Impacts of the 2015-2016 El Niño on Coastal Oregon and Washington

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Purpose

The El Niño event of 2015-2016 is arguably the largest El Niño event on record. It was forecast to unleash many weather surprises through the Fall and Winter of 2015. In the Pacific Northwest this event was anticipated to be as strong or stronger than the major 1983 and 1997 events, both of which caused significant coastal erosion in Oregon and Washington State.

This is the first major El Niño in the 21st Century, and is operating in a warmer world in which forecasters have no prior experience. In this study precipitation, mean temperature, sea surface temperature (SST), barometric pressure and tide level anomalies were compared to past events to see if the impacts of the 2015-2016 event on coastal Washington are comparable to those observed during the 1983 and 1997 El Niño's. The coastal beaches within the Columbia River Littoral Cell at risk from this El Niño where then identified.

Data

The following Data sets were utilized in this study

- Monthly Total Precipitation and Monthly Mean Temperature[1],
- Monthly Mean sea surface temperature (SST) [2],
- Hourly barometric pressure and Hourly tide levels[3],
- Hourly Wave Height and Period[4] (2015) and
- ENSO, Modoki ENSO, and PDO Indexes

[1]U.S. Historical Climatology Network-Monthly (USHCN) Version 2.5.5.20160315

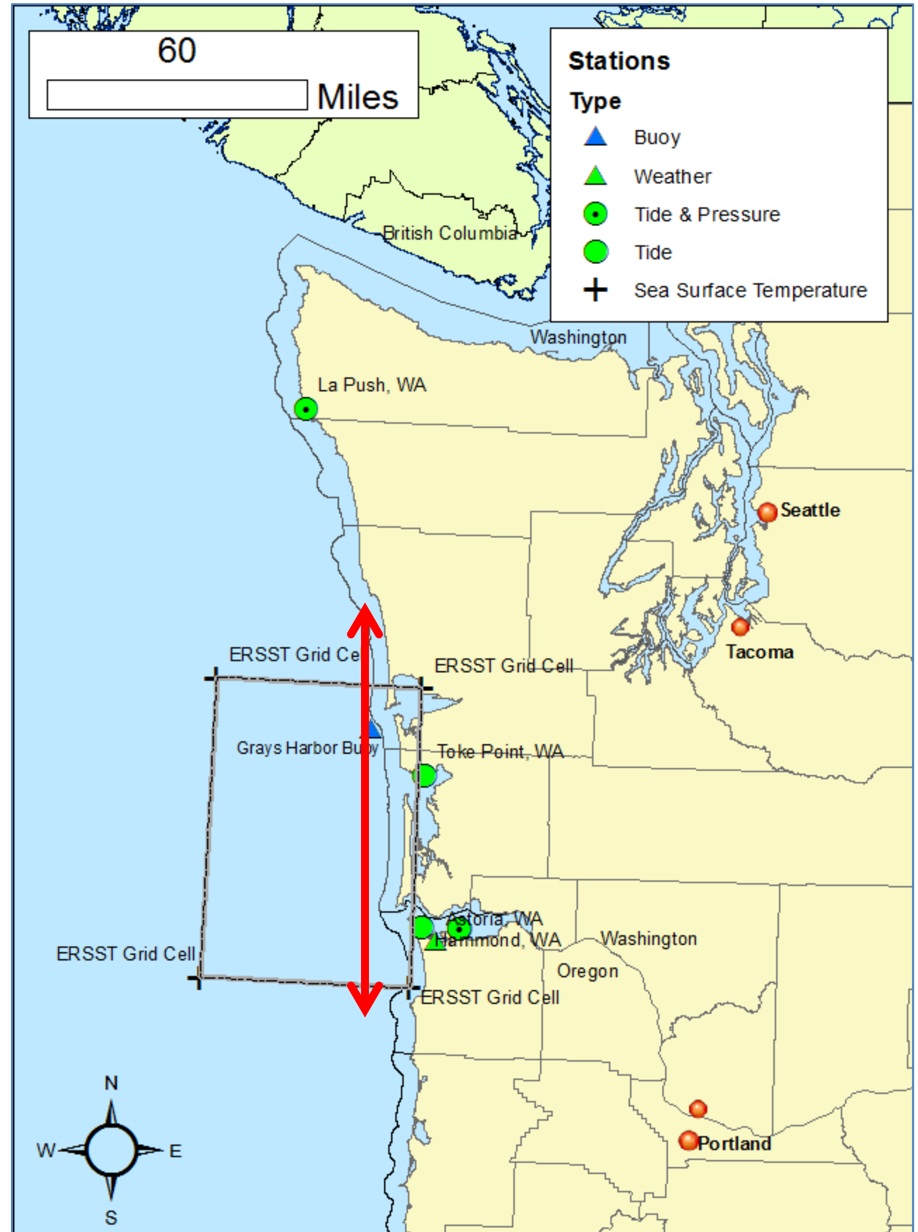
[2]NOAA Extended Reconstructed Sea Surface Temperature (ERSST), Version 3

[3]NOAA Tide & Currents Tide/Water Levels and Meteorological Observations: Stations Toke Point, WA, La Push, WA, Astoria, OR and Hammond, OR

