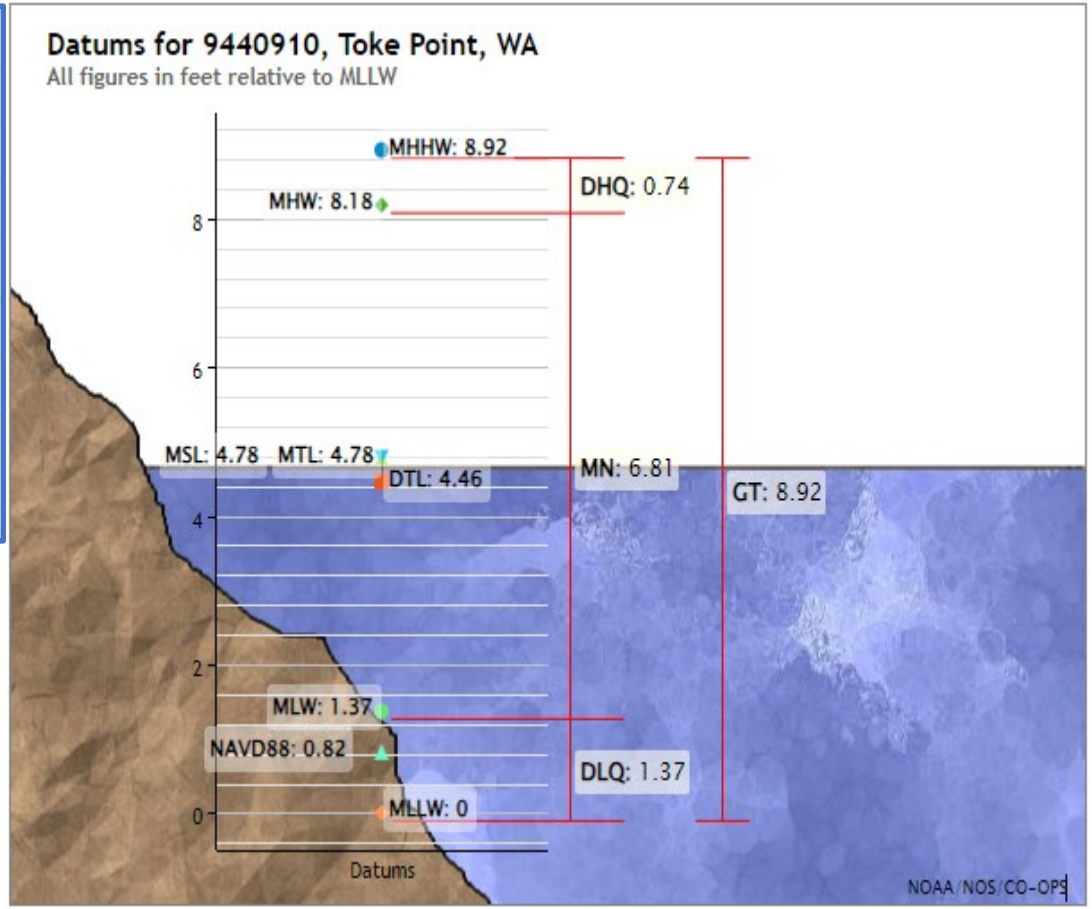
Using a Tide Level Anomaly Index as a Predictor of Coastal Erosion in the Pacific Northwest during El Niño/ENSO events

Datum	Value	Description
MHHW	8.92	Mean Higher-High Water
MHW	8.18	Mean High Water
MTL	4.78	Mean Tide Level
MSL	4.78	Mean Sea Level
DTL	4.46	Mean Diurnal Tide Level
MLW	1.37	Mean Low Water
MLLW	0.00	Mean Lower-Low Water
NAVD88	0.82	North American Vertical Datum of 1988



Datums from NOAA 1983-2001, Station Home Page - NOAA Tides & Currents

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Abstract

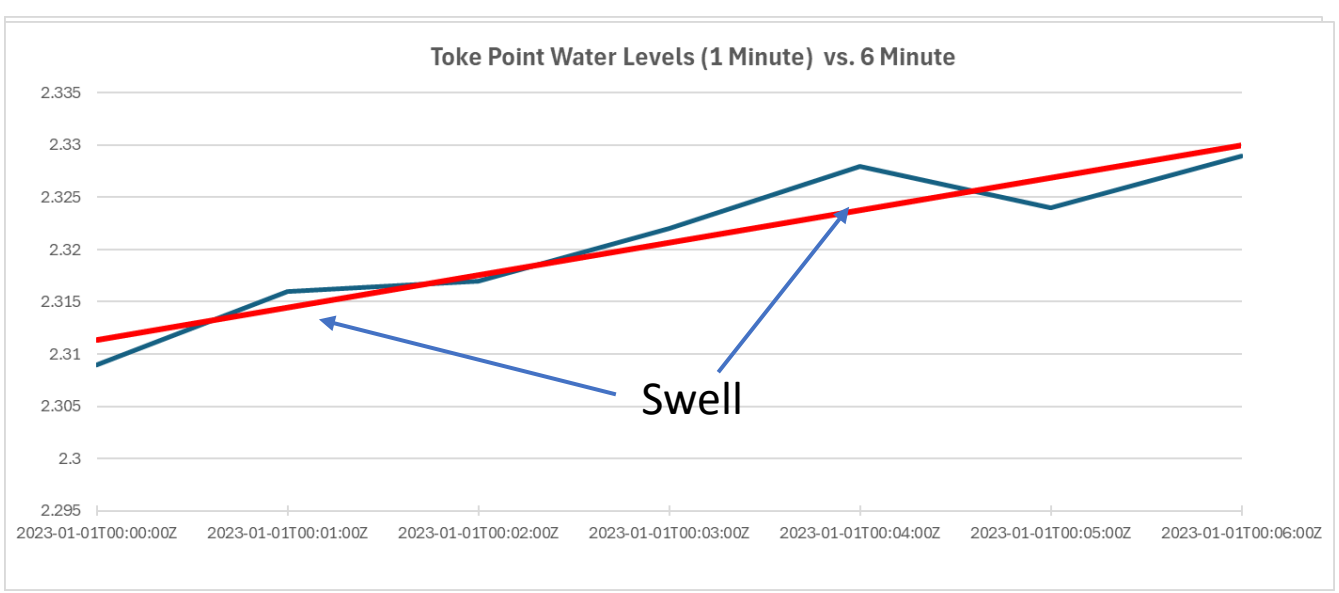
The El Niño event of 2023-2024 had a 95% probability of being one of the stronger events in the last 50 years and was predicted to be as strong as the record 1982-83, 1997-98, or 2015-16 events. Strong events are associated with elevated water temperature and sea levels along the northwest Oregon and southwest Washington coast. During the winter season In the Pacific Northwest (PNW) the amount of time that sea levels exceed the regional mean high-water level (MHW) is directly correlated with increased erosion on sandy beaches. In this study a 'Water Level Anomaly Index' for the northwest Oregon and southwest Washington coast was derived based on tide elevation data from NOAAs National Ocean Services Station 9440910 Toke Point, WA (Missing data points were estimated based on linear correlation equations derived for station Astoria, OR or Hammond, OR). The index represents the number of hours during each Year, and during each Fall-Winter season (October 1 to March 31), that water levels exceed the stations MHW elevation. On average, water levels exceed MHW 1037 hours each Fall-Winter period. During strong El Niño events the number of hours the beach is exposed to elevated water levels increase; for example, during the 2016 event water levels exceeded MHW an additional 196 hours or 8 days. This paper extended this index backward to 1974 and forward to March 2024. It was determined that the 2023 El Nino was weaker than predicted, and in terms of strength was the 7th largest event in the last 51 years (1974 to 2024), falling behind the 1997, 1982, 2015, 1998, 2015, and 1994 events.

