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The Effects of Climate on the West Coast of Vancouver Island, British Columbia

Abstract

The west coast of Vancouver Island, British Columbia has many variables that affect the climate of this northeast pacific isle. The purpose of this paper is to examine the various physiographic, atmospheric, and oceanic systems that control the climate of the West coast of Vancouver Island. Ocean currents and their drivers, along with storm systems affect the island. Marine west coast climates are productive environments, which support the inhabitants of the area with high primary productivity on land and in the ocean. The conifer forest and mountain range of the island create multiple climates due to elevation and rain shadow on the leeward side of the island. The mid-latitude position of the island greatly affects the total solar radiation in this mild, temperate climate. The latitude also results in the length of the sunlit day being extremely seasonal. The Northern Pacific High (NPH) and The Aleutian Low (AL) systems alternately form the seasonal weather patterns of the island. Investigation of teleconnections and the variance they cause in the severity of the NPH and AL storm systems is the focus of this study. Examination of a collection of previous data on teleconnections, such as the Southern Oscillation and El Nino (ENSO), and the Pacific Decadal Oscillation (PDO), will be the means for determining impacts on NPH and AL systems. The 11-year solar cycle is also responsible for variations in the NPH and AL causing changes to precipitation and temperature of the coastal region. The climate of Vancouver Island has undergone changes in the past, climates are now changing globally, and projections indicate they will continue to change. Variables such as latitude, teleconnections, and pressure gradients give Vancouver Island its mild, temperate climate and a greater understanding of the impact each variable has on the climate will aid in predicting the island's climate as the planet continues to warm.

Introduction

The west side of Vancouver Island, British Columbia has a mild, mid-latitude marine west coast climate. Settlement by Europeans began around 1790 and was very gradual due to the isolation of the island and in later years, the price Britain required for parcels of the land. Many British immigrants chose to settle the island due to the climate that reminded them of the "old country" of the eastern Atlantic. The temperate climate of the island creates an ideal refuge for tourists fleeing less favorable environments in present times (Wood 1979). The mountains of the island add multiple climate regions and precipitation regimes in the higher elevations and leeward rain shadow.

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The concentration of this paper is the marine west coast climate, with the designation of "cfb" in Koppen's climate classification system (Veregin 2010). Vancouver Island lies in the prevailing westerly winds of the mid-latitudes in the 300 to 500 millibar mean flow (Tuller 1979). The westerly winds alternately change in pressure seasonally as the Northern Pacific High (NPH) and The Aleutian Low (AL) systems advect onto the island (Patterson et. al. 2013). Examination of the effects of NPH and AL, along with additional climate variables and the impact each variable has on the climate, will aid in predicting the island's climate as the planet continues to warm.

Physiographic Conditions

Vancouver Island, British Columbia is located off the west coast of Canada in the Eastern Pacific Ocean (See Figure 7). Vancouver Island's location is latitudes 48°20' - 50°40' north and longitudes 123°10' - 128°30' west and has an area of some 32,100 km2. The island has an elevation range of sea level to 2,200 m at the tallest peak, which is Golden Hinde. The Vancouver Island Mountains and the Insular range create a rugged terrain with volcanic and sedimentary materials. The predominantly forested island is home to western hemlock, western red cedar, coast redwoods, and lesser abundance of various firs and Sitka spruce (Foster 1979). Vancouver Island has a Marine West Coast Climate that falls under the classification of Mild Mid-Latitude Climates. Tofino, British Columbia is on the west coast of Vancouver Island at Latitude 49°05' north and Longitude 125°46' west and the station has an elevation of 24.5 meters. The climate station at Tofino, designation "Tofino A," meets World Meteorological Organization (WMO) standards. The Canadian Government's climate division provides station data, including the 1981 to 2010 Canadian Climate Normals station data (Canada 2014).

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Objectives

What are the factors that determine the marine west coast climate of Vancouver Island and what are the variables that alter those factors? The ability to determine the factors and variables that affect the west coast of the island will allow a prediction regarding climate change as the planet warms. The effects of NPH and AL are fairly well known, but the effects of ENSO, PDO, and the eleven-year solar cycle have on the climate of Vancouver Island require more investigation. Examination of ENSO, PDO, and the eleven-year solar cycle to determine the effects on NPH and AL is the focus of this study regarding the climate of the island's west coast. The effects weather systems have on the coast and ocean currents are also within the focus of this study.