[4]NOAA National Data Buoy Center: Station 46211 – Grays Harbor, WA

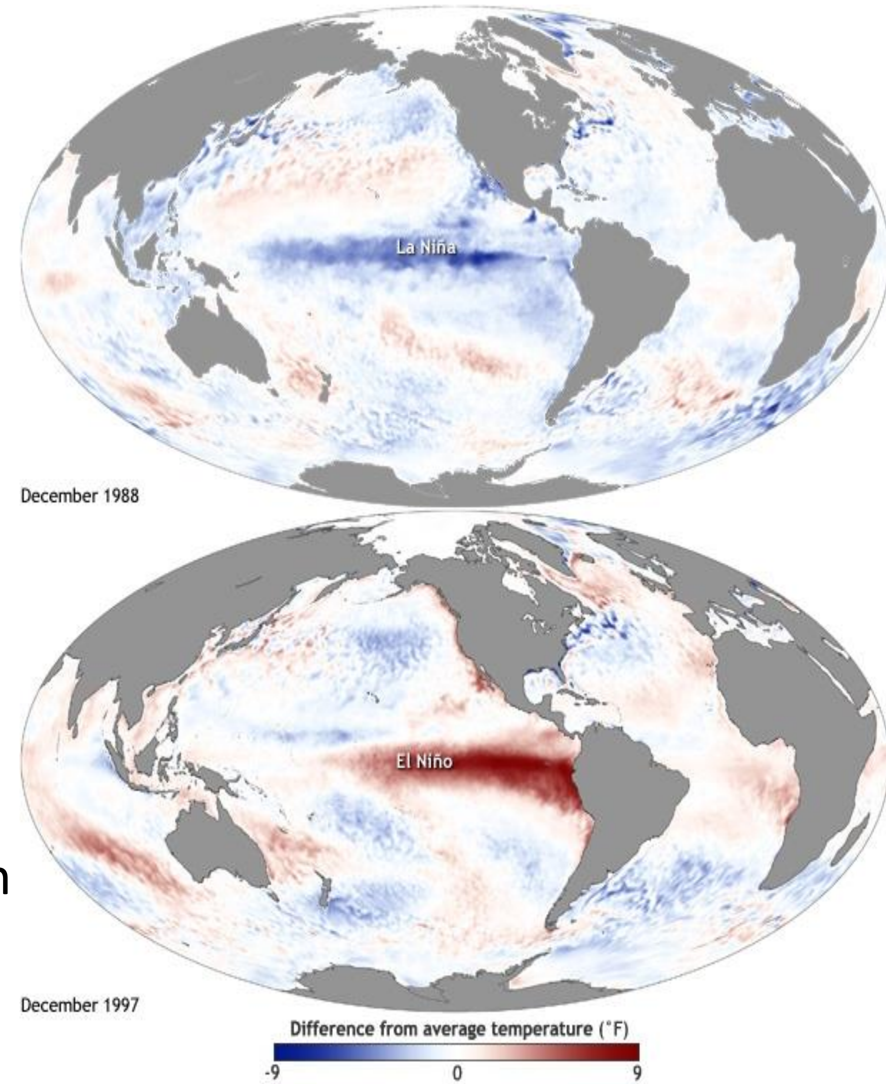
Study Area and Station Locations

- The primary tide gauge station used for this study is Toke Point, WA. Data was obtain for hourly tide levels from 1/1/1981 to 3/23/2016. Data from stations Astoria, OR (r^2=0.96) and Hammond, OR (r^2=0.98) were used to fill gaps in the record. Correlations were conducted based on 8,761 hourly measurements taken during 2013 and a linear equation developed to estimate missing data. Data fill was required on about 1.5% of the data.
- Barometer pressure data were obtained for Astoria, OR. Data was obtain for hourly mean pressure from 1/1/2005 to 3/25/2016.Data from La Push, WA (r^2=0.96) were used to estimate missing data values. Data fill was required on 4% of the data.
- Monthly Precipitation totals and mean temperature were obtained for Astoria, OR for 1/1981 to 2/2016.
- Monthly mean SST were obtained for 1/1981 to 1/2016 from 1° Degree gridded data.