Tide Data is Big Data

- What makes BIG Data Big? Changing the number of any parameter will rapidly increase the amount of data collected.
  - Frequency (Time)
  - Location (Geography)
  - Elevation
- Historically even large well funded organizations were unable to store, see, and work with large datasets. This was overcome by using statistics to calculate minimum, means, and maximum values for daily to annual time periods.
- These statistical values were later used in models and estimating regional trends in water level
- A new area of research will be the recovery and re-analysis of historical data to look for and understand the 'why' around outliers -in the past these were 'masked' by the averaging process.
- Discover New information from old Data

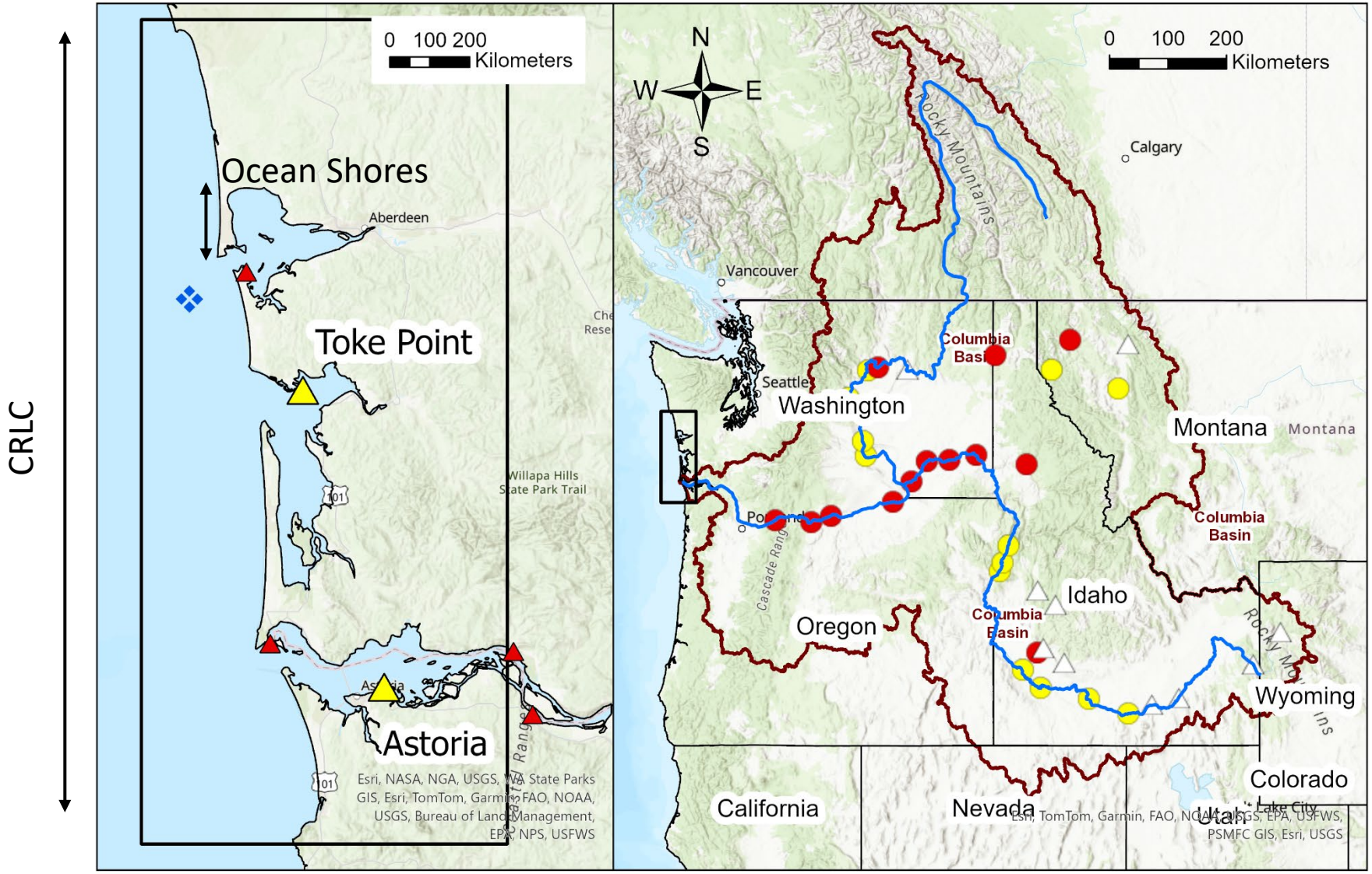
Sample Frequency	Annual Samples Required	Record length (45 bytes) Kb of data	Years of Record 2006 to 2023 (Gb)
1 Minute	525,600	23652	425.736
6 Minute	87,600	3942	70.956
1 Hour	8,760	394.2	7.0956
1 Day	365	16.425	0.29565
1 Month	12	0.54	0.00972
1 Year	1	0.045	0.00081

*Windows 32 bit Operating System maximum file size is 2 GB (4 GB maximum)



Datums from NOAA [Water Levels - NOAA Tides & Currents]

Area of Interest: Columbia River Littoral Cell (CRLC)