Methods

To determine the conditions, factors, and variables that lead to a marine west coast climate this study will examine historical data, and the findings of documented research. Thirty-year climate data from a local climate station in Tofino is the historical database of the study (See Figure 7). Utilization of an accumulation of literature and data from previous researchers yields information on the variables. The study shall also examine other data such as solar radiation and the Eleven-year solar cycle research. Tofino has a wide variance in day length, depending on the season of the year. On or around June 20^{th} the town receives somewhat more than 16 hours of daylight. In contrast, on or around December 21^{st} Tofino only receives slightly more than 8 hours of daylight, about half of the maximum. This wide variance in daylight hours is the result of the tilt of the earth and the latitude of Tofino, which is just north of the 49^{th} parallel (Diebel and Norda 2014). Solar insolation is much lower during Vancouver Island's winter months as well. The mean solar radiation for Vancouver Island BC varies with latitude and longitude on the island, as well as seasonally. Table 1 contains the values for several positions on the island and range from a minimum of 1.72 MJ m^{-2}

day $^{-1}$ at Alberni, Lupsi Cupsi in December to 24.05 MJ m $^{-2}$ day $^{-1}$ at Nanaimo, Departure Bay in July. (Tuller 1979)

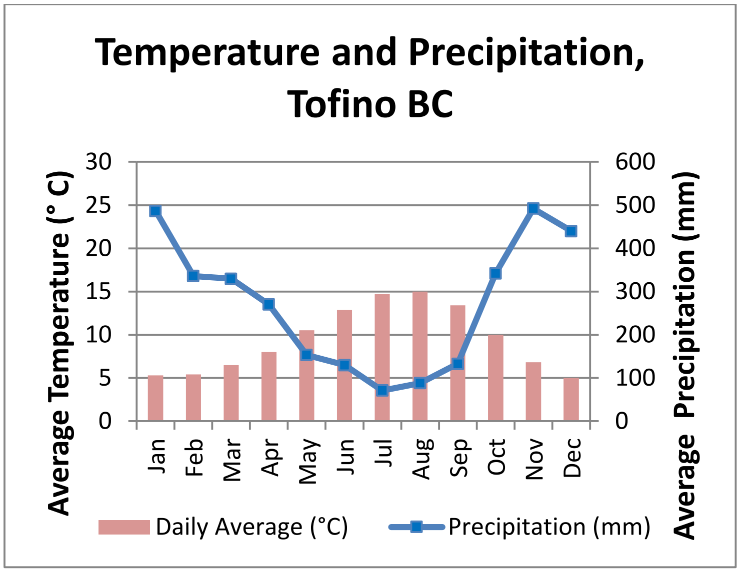

Figure 1: The above climograph represents data from the Tofino A climate station on the west coast of Vancouver Island British Columbia (Canada 2014).

Temperature averages for the "Tofino A" climate station range from 5° C in the winter month of December to 15° C in the warm summer month of August (see Figure 1). The minimum daily average temperature is 1.9° C, in December and February. The maximum average daily temperature for the Tofino A station is 19.1° C for the month of August.

Table 1: Mean daily solar radiation in MJ m^{-2} day $^{-1}$. The solar radiation values for locations on Vancouver Island, British Columbia reproduced from Table 1.4, page 77 of *Vancouver Island Land of Contrast* (Tuller 1979).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alberni, Lupsi Cupsi	2.16	4.58	8.16	12.90	19.08	19.18	22.26	17.83	15.80	5.99	2.86	1.72
Campbell River	2.60	5.68	9.05	13.85	20.29	19.59	23.33	18.20	12.25	6.57	3.32	1.88
Cowichan Lake Forestry	2.36	4.96	8.03	12.15	16.59	16.77	19.92	16.51	12.08	6.61	3.26	1.93
Nanaimo, Departure Bay	2.92	6.92	10.66	15.91	21.50	22.12	24.05	19.91	14.26	7.76	3.75	2.36

Over the 1981 to 2010 sample period, the extreme high temperature was 32.8° C, and the extreme low temperature recorded during this period is -12.7° C (Canada 2014). Typically, Tofino's warm season is from June 22nd to September 24th, with the hottest day near July 25th. November 15th to March 13th is the winter cold season and the coldest day around December 27th. The climate of Tofino is mild humid temperate resulting in the absence of a dry season in the warm summers (Diebel and Norda 2014).