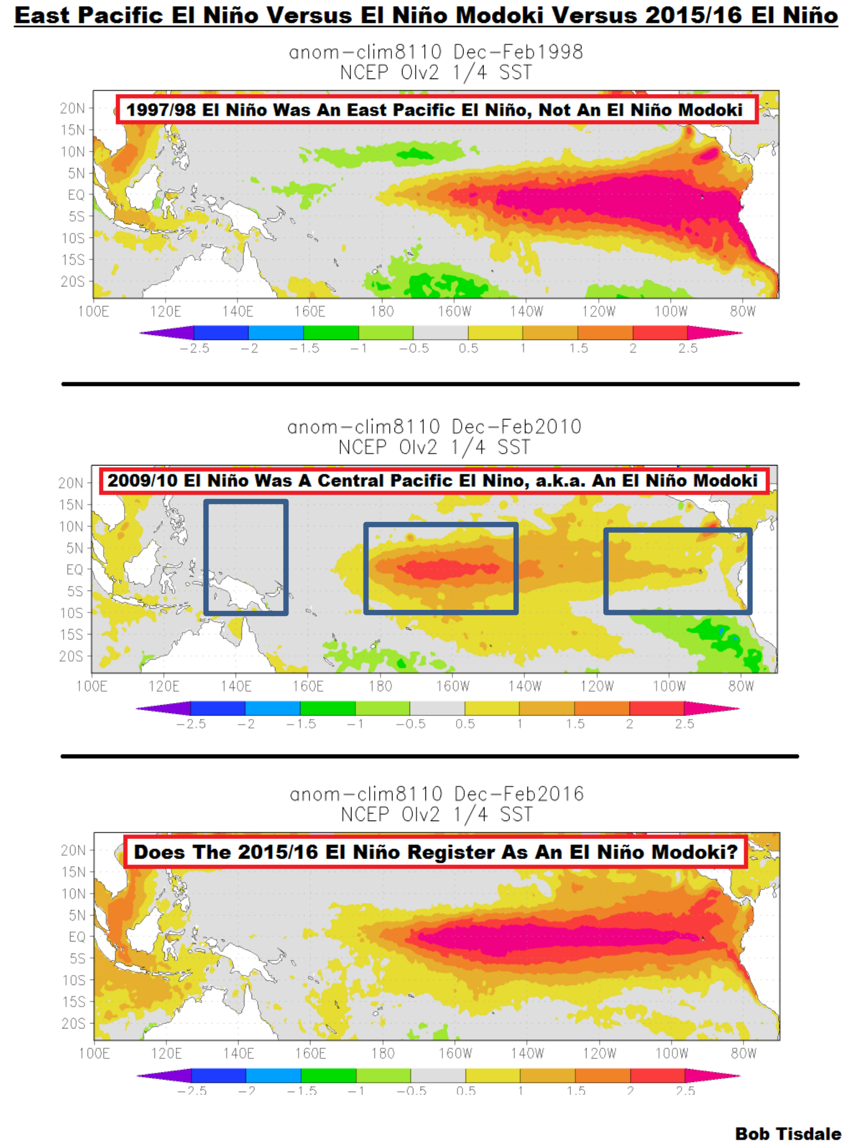
ENSO, Modoki ENSO, and PDO O'my

- El Niño/Southern Oscillation (ENSO) – Is an index that measures the air pressure difference between the eastern Pacific and western Pacific. Air pressure is related to local SST.
- In the Pacific Northwest:
  - La Niña: A cooling of the ocean surface, or below-average sea surface temperatures (SST), brings us cold, wet winters.
  - El Niño: A warming of the ocean surface, or above-average sea surface temperatures (SST), diverts winter storms southward into California and brings us milder than average winters.



Modoki ENSO

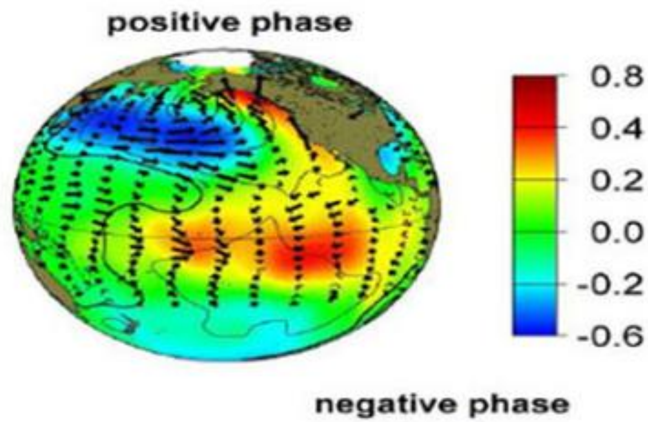
- This index was first recognized in 2007 and is designed to identify SST anomalies between east, central, and western Pacific.
- “Strong” Modoki phases is characterized by anomalously warm central equatorial Pacific flanked by anomalously cool regions in both west and east. Such zonal SST gradients result in anomalous two-cell Walker Circulation over the tropical Pacific, and a wetter than average season in California.
- This phenomenon is a second dominant mode of inter-annual variability in the tropical Pacific after ENSO.



Weng, H., K. Ashok, S. K. Behera, S. A. Rao, and T. Yamagata, 2007 : Impacts of recent El Niño Modoki on dry/wet conditions in the Pacific rim during boreal summer. Climate Dynamics, 29, 113-129.

Pacific Decadal Oscillation (PDO)

- Developed in 1996 this index tracks long-lived El Niño-like pattern of Pacific climate variability. PDO "events" persisted for 20-to-30 years and consists of warm and cold phases



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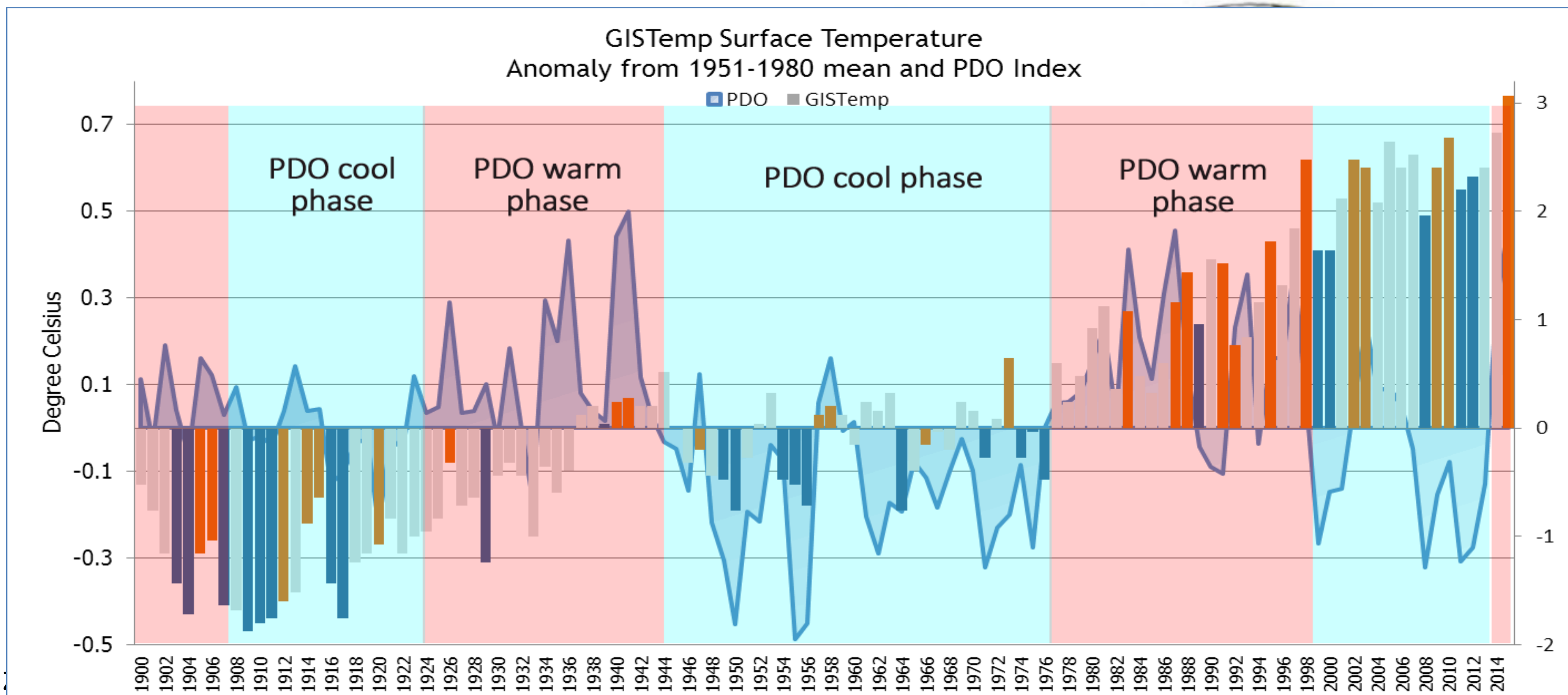