Shoreline Length 230 km or 143 miles

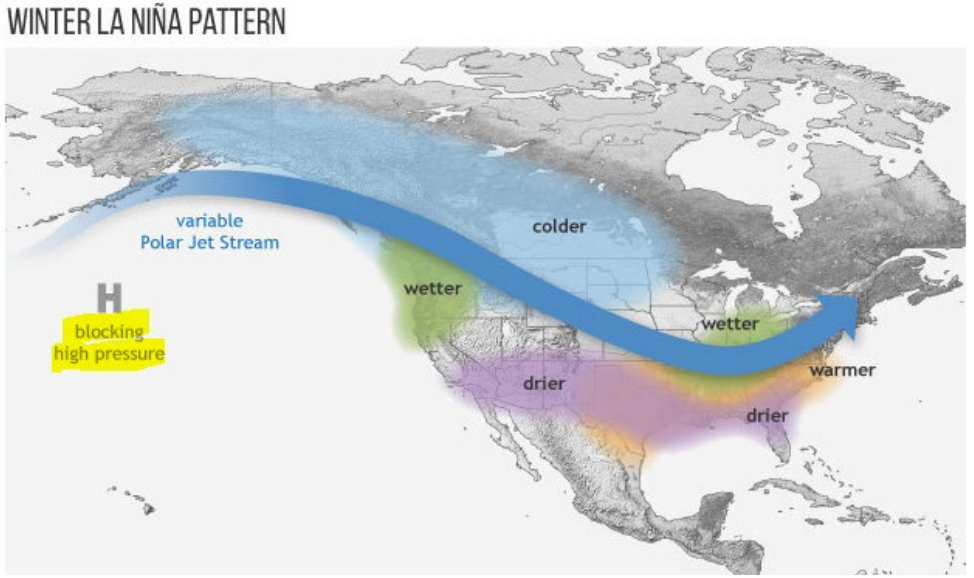
Drainage Area is 668,000 km2 or 258,000 square miles

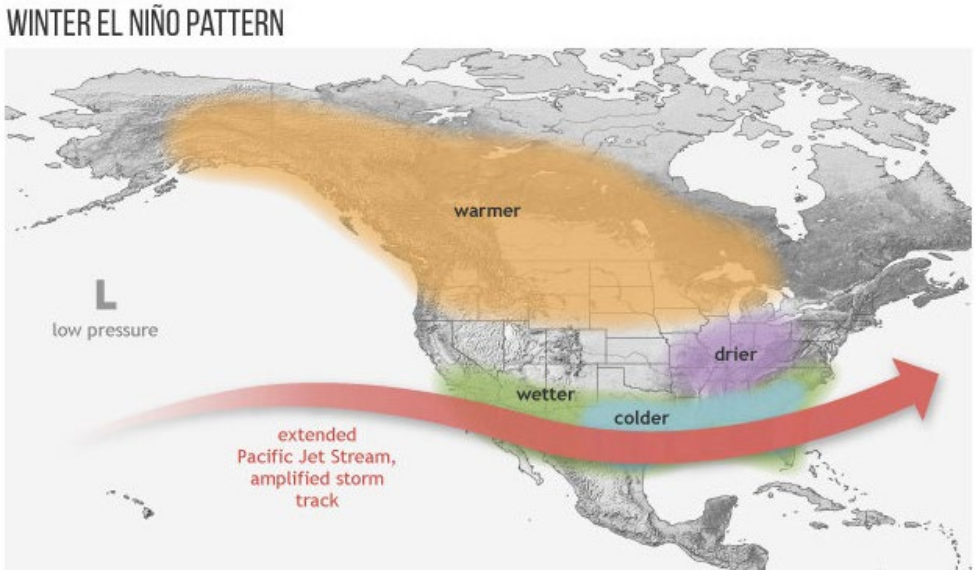
El Niño-Southern Oscillation

El Niño and La Niña are the warm and cool phases of a recurring climate pattern across the tropical Pacific—the El Niño-Southern Oscillation, or “ENSO” for short.

The pattern shifts back and forth irregularly every two to seven years, bringing predictable shifts in ocean surface temperature and disrupting the wind and rainfall patterns across the tropics. These changes have a cascade of global side effects.

El Niño has its strongest influence on U.S. seasonal climate in winter. On the United States West Coast, the Pacific jet stream strengthens and carries more storms across North California and favoring cooler, wetter Winters on the West Coast





Maps from NOAA 2016, [El Niño and La Niña: Frequently asked questions | NOAA Climate.gov]

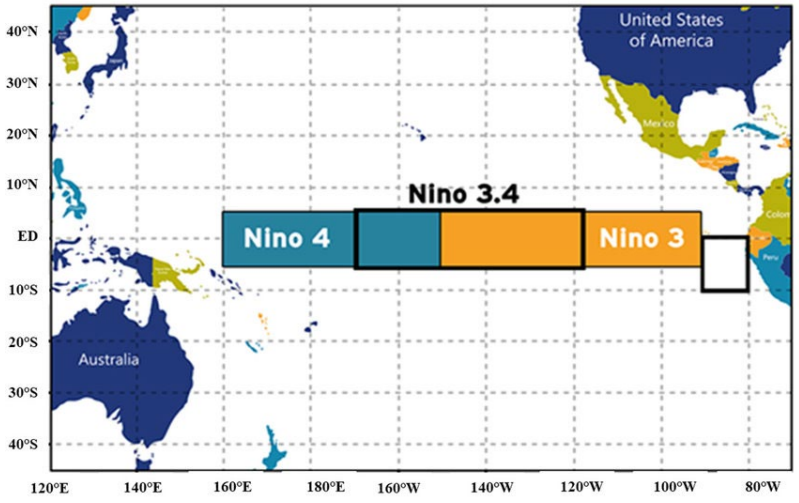
El Nino-South Oscillation (ENSO) 3,4, PDO, SOI and more