The climate of Vancouver Island is very similar to Valencia, Ireland on the eastern side of the Atlantic Ocean. The warm North Atlantic Drift greatly influences the climate of Valencia, Ireland. Similar to Vancouver Island with latitude of 51.90N, Valencia has a marine west coast climate classification of "Cfb" (Veregin 2010).

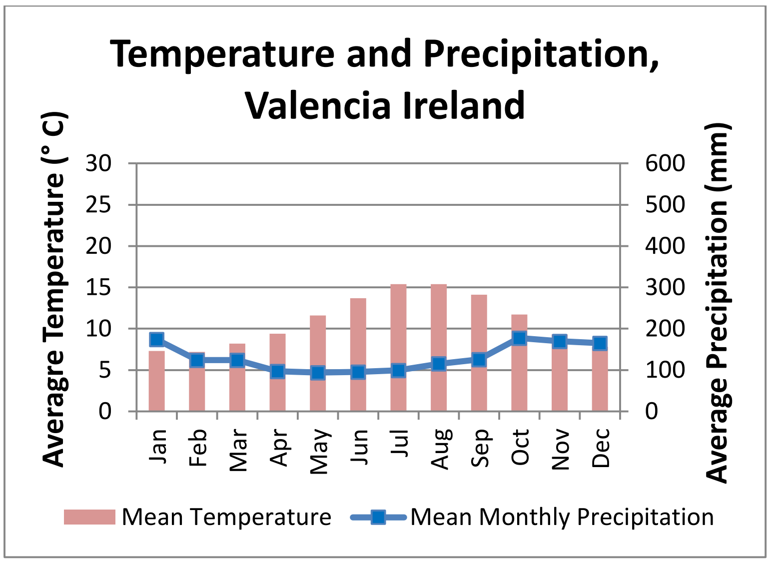

Figure 8: The above climograph represents data from the Valencia climate station on the west coast of Ireland (Valentia 2014).

Valencia, in comparison to Vancouver Island, is normally slightly warmer in average temperature during winter months, but Valencia has about half of the yearly precipitation of Vancouver Island (See Figures 1 and 8), receiving an average of 1,560 mm a year while Vancouver Island gets 3,270 mm.

Vancouver's Climate Classification

According to the Encyclopedia of Earth (Pidwirny 2011), Wladimir Köppen (1846-1940) created his climate classification system primarily on a temperature profile associated with latitude. Köppen classified regions with the use of precipitation and temperature annual and monthly averages. The system is a series of three letters, each representing a different characteristic of the climate. Some areas may have a fourth letter added to classify a sub or microclimate within a region more accurately. Vancouver Island has the classification of "Cfb," in the Köppen climate classification system. The "C" represents moist mid-latitude climates with mild winters. Temperatures range from -3° C to 18° C with the winters being mild and summer temperatures are warm to hot. The "fb" represents marine mild winter, mild and wet without a dry season, and the average temperature is lower than 22° C in all months. A minimum of four months have temperatures averaging above 10° C and the region's rainfall is spread equally throughout the year. (Pidwirny 2011)

Precipitation Patterns of Vancouver Island

During the winter months when the AL increases force, the west coast of Vancouver Island receives a majority of the annual precipitation from intense, moisture-laden storms that move horizontally shoreward (Galloway 2013). The precipitation at "Tofino A" climate station ranges from 71 mm in July to 492.1 mm in November, based on the 1981 to 2010 Canadian Climate Normals station data (see Figure 1). The effects from ENSO appear in three to seven year oscillations (Patterson et. al. 2013), while PDO has a multi-decadal pattern of fluctuation (See Figure 5). ENSO causes abnormally dry periods in the northeast pacific as the more southern areas receive a noticeable increase in rainfall. (Patterson et. al. 2013) The average relative humidity at the "Tofino A" station ranges from 71.3% in May to 84.6% in December on the 1500 LST (Local Standard Time) (see Figure 2) (Canada 2014).