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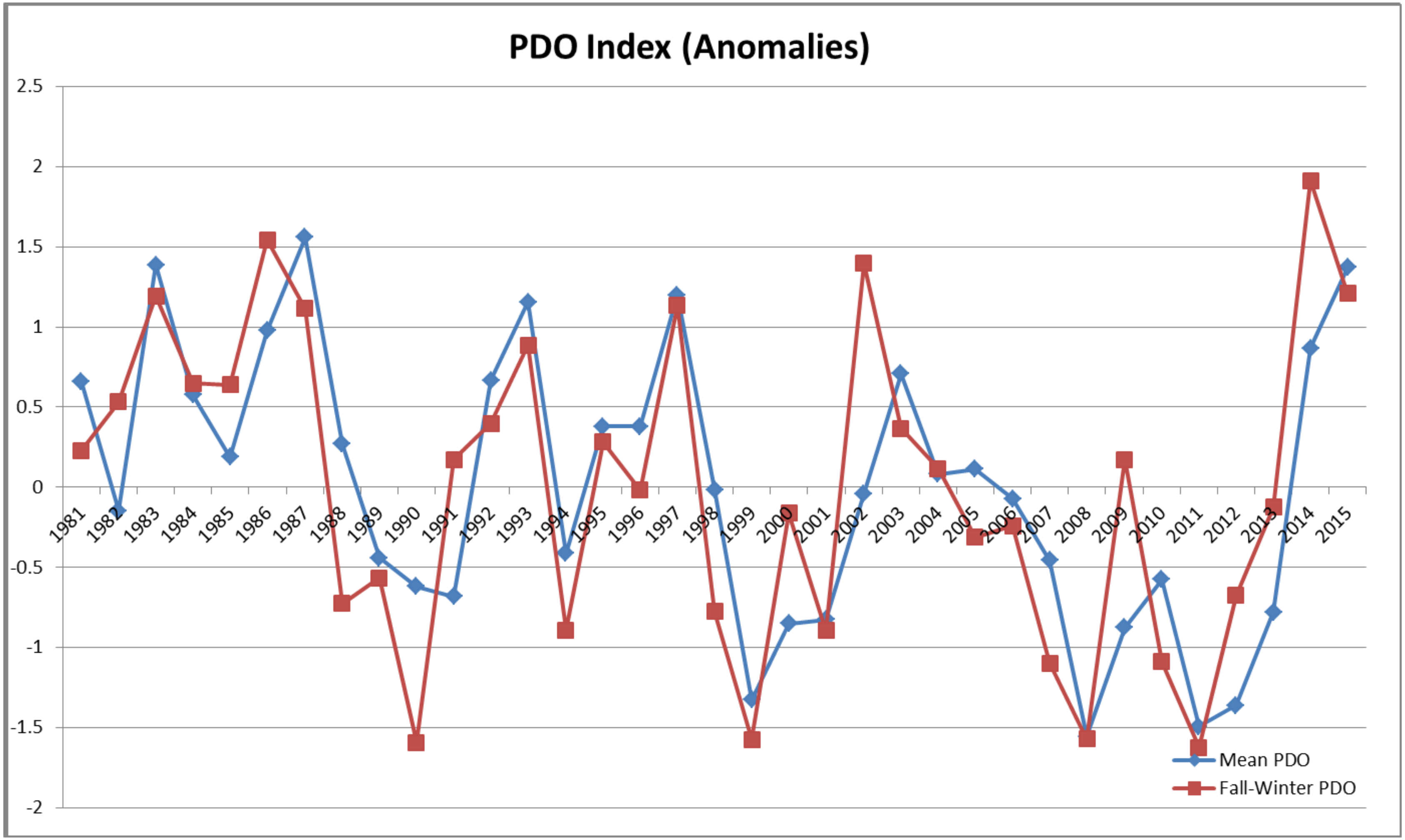
Comparison



Annual		
r^2 between	**Modoki**	**PDO**
ENSO	0.31	0.12
Modoki		0.08

Fall-Winter		
r^2 between	**Modoki**	**PDO**
ENSO	0.34	0.05
Modoki		0.14

Indexes vs. Coastal Washington Climate Variables

- Annual

r^2 between	Anomaly Total Precipitation*	Anomaly Mean Monthly Temperature*	Anomaly Sea Surface Temperature*	Anomaly Hours > Predicted Tide	Anomaly Hours above MHW
ENSO	(-) 0.00	0.19	0.29	0.19	0.17
Modoki ENSO	(-) 0.07	0.03	0.07	(-) 0.01	(-) 0.01
PDO	(-) 0.01	0.27	0.31	0.21	0.19