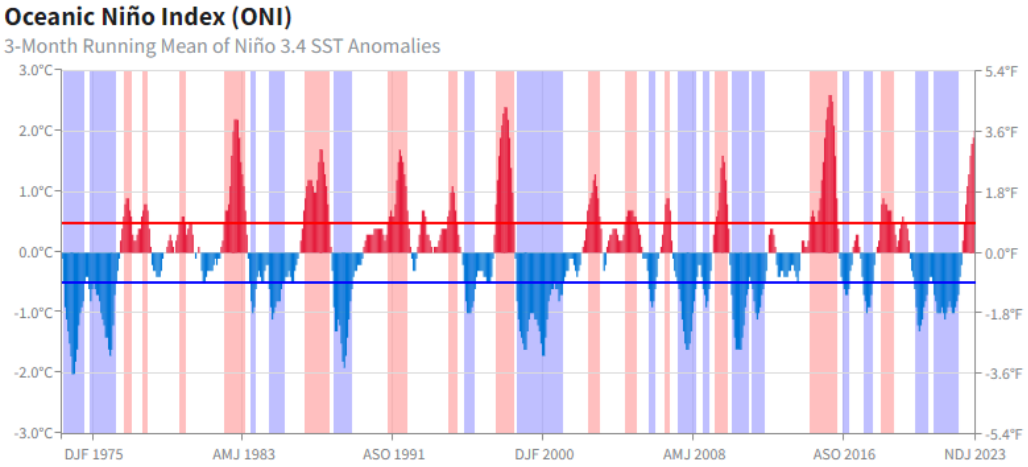
- Several indexes and anomaly measurements have been derived over the years to identify interconnection between monthly and annual climate in the tropical pacific and other parts of the world. Examples of these include:
  - **Southern Oscillation Index (SOI),** the difference between the atmospheric pressure at sea level at Tahiti and at Darwin.
  - **Pacific Decadal Oscillation (PDO)** is a recurring pattern of ocean-atmosphere climate variability centered over the mid-latitude Pacific basin. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20°N
  - **Oceanic Niño Index (ONI),** is based on sea surface temperature (SST) in the east-central tropical Pacific Ocean.
  - **Niño1, Niño2 (combined into Niño1+2), Niño3 and Niño4**—SST measurements taken in the central Pacific, locations selected based on consistent availability of data coming from ships passing through those areas.
  - **Niño3,4 (a.k.a., ENSO 3,4)** has been identified as being the most ENSO-representative in the PNW (Barnston et al. 1997). Located between (and overlapping with) Niño3 and Niño4, this is the region whose temperature anomaly is reflected in the ONI and best correlates with climate impacts on Pacific Northwest of the United States.
- The reason for separate indexes is that the location of the user matters. For example, people in Hawaii may care more about SST, while those in the continental United States are concerned with large-scale changes in sea level air pressure that impacts the location of High- and Low-pressure systems.

El Nino-South Oscillation (ENSO) 3,4, PDO, SOI Comparison

	Mean PDO	SST ENSO3,4	ENSO SOI Traditional	ENSO Standard SL Pressure	Anomaly Over MHW Total	Anomaly Over MHW Fall-Winter
Mean PDO	1					
SST ENSO3,4	0.50	1				
ENSO SOI Traditional	-0.60	-0.90	1			
ENSO Standard SL Pressure	-0.62	-0.90	0.99	1		
Anomaly Over MHW Total	0.34	0.42	-0.40	-0.42	1	
Anomaly Over MHW Fall-Winter	0.22	0.51	-0.46	-0.45	0.64	1

ENSO 3,4 Says 2023-24 is the 4th largest ENSO event on Record

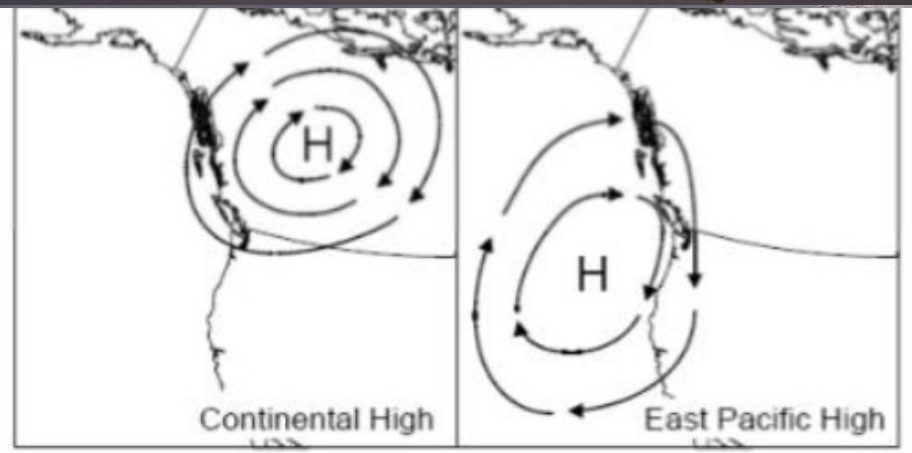




Source: https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt

Winter Climate Patterns the Pacific Northwest Coast

- **Winter Conditions (Fall-winter)**
  - Low Pressure systems generate winds from the S and SW, which generates larger average wave heights and push water (wave setup) onshore causing increased storm surge and longshore sediment motion to the north
  - **During La Nino offshore blocking High pressure north of Hawaii reduces the number of storms impacting the PNW**
- **Summer Conditions (Spring-Summer)**
  - High pressure systems generate winds dominantly from the N and NE, which push water away from the coast and reduces the average wave height.
  - This allows seasonal onshore migration of sediment and beach recovery from winter storms.

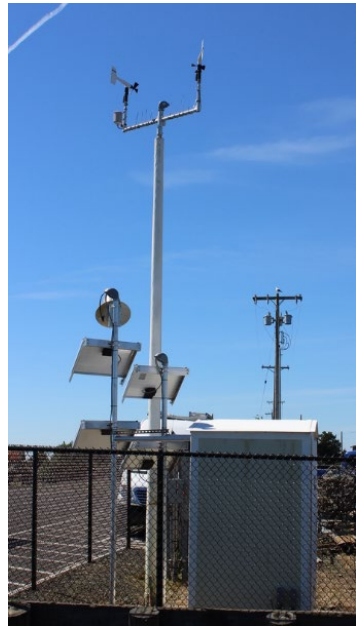


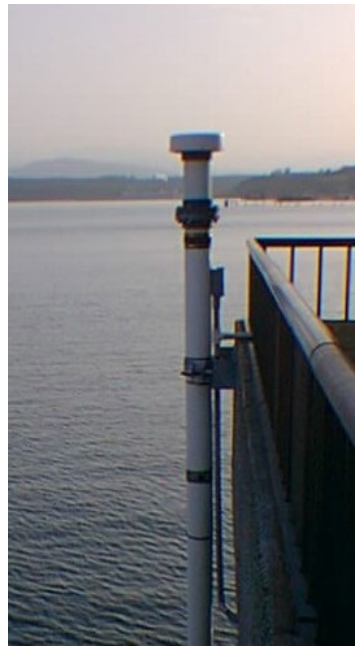
Tidal Water Levels for the Columbia River Littoral Cell

Toke Point Tide Gauge State was selected as representative of the littoral cell because:

1. Length of Record, 1922-Present
2. Minimal Missing Data, 1974- 3/32/2024 (< 4%); Astoria, Oregon Gauge used to fill missing data (R2=0.96)
3. Location near center of cell and adjacent to coast
4. Minimal influence by adjacent large rivers

Tide measurements at Toke Point have been compared with open beach GPS surveys of the observed Average Highwater and Higher High-Water Line (as seen on the ground) and compared with LIDAR elevations models in 1996, 1997 and 2014 and 2016. These tests established that the observed Mean High Water (MHW) and MHHW height could be translated to observed water lines, when wave setup and runup are considered.