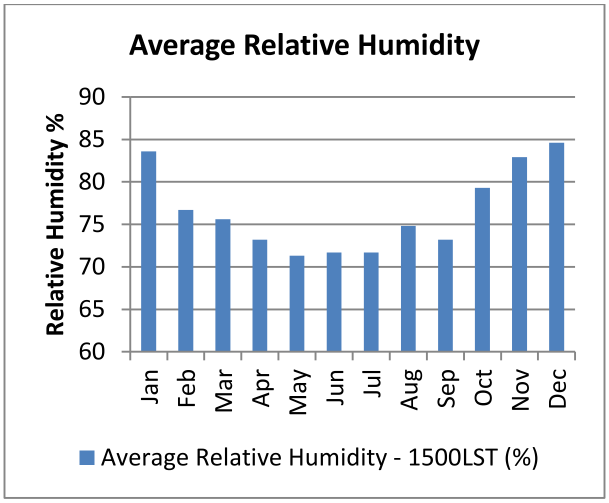

Figure 2: The average relative humidity graph for "Totino A" is created from 1981 to 2010 climate normals (Canada 2014).

Precipitation can reach 400 cm per year on Vancouver Island, which has a cool-temperate climate. The Pacific Decadal Oscillation (PDO) and El Nino Southern Oscillation (ENSO) also affect precipitation and storm intensity in this region of the northeast pacific (Patterson et. al. 2013).

Results

Initial findings indicate that the climate of western Vancouver Island is seasonally dependent on two very different weather systems. These two atmospheric pressure systems are the Northern Pacific High (NPH) and The Aleutian Low (AL) (Patterson et. al. 2013). During the Northern Hemisphere (NH) winter from October to March the AL atmospheric pressure system location is the controlling pressure system for the island (See Figure 3). Cyclonic storms, the creation of frontal systems generated by the AL, affect the island during the rainy winter months. During the NH summer from April to September the position of the NPH pressure system influences the island. The NPH generates massive anti-cyclonic systems that influence local weather conditions on Vancouver Island. Winds prevail from a southeasterly direction during the AL driven NH winter months of October to March. The NH summer months of April to September experience strong northwesterly winds due to NPH anti-cyclonic systems (Patterson et. al. 2013).

The AL delivers powerful and plentiful storms to the northerly end of Vancouver Island as it moves easterly. These northerly storms, driven by strong meridional airflow, leave the southern end of the island with less than normal precipitation in the winter months. In winters where the AL moves westerly creating fewer storms, zonal airflow systems direct rainstorms toward the southerly end of Vancouver Island, leaving the northerly end with less precipitation and cooler temperatures (Galloway 2013). The eleven-year solar cycle has a detectible association to the location of northern Pacific Ocean atmospheric pressure gyres. The NPH may be redirected as much as 300 km north during a sunspot minimum and the AL will divert as much as 700 km westerly during a sunspot maxima (Patterson et. al. 2013). Latitudinal changes in the Pacific-North American pattern (PNA) may have an effect on Vancouver Island. During PNA's positive phase, meridional-flowing Rossby wave-pattern air masses may influence cyclonic activity in the island region. The upper level air masses effect moisture, surface winds, temperature, and precipitation (Lui et. al. 2012).

Sea Surface Temperature

ENSO sea surface temperature (SST) abnormalities in the eastern Pacific Ocean peak several months prior to the correlating SST alterations that occur in the northern Pacific. The SST anomalies result from ENSO driven tropical convection changes that alter circulation in the atmosphere on a global scale. Observation of multiyear memory in the SSTs through the winter months is characteristic of the ENSO forcing. The colder water returns to the surface during the increase in winter mixing altering the stratification layer of the warmer summer season (Newman 2003). The average sea level pressure (SLP) in the form of the North Pacific index (NPI) denotes the atmospheric variability. Over the Northern Hemisphere winter, the strength of the Aleutian Low is gaged by the NPI, which also represents the range of SLP maximum fluctuation during all North Pacific seasons. The Pacific Decadal Oscillation (PDO) annual cycle contains a lag autocorrelation (See Figure 4). Autocorrelation refers to the past and future values correlating to the time series. "The prevailing null hypothesis of midlatitude SST [sea surface temperature] variability posits that the ocean integrates forcing by unpredictable and unrelated weather, approximated as white noise, resulting in 'reddened' noise with increased power at low frequencies and decreased power at high frequencies(e.g., Frankignoul and Hasselmann 1977) (Newman et.al. 2003)." The largest forcing is seen in the winter to spring transition and the least noticeable forcing is in the summer to fall transition. The PDO index lags behind the ENSO index multiple months and the most prominent lag is seen in winter and summer (Newman 2003).