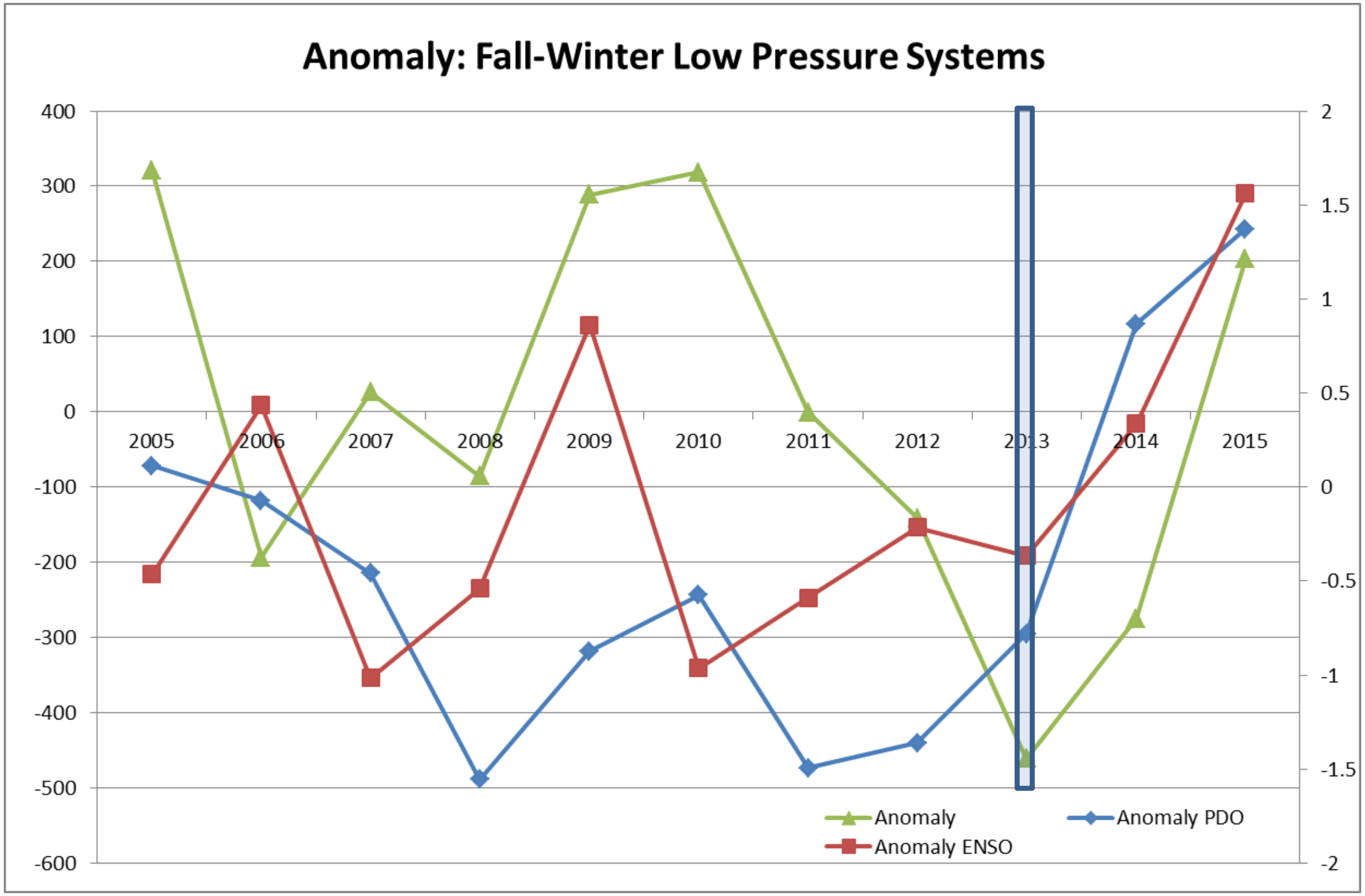
*Monthly Data

- Fall-Winter

r^2 between	Anomaly Total Precipitation*	Anomaly Mean Monthly Temperature*	Anomaly Sea Surface Temperature*	Anomaly Total Hours > Predicted Tide	Anomaly Hours above MHW
ENSO Annual	(-) 0.02	0.14	0.32	28	0.31
ENSO Fall-Winter	(-) 0.04	0.35	0.33	0.26	0.28
Modoki ENSO	(-) 0.06	0.05	0.11	0.06	0.04
Modoki Fall-Winter	(-) 0.08	0.08	0.09	0.00	0.00
PDO	(-) 0.02	0.03	0.27	0.08	0.09
PDO Fall-Winter	(-) 0.08	0.22	0.42	0.06	0.08