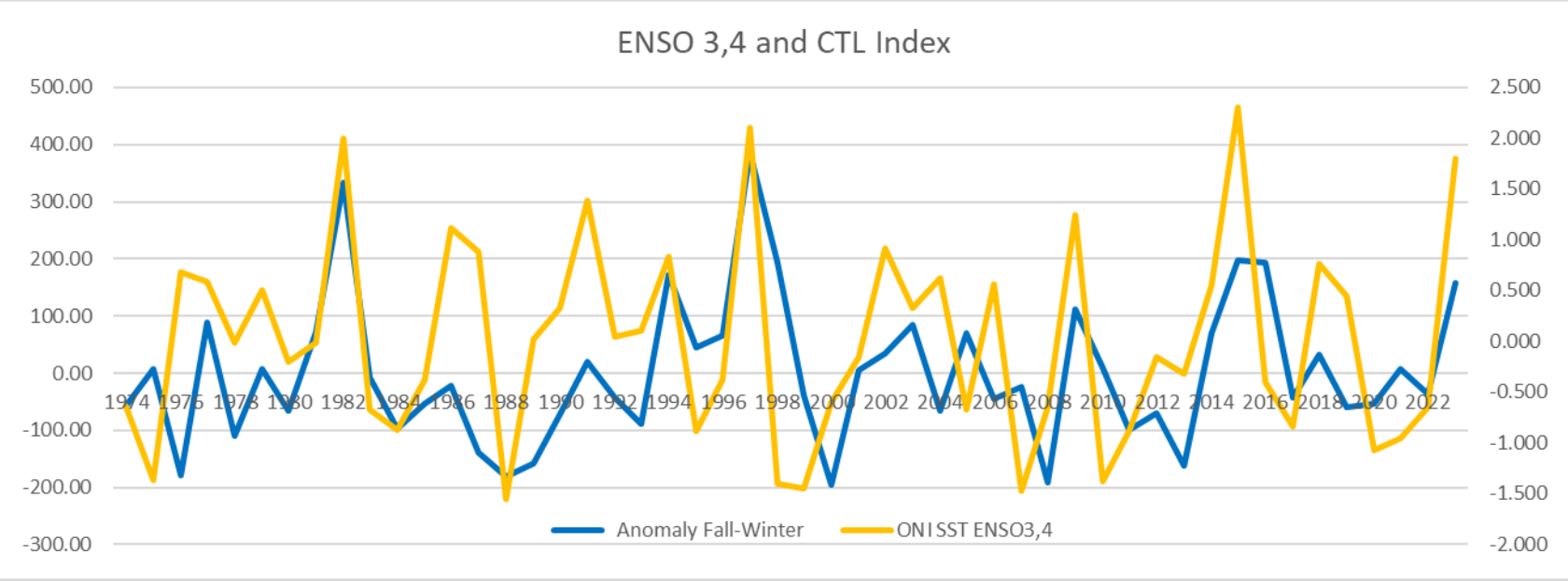




Station Photos - NOAA Tides & Currents

CRLC Tide Level (CTL) Index Calculation

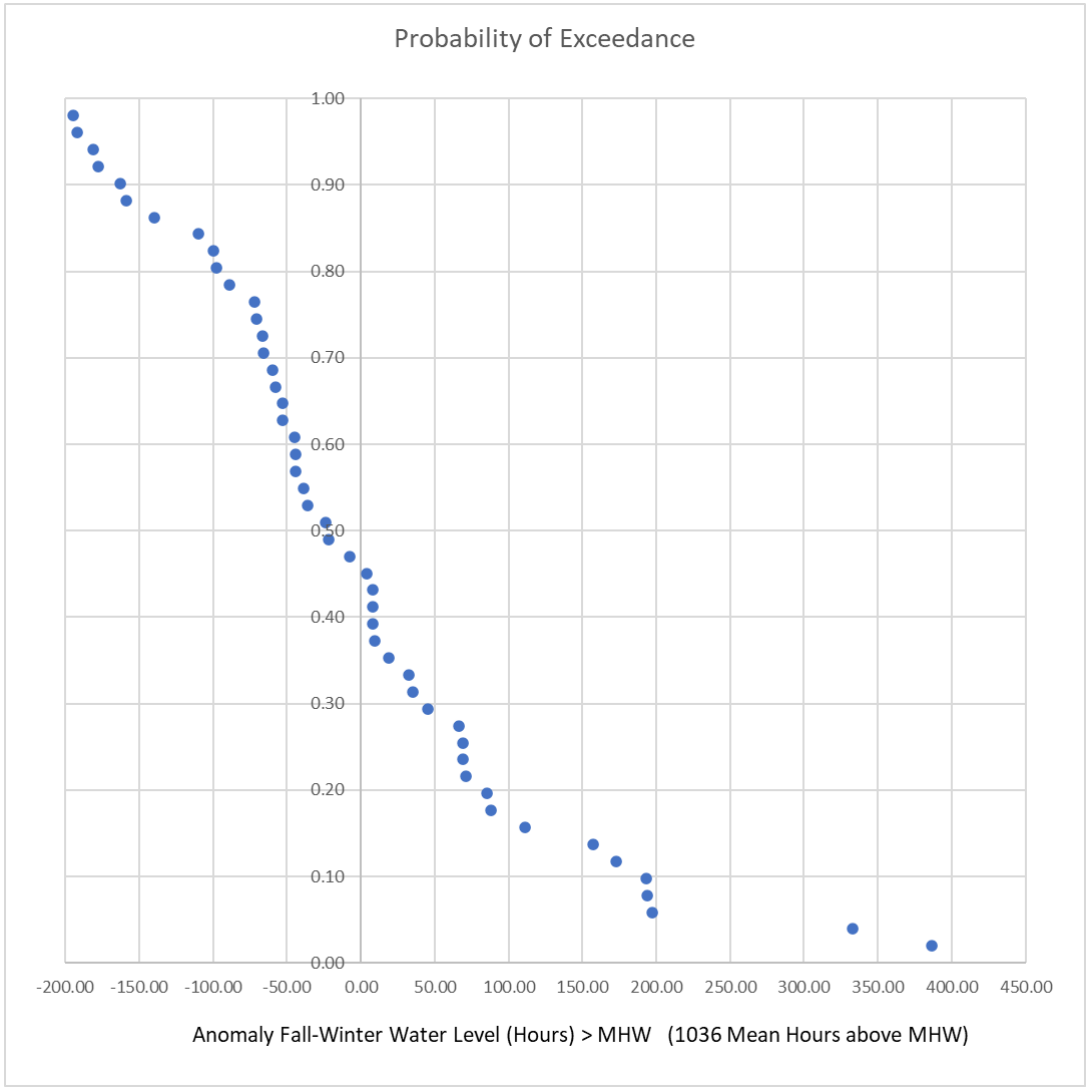
- Tide Level Anomaly Index for the Columbia River Littoral Cell was derived from 6 minute and hourly tide data from NOAAs Station 9440910 Toke Point, WA (Missing data points calculated based on linear correlation from station Astoria, OR).
- CTL represents the number of hours during each Fall-Winter season (October 1 to March 31) that water levels exceed the stations MHW elevation.
- On average, water levels exceed MHW 1041 hours each Fall-Winter period and 1709 hours annually.
- During strong El Niño events the number of hours the beach is exposed to elevated water levels increases (e.g., during the 2016 event water levels exceeded MHW an additional 193 hours or 8 days).