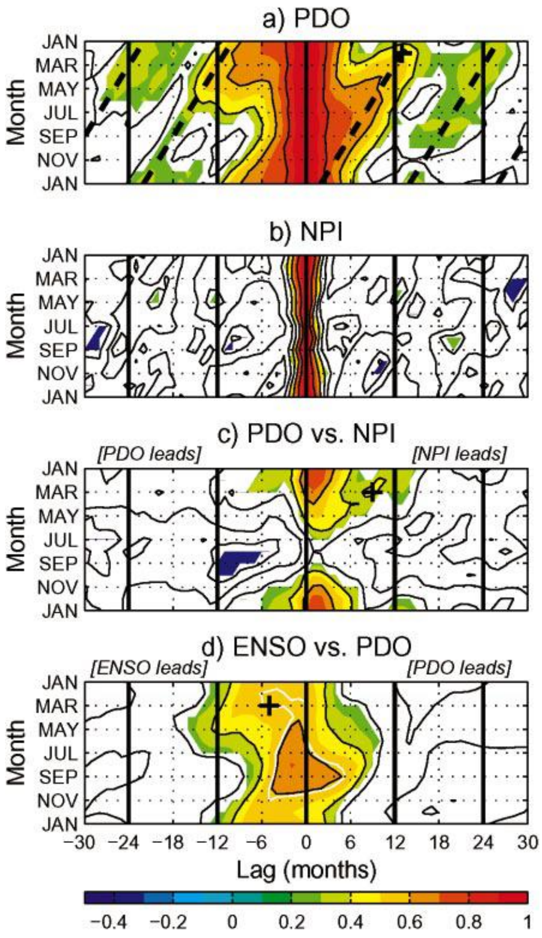

Figure 4: (a) Annual cycle of PDO autocorrelation, plotted as a function of month. Heavy dashed lines indicate correlation with Mar PDO; e.g., the cross represents correlation of the PDO in Feb of year 0 and Mar of year 1 (i.e., lag 113). (b) Same as (a) but for the NPI. (c) Annual cycle of cross correlation between the PDO and the NPI. The NPI leads the PDO for positive lags; the PDO leads the NPI for negative lags. The month ordinate refers to the NPI; e.g., the cross represents correlation between Mar NPI and Dec (lag 19) PDO. (d) Annual cycle of cross correlation between ENSO and the PDO. The PDO leads ENSO for positive lags; ENSO leads the PDO for negative lags. The month ordinate refers to the PDO; e.g., the cross represents correlation between Mar PDO and Oct (lag 25) ENSO. The thin white line is the 0.58 contour. Correlations are for the period 1950–2001, and contour (fill) interval is 0.2 (0.1). Only values that are at least 90% significant are shaded. (Figure and data from Newman et.al. 2003)

Ocean Currents

Vancouver Island is east of the Subarctic Current divergent zone (See Figure 3) where the California Current and Alaska Current originate and flow south and north respectively (Patterson et.

al.). AL and NPH wind patterns generate the majority of the ocean currents affecting the island (See Figure 3). The Vancouver Island Coastal Current (VICC) travels along the island in a pole-ward direction after initiating north of the Strait of Juan De Fuca. The main source of fresh water affecting the current in summer is the Fraser River via the Strait of Georgia. The current moves in the opposite direction of the prevailing northwesterly wind surface current and Shelf-break current in the summer months (Masson and Cummins 1998). The island receives warm water influences from the Coastal Undercurrent year-round and Northeast Pacific Coastal Current in winter months.