*Monthly Data

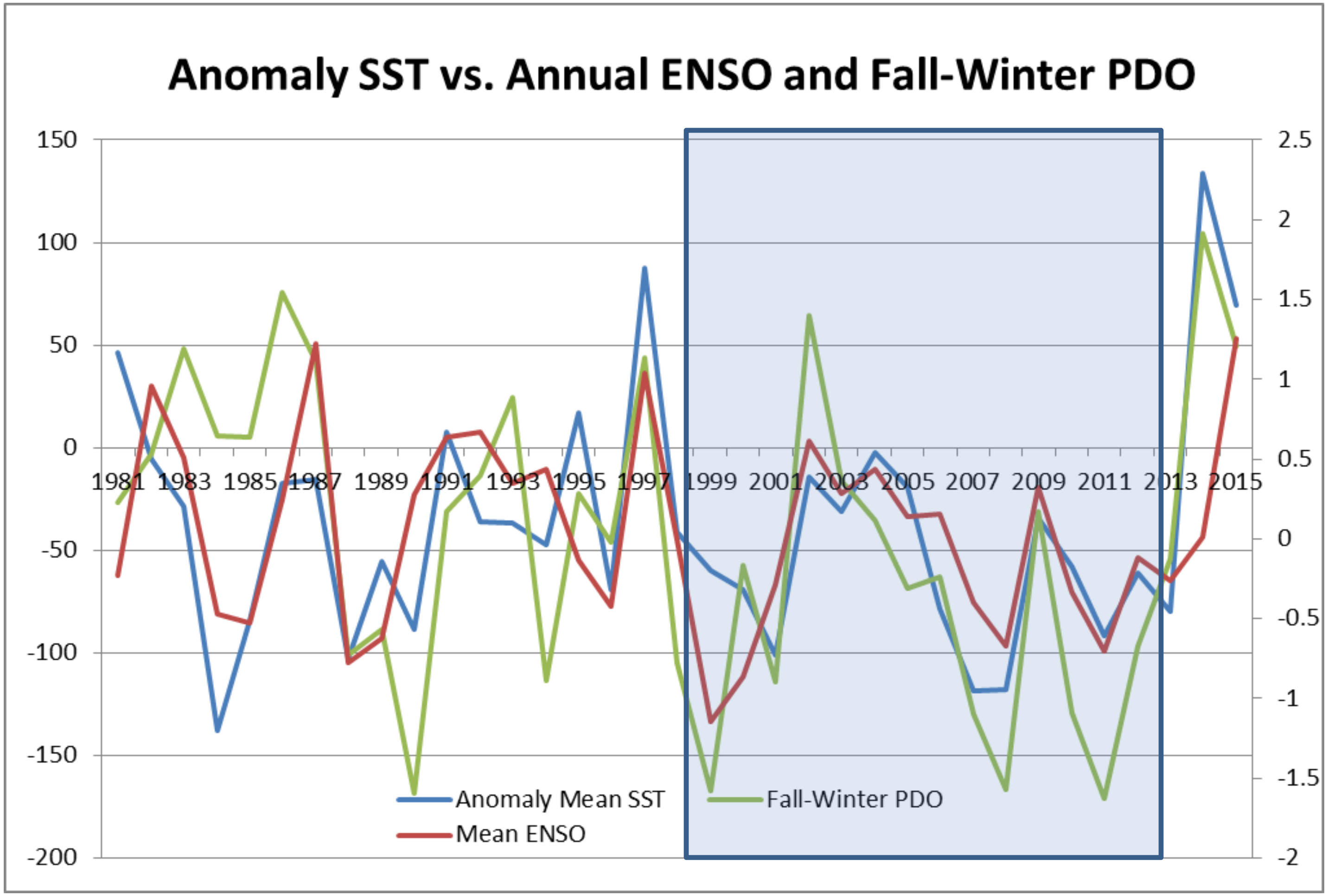
Indexes vs. Surface Air Pressure



Annual	
r² between	**Anomaly air pressure < 1013.2 mbar**
ENSO	0.01
PDO	0.02

Fall-Winter	
r² between	**Anomaly air pressure < 1013.2 mbar**
ENSO	0.21
PDO	0.02

Climate Indexes vs. SST



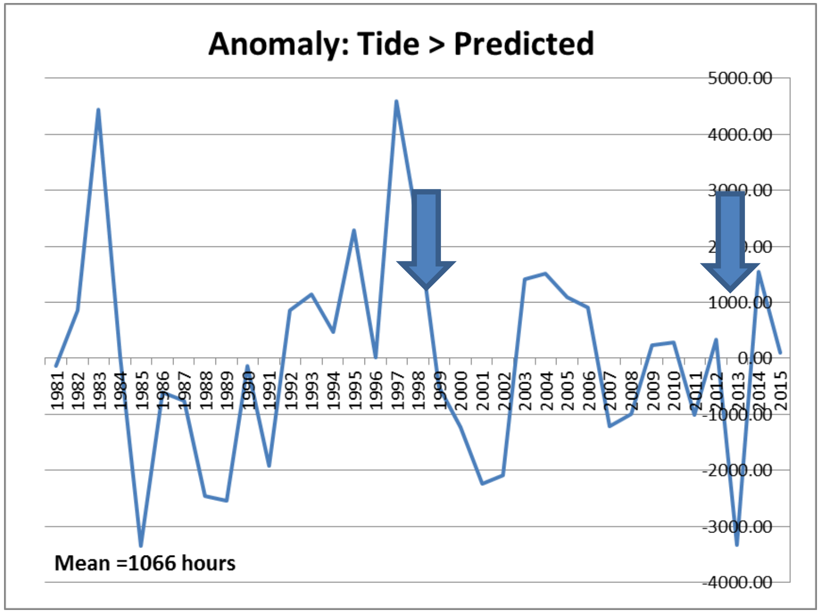
Annual	
r2 between	SST Anomaly
ENSO	0.34
Modoki ENSO	0.12
PDO	0.29

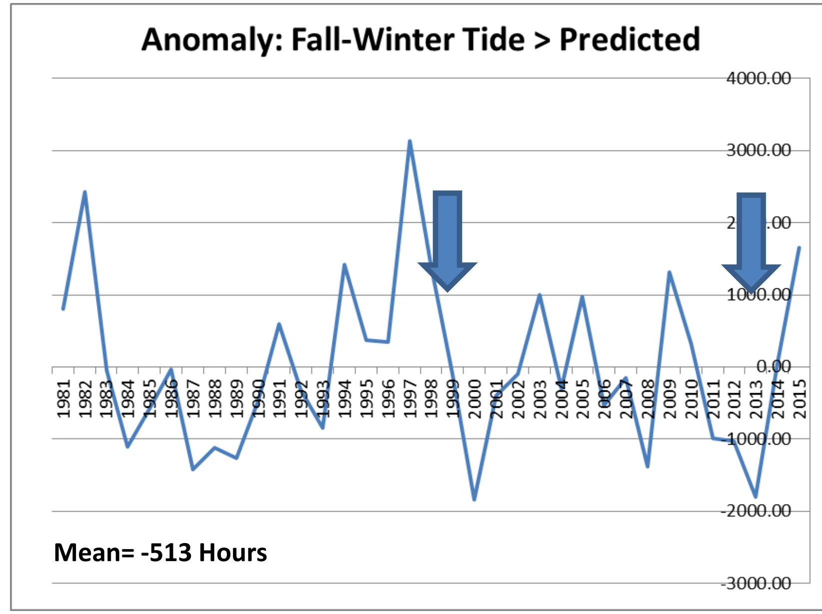
Fall-Winter	
r2 between	SST Anomaly
ENSO	0.36
Modoki ENSO	0.09
PDO	0.42