CTL Anomaly Index Reoccurrence Intervals

ENSO 3,4 Says 2023-24 is the 4th largest ENSO event on Record BUT for the CRLC CTL, it was found to be 7th

Rank	MHW Year	Anomaly Over MHW Fall-Winter (Hours > MHW)	Return Period (T)
1	1997	386.14	51.0
2	1982	333.14	25.5
3	2015	197.14	17.0
4	1998	194.14	12.8
5	2016	193.14	10.2
6	1994	173.14	8.5
7	2023	157.14	7.3
8	2009	111.14	6.4
9	1977	88.14	5.7
10	2003	85.14	5.1
11	1981	71.14	4.6
12	2005	69.14	4.3
13	2014	69.14	3.9
14	1996	66.14	3.6
15	1995	45.14	3.4
16	2002	35.14	3.2
17	2018	32.14	3.0
18	1991	19.14	2.8
19	2010	9.14	2.7
20	1975	8.14	2.6
21	1979	8.14	2.4
22	2021	8.14	2.3
23	2001	4.14	2.2



Northwest Oregon and Southwest Washington Coast Environmental Parameters

- Wide (50-100 m) dissipative beaches with slopes of 1.5 to 3%, ~2% average
- Beach material is sand 0.1 to 3.71 mm, ~2 mm average for foreshore
- Winter-Fall 2023-2024 Average Significant Wave Height (H_{50})=2.35 m, Wave Period (T_{50})= 8.33 sec
- Top 2% of waves H_2=4.6 m, T_{50}= 9.63 sec

Station 46211 - Grays Harbor, WA

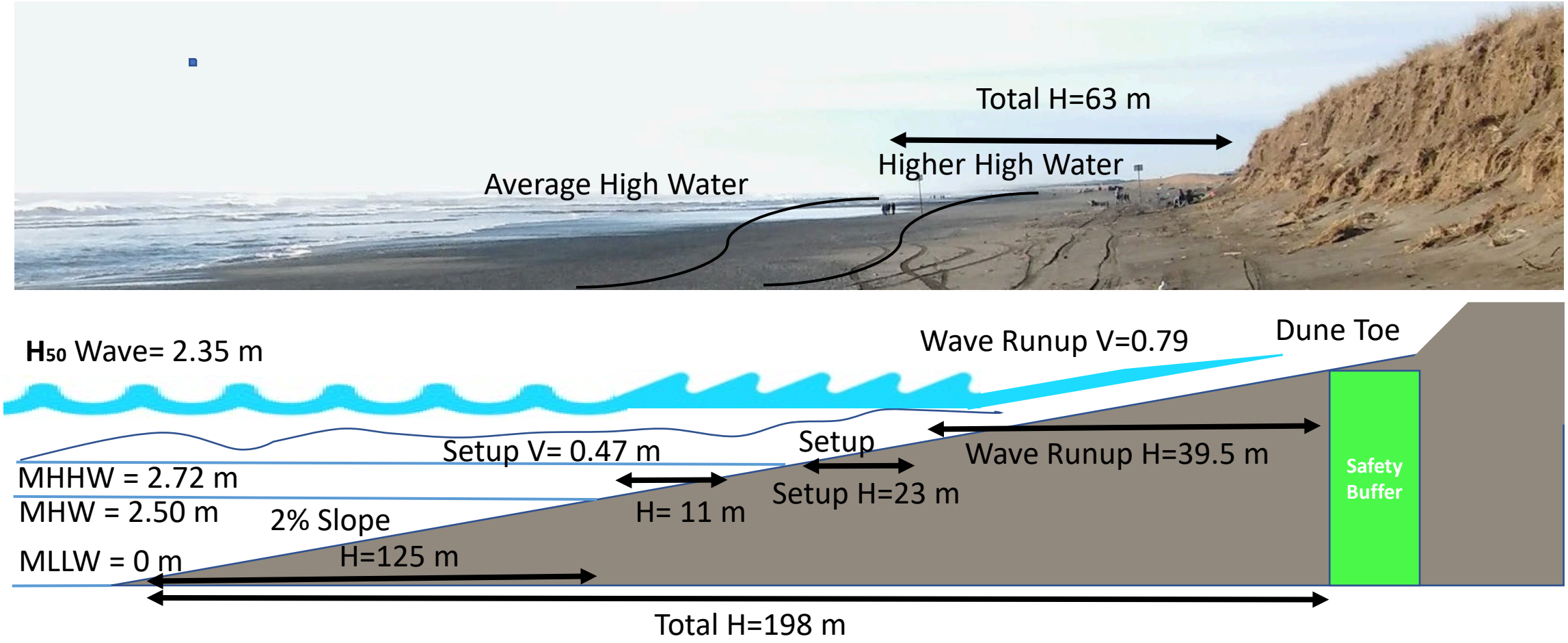
Date	Time (PST)	Time (GMT)	T50 Period (sec)	Hs Hight (m)	L	ξ	Wave Setup	Hunt 1959 Wave Runup (m)	Stockdon et al. 2006 Wave Runup (m) ξ < 0.3	Horizontal Distance without tide Hunt	Stockdon ξ < 0.3
Mean Hs (Feb-March 2024)			8.33	2.35	108.34	0.14	0.47	0.79	0.69	39.46	34.31
3/31/2024	15:30	22:30	7.5	2	87.82	0.13	0.4	0.67	0.57	33.25	28.49
3/31/2024	16:30	23:30	7.4	2.1	85.50	0.13	0.42	0.69	0.58	34.40	28.81
Hs2% Wave (Feb-March 2024)			9.63	4.6	144.79	0.11	0.92	1.44	1.11	71.81	55.49