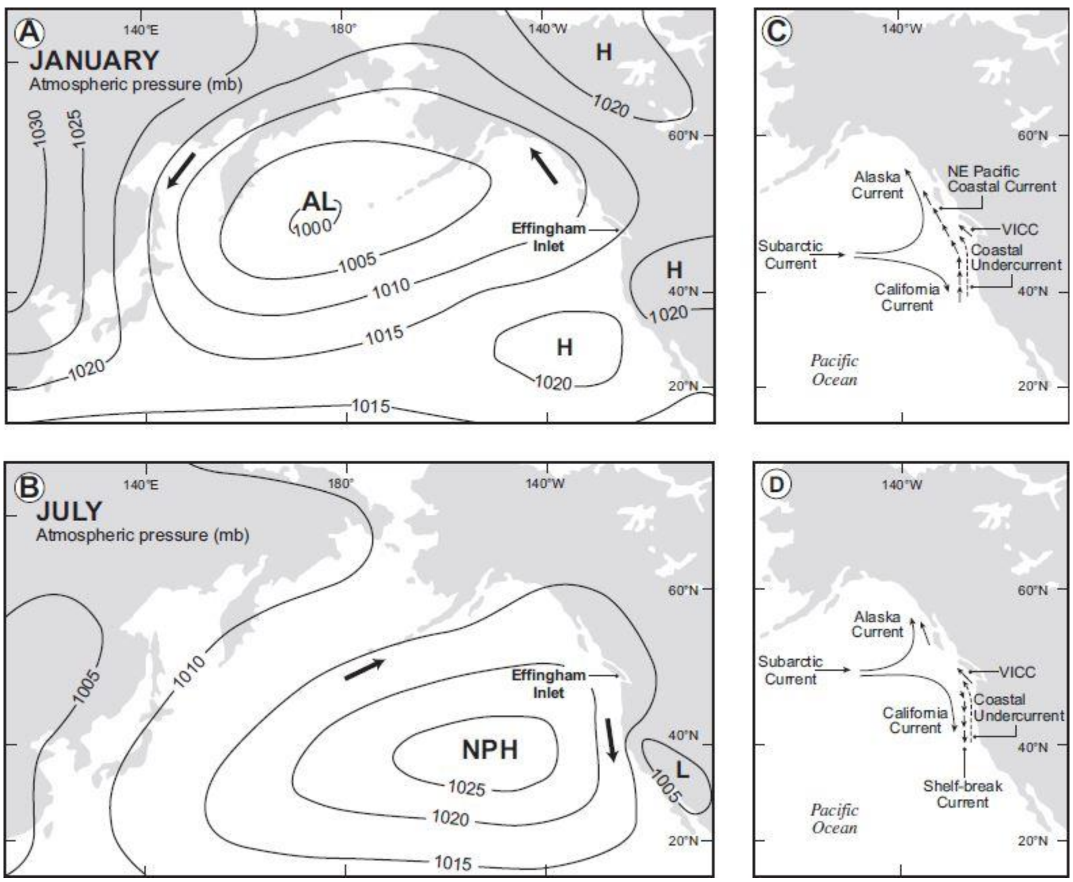

Figure 3: Maps showing main ocean-atmosphere circulation features for the NE Pacific region in winter (A, C) and summer (B, D) months. In summer, northerly North Pacific High (NPH) winds generate the southward Shelf-Break Current at the surface. During winter, southerly Aleutian Low (AL) winds generate a northward drift producing the NE Pacific Coastal Current. The Vancouver Island Coastal Current (VICC) and Coastal Undercurrent are permanent features although they vary in strength seasonally. (Map and data from Patterson et. al. 2013)

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ENSO and PDO

Although ENSO events may be absent in the tropic region, the conditions in the extratropical Pacific remain similar to the state ENSO normally produces. This ENSO like state remains prominent for decadal periods (Mantua and Hare 2002). Warm (cool) PDO conditions lead to less (more) precipitation in the mid-latitudes (See Figure 5). The differences between ENSO and PDO have three major points. The first difference is in the time span with ENSO lasting for 6 to 18 months and PDO having a 20 to 30 year span (See Figure 6). The second difference between ENSO and PDO is the position of activity. The position of activity for ENSO is the tropics, whereas PDO activity is extratropical in nature. Thirdly, climatologists have a good understanding of ENSO, but the PDO drivers are unconfirmed at this time. Both ENSO and PDO affect Vancouver Island, including temperature, precipitation, and SST (Mantua and Hare 2002). This change in SST greatly affects salmon, which prefer colder water. This may affect the food security of the native population as well as the economy of the island. Zooplankton populations may be affected leading to algal blooms, which may also have negative effects on fisheries including shellfish (Mantua and Hare 2002).