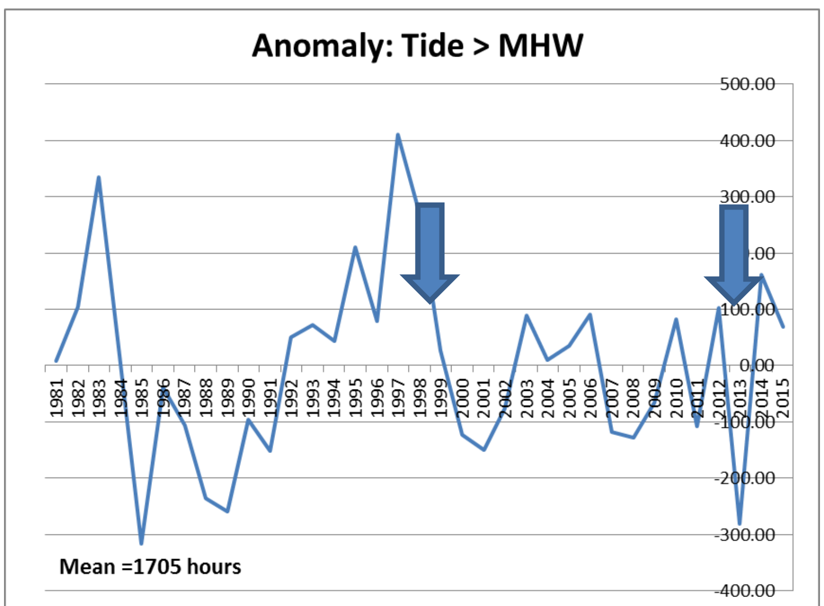
Climate Indexes vs. Tide Levels

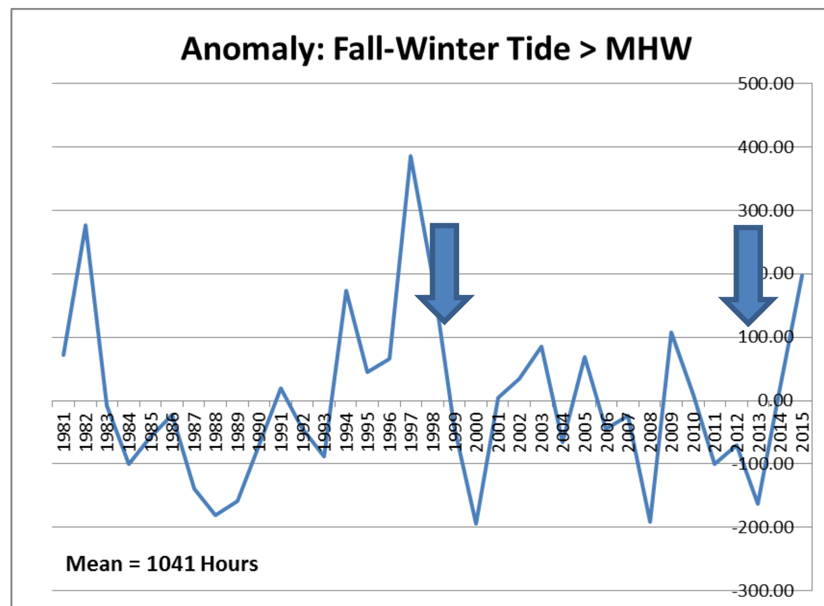
- Annual ENSO and Fall-Winter PDO have the highest correlations with SST and air pressure in coastal Washington.
- Higher SST and lower air pressures result in elevated water and tide levels along the Washington coast.
- The longer tide levels are above predicted levels, the greater the chance that beach and bluff erosion will occur.
- When tide levels are higher than Mean High Water, even minor storms with average waves will cause wave run-up that may impact the toe of the primary dune, depending on the width of the beach.

Tide Height Anomalies









Impacts: 1996-1997

- The 1996-1997 El Niño resulted in extensive beach recession, dune scarping, and coastal flooding in Washington resulting in a State of Emergency declaration by the Governor.
- These emergency declarations paved the wave for the first permitted semi-permanent coastal armory projects ever constructed on Washington's ocean coastline.

1997-2004 Road to Recovery at Ocean Shores, WA
Wave Bumpers at the Grays Harbor North Jetty

Impacts: 2015-2016

- The 2015-2016 El Niño has resulted in measurable beach recession, dune scarping, and coastal flooding; resulting in declared state of emergencies in come coastal communities.
- The impacts appear to be less severe than were experienced in 1996-1997; most likely because of jetty reconstruction efforts completed at Grays Harbor (2000) and at the Mouth of the Columbia (2015), which protected the most built-up and visited areas along the coast from coastal flooding.
- However, additional semi-permanent coastal armory projects were constructed to protect existing structures that were at the end of there design life (e.g., Geotubes installed in 1999 to protect the 1997 scarps began to fail by 2010).

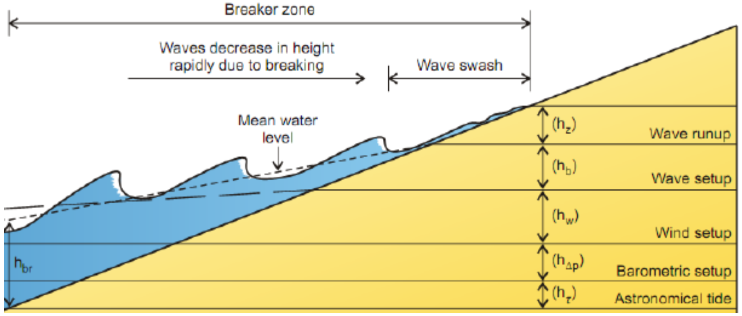
2013-2016 Ocean Shores, WA
El Nino induced erosion at the Grays Harbor North Jetty

At Risk Shorelines on the Washington Coast

- Hedges and Mase 2004 wave run-up equation was used in conjunction with an measured beach migration rate for Fall-Winter 2015 to estimate the minimum beach width that would be needed to prevent dune toe erosion.
- Where:
  - Beach Slope = 3%
  - Deep water significant wave height, Hs = 1.97 m, Hs2%= 6.052 m
  - Wave Period 7.44 Seconds, Dominant Wave Period 11.149 Seconds.

	Average Wave	**Corrected**			**Storm Wave**	**Corrected**
Run-up Vertical (m)	1.25	1.19		R2%	3.85	3.66
Run-up Horizontal (m)	23.91	22.72		Run-up Horizontal	73.47	69.79
Overpredicts by 5% after Shand et. al. 2011						

*** Wave and Period from 2015 Buoy Data**



Columbia River Littoral Cell

- The beach migration rate for Fall-Winter 2015 was calculated using the change envelope between a shoreline digitized from a NAIP air mosaic (flown 8/16/2015) and a shoreline collected on the ground using GPS on 3/18/2016. A two mile stretch of shoreline north of the Grays Harbor Jetty was analyzed, the mean shoreline migration for Fall-Winter 2015 was 25 meters.