Wave Information from NOAA 2024, [NDBC - Station 46211 Recent Data (noaa.gov)]

CTL Use for Hazard Assessment

- ENSO events impact SST, air pressure, and the location of High- and Low-pressure systems in the Pacific. In the Pacific Northwest, during the El Niño phase of ENSO, increased sea levels (from low air pressure), warmer temperatures, and increased precipitation are observed along with increased storm intensity and frequency.
- CTL is a significant constituent that must be considered when estimating the potential for erosion on the coast. The CTL, in conjunction with other environmental parameters can be used to determine the amount of time that the toe of the dune would be exposed to wave action IF the wave reached the dune. Hazard Assessment requires the following data:
  - Near Realtime wave buoys used to obtain wave heights at the same time as the tide gauge,
  - Wave runup models that predict setup and horizontal and vertical runup from the waves, and
  - Current High accuracy digital elevation models (e.g., LIDAR)
- This information is used to calculate beach widths based on the MHW and MHHW lines + wave runup.

CTL Conceptual Relationship with Observed Water Lines and Erosion Potential



CRLC Areas Potentially Impacted by the 2023-24 ENSO Event in Ocean Shores North Jetty

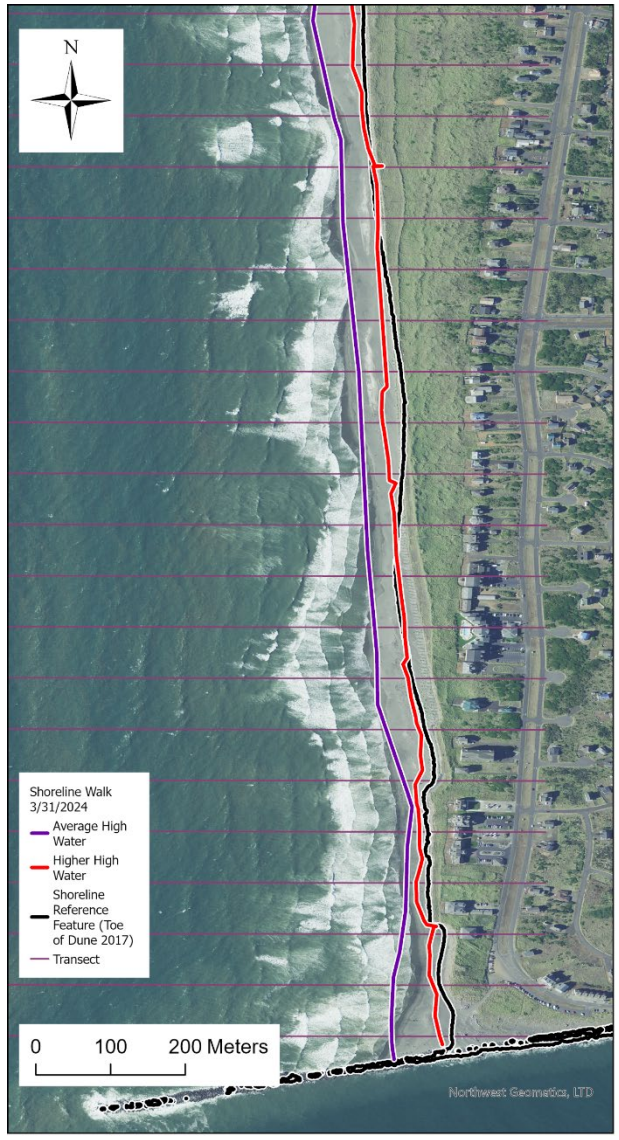


Figure 1. Shorelines

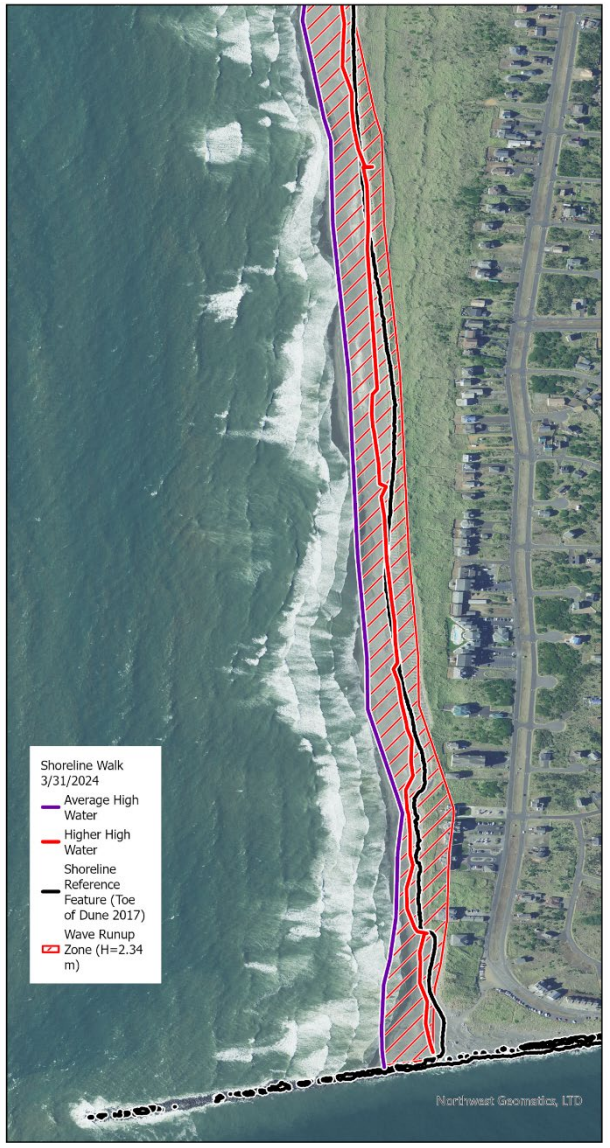


Figure 2. H_{50} Wave Runup