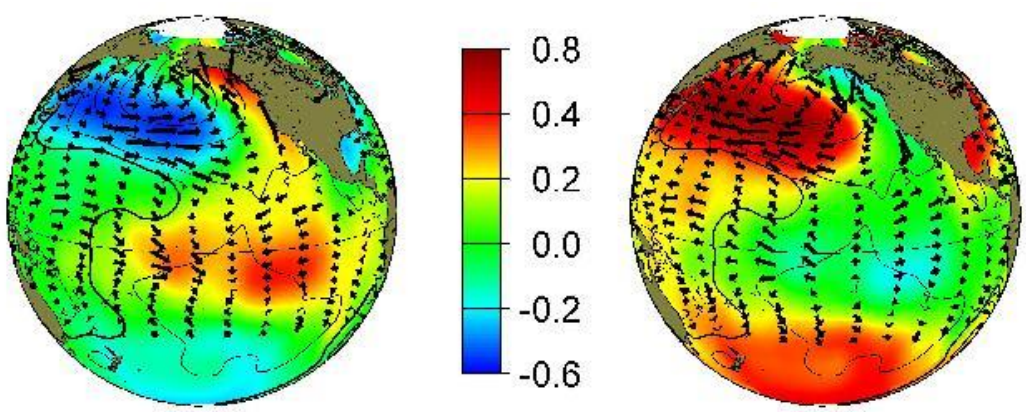

Figure 5: The Pacific Decadal Oscillation warm and cold phases.
(http://jisao.washington.edu/pdo/graphics.html)

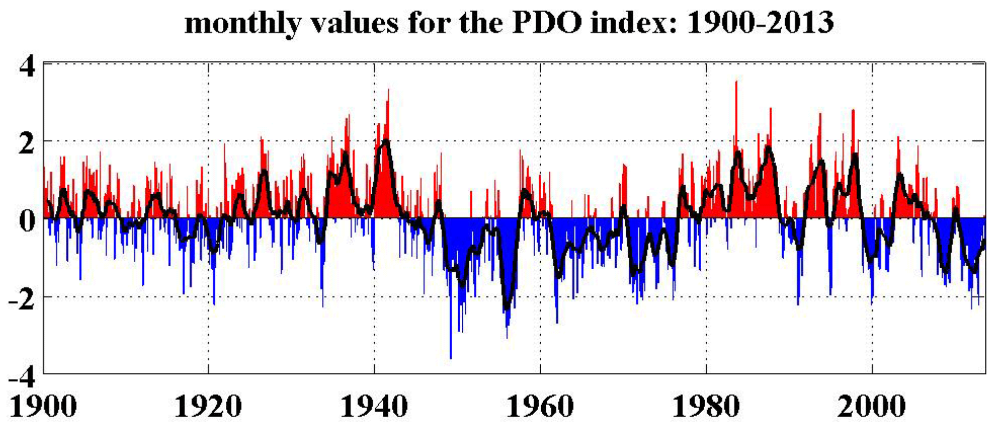

Figure 6: Graph indicating Pacific Decadal Oscillation cold and warm phases (http://jisao.washington.edu/pdo/graphics.html).

Land and Sea Interactions

Increases in storm strengths correlate to an increase in regional coastal erosion when overlain with larger wavelengths and heights. Increases in existing water levels are also a contributing factor to erosion. Data compilations indicate the Eastern Pacific coastline is experiencing an increase in incidence and the severity of those incidents. Positive phases of PDO and ENSO contributing to the strength of AL may have an influence on the increase in erosional activity. During ENSO years, mean sea level rose 10 to 20 cm on the west coast of Vancouver Island intensifying erosion (Heathfield 2012). The three main factors contributing to coastal erosion are storm surge, on shore wave intensity, and a climatic increase in sea level. Vancouver Island storm surges initiate from the AL system before advecting to shore. The Western Cordillera often stalls storm advance over coastal areas increasing the overall effects of the storms including the erosional effect (Heathfield 2012). Heavy precipitation may lead to flooding and create the potential for landslides on the western side of the island. The location of the AL in conjunction with ENSO and PDO phases influences variations in sea level and climate conditions. The AL storms generate intense southeasterly winds in contrast to the milder summer winds of the NPH that are west-northwest. Gust on the western coast of Vancouver Island can surpass 100 kmh $^{-1}$ creating hazardous conditions for inhabitants. Although SST increases cause sea level rise due to thermal expansion, PDO has the least effect on coastal erosion, and the teleconnections between ENSO and the AL, predominantly the latter, have the greatest effect on Vancouver Island coastal erosion. La Nina years tend to intensify the AL storms and shift activity towards the north end of the island (Heathfield 2012).

Past and Future Climate Conditions

Tree ring data for the past 4000 years (Zhang and Hebda 2005) indicates variances that range on decadal and yearly, to centuries long scales. Douglas fir trees (*Pseudotsuga menziesii*) are sensitive to changes in precipitation levels making the trees ideal for past climate assessments. The study area is the southern end of Vancouver Island, British Columbia. The data indicates a drought period in the 1920s AD based on five years of continuous 2-unit standard deviation from the mean value. The 1840s to mid-1460s AD and approximately mid 1860s BC experienced severe drought. From the 1440s to 1560s AD the region experienced the longest lasting drought period. Approximately 800 BC, as well as the mid-760s to 800s, the 540s to 560s, and the 150s to late-190s AD experienced severe and multidecadal droughts. The period from the late 1560s to mid-1760s, known as the Little Ice Age, indicates an extremely wet environment persisted and the period after underwent sporadic wet conditions. Conditions from the 10th to the 14th centuries were stable in correlation to the North Atlantic Medieval Warm Period. The 19th century BC underwent extreme climatic change causing a pentadecadel oscillation leading to a period of four years having a 71% decrease in radial growth. In the 19th and 20th centuries AD climate oscillations were at a pentadecadel time scale (30 to 80 years) which is also the case for 19th century BC. The 6th to the early 9th centuries with the 2nd to mid-3rd AD, and the mid-3rd to 4th and the mid-8th and 9th centuries BC experienced century long oscillations scales. Over the last 4000 years, oscillations in the bi-decadal (10 to 30 years) and inter-annual (2 to 8 years) ranges with varying amplitude and persistence have existed sporadically. (Zhang and Hebda 2005)

Climate projections for mid-latitude regions such as Vancouver Island are less severe than the Tropics and Polar Regions. The Intergovernmental Panel on Climate Change (IPCC) 2013 report shows summer months will likely be warmer to hotter and the amount of heat increase depends on which Representative Concentration Pathway (RCP) the planet is experiencing. RCP 2.6 is the ideal scenario, which is the immediate and drastic reduction of greenhouse gases (GHGs). RCP 8.5, the business as usual approach would lead to much higher forcings and a greater change in climate. Climate models show an increase in precipitation for the mid-latitudes, again depending on which RCP conditions exist determines the magnitude. The projections indicate the yearly precipitation is less likely to be in the form of snow changing the hydrologic patterns for spring and summer snowpack runoff. Winter months will have fewer extreme cold days and nights. Projections show the potential for increases in severe weather events including cyclonic winds, heat waves and flooding. The potential for drier, drought-like conditions will also increase the potential for wildfire. (IPCC 2013)

Climate change has increased global temperatures by 0.4 to 0.8° C in the last century (Hurley et al. 2006). This change in temperature is leading to a 2 mm year $^{-1}$ rise in sea level due to thermal expansion and additional fresh water inputs from glacial and ice sheet melting. Continental warming will be greater than oceanic warming which will increase pressure gradients leading to stronger wind patterns in coastal areas. These changes in wind patterns and strengths may lead to increases in upwelling in the Western Pacific. Changes in the thermocline due to influxes of fresh water may inhibit colder nutrient laden waters from reaching the surface. This lack of nutrients will greatly effect primary production leading to a breakdown in the food chain, which affects food securities of indigenous peoples and the economy of coastal areas dependent on fisheries. Increased and enhanced storm activity is occurring and the expectation is for further increases in coastal areas where circulation patterns will alter precipitation leading to changes in salinity, turbidity, and terrestrial nutrient and pollution inputs. The changes in wind patterns may also be altering ocean currents. Ocean acidity (pH) is increasing as higher atmospheric CO_2 levels increase transfer of CO_2 to ocean waters. This higher level of acidity greatly affects calcifying organisms reducing shellfish harvests. This loss of harvest is greatly affecting food security and the fisheries based economies of Vancouver Island. (Hurley et al. 2006)

Conclusions

The AL and NPH create the storm systems that affect the west coast of Vancouver Island. The position of the two atmospheric systems varies in direct relation to the eleven-year solar cycle, which changes the precipitation and temperature on the island's west coast. The severity of the NPH and AL systems fluctuate in correlation to the phases of ENSO and PDO. This fluctuation