- At the start of Fall this year, to be safe from dune toe erosion under average wave conditions the beach needed be > 47 meters wide, during storm conditions the beach needs to be > 95 m wide.

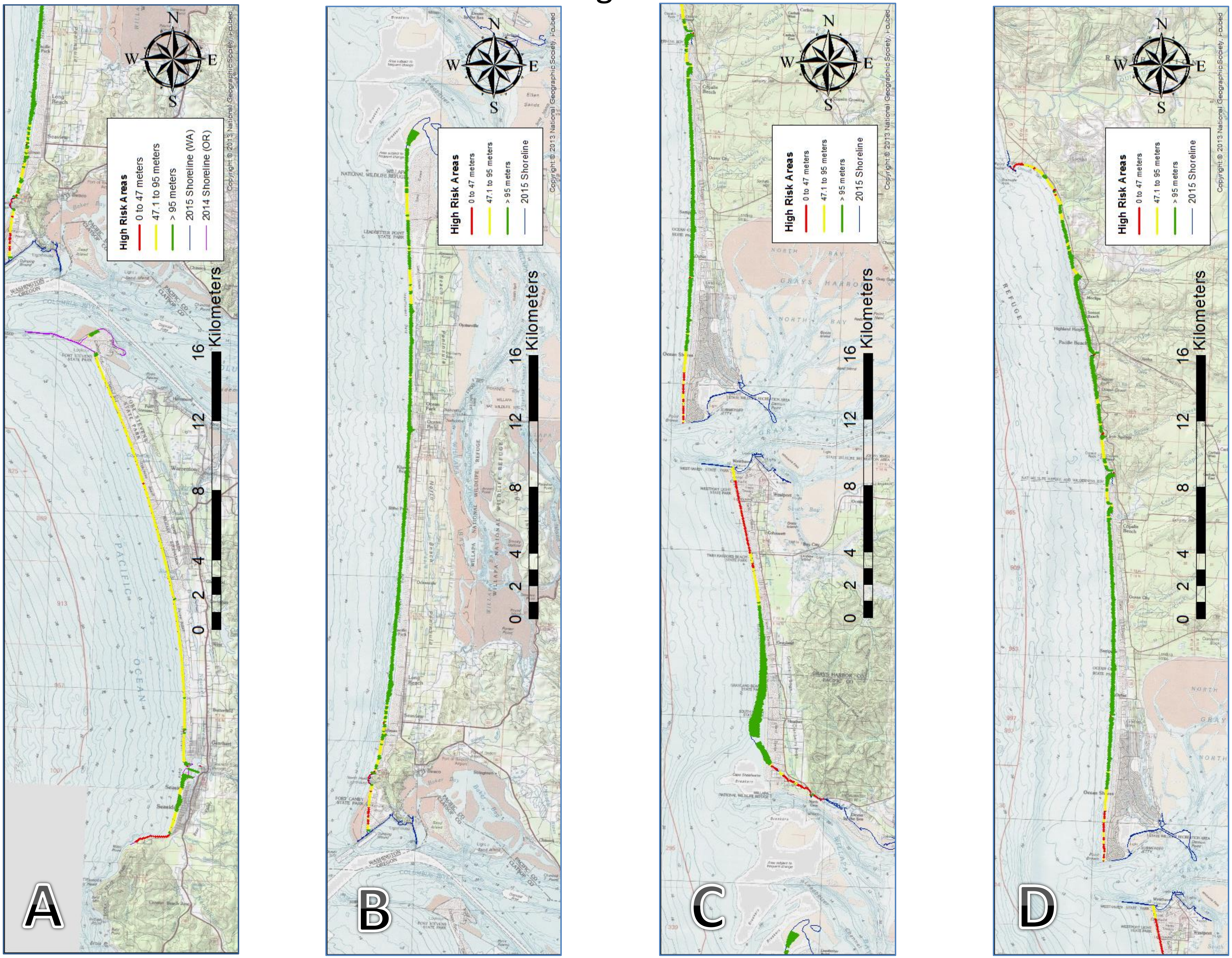
- High risk areas within the cell were identified and mapped based on transects at 100 m spacing and the beach width at each location. The width is the distance between the average high water line and the erosion reference feature (e.g., toe of dune or existing erosion scarp). The shoreline and erosion reference feature were digitized from 2014 (OR) and 2015 (WA) NAIP air mosaics.

- Three risk categories were mapped:

  High 0 to 47 m
  Moderate 47.1 to 95 m
  Low > 95 m

Region	Length (km)	High Risk (%)	Moderate Risk (%)	Low Risk (%)
A. Oregon	32.3	7%	79%	13%
Washington (Totals)	109.7	12%	19%	69%
B. Long Beach	42.6	4%	17%	79%
C. North Cove-Westport	21.8	36%	19%	45%
D. Ocean Shores-North Beach	45.3	9%	21%	71%
Grand Total	251.7	12%	27%	62%

Columbia River Littoral Cell - High Risk Areas 2015-2016 El Niño



Summary

- The 1982-83, 1996-1997, and 2015-2016 El Niño events all occurred during a **warm phase** of the PDO and are the largest ENSO events on record (1950 to present).
- This El Niño appears to be the **largest** event in the last 31 years based on the ENSO and PDO Indexes.
- In coastal Washington major El Niño events are associated with region-wide beach recession, **dune scarping**, and coastal flooding.
- There were significant **increases** the number of hours during the Fall-Winter season were the tide exceeded mean high water (i.e., 278 hours 1982-1983;387 hours 1996-1997; 157 hours 2015-2016).
- During this El Niño event **37% (96 km)** of the ocean shorelines within the Columbia River Littoral Cell were at high to moderate risk of dune scarping and erosion.
- Based on tide-level indicators the 2015-2016 El Niño event will impact the coast to a **lessor extent** than the 1996-1997 and 1982-1983 event.