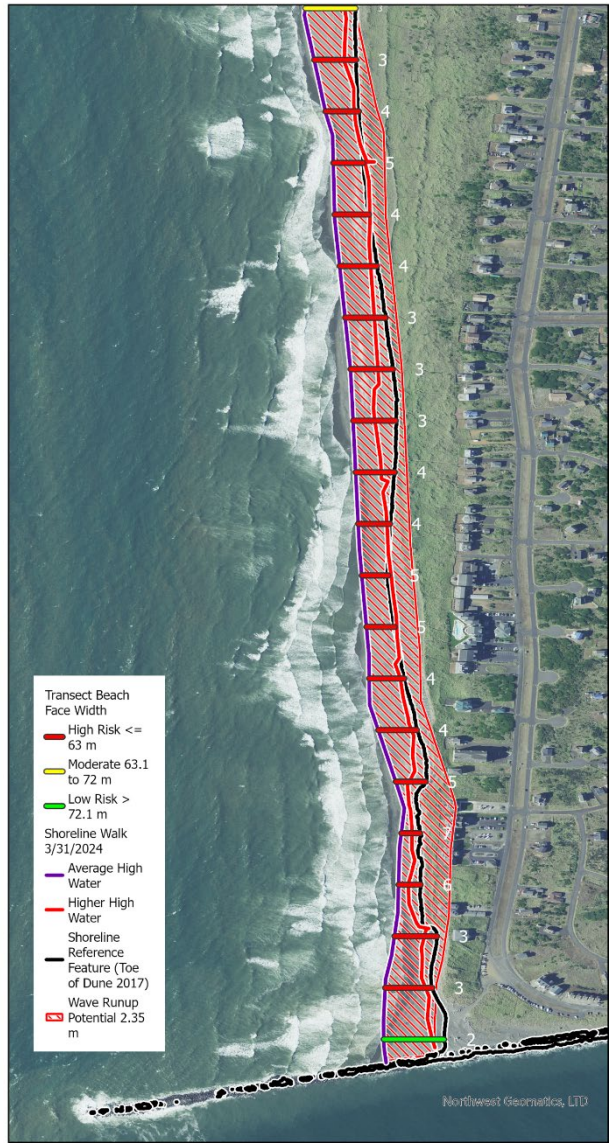
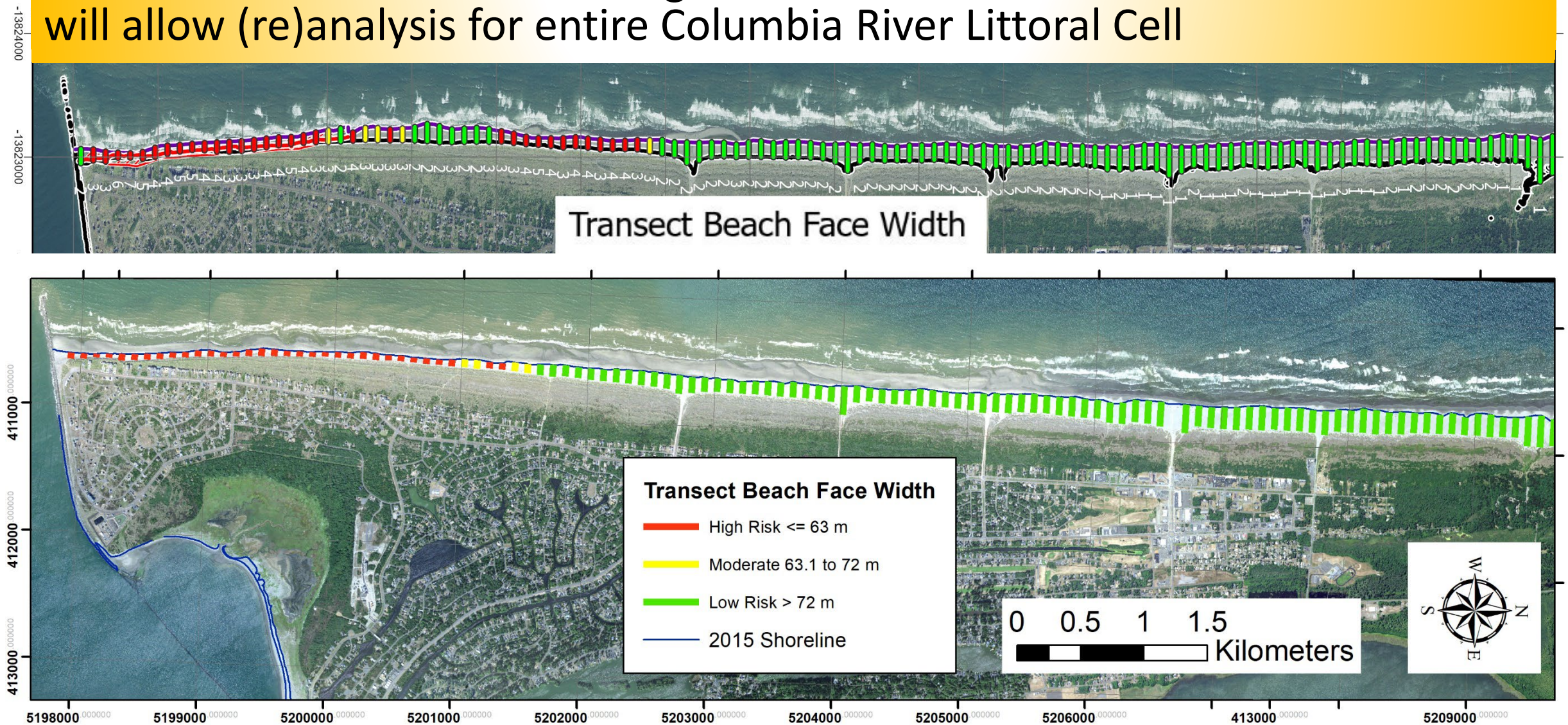


Figure 3. Hazard Zones

CRLC (Ocean Shores, WA) 2023-24 ENSO Hazard Areas

Future Research – USGS Lidar flight scheduled for October-December 2024 will allow (re)analysis for entire Columbia River Littoral Cell



Results

- Strong ENSO events are associated with elevated water temperature and sea levels along the northwest Oregon and southwest Washington coast.
- During the winter season In the Pacific Northwest (PNW) the amount of time that sea levels exceed the regional mean high-water level (MHW) is positively correlated with observed erosion on sandy beaches.
- The El Niño event of 2023-2024 was predicted to have a 95% probability of being one of the stronger events in the last 50 years and was predicted to be as strong as the record 1982-83, 1997-98, or 2015-16 events.
- For the CRLC, the CTL found that the 2023-24 El Nino was weaker than predicted, and in terms of strength was the 7th largest event in the last 51 years (1974 to 2024), falling behind the 1997, 1982, 2015, 1998, 2015, and 1994 events.
- Calculation of water elevation by combining multiple sensors (i.e., tide, buoy) allows derivation of key reference features directly from high resolution digital elevation models, such as the Mean High Water and Dune toe elevation.
- We can now calculate the Slope shoreline parameter for each Transect directly from the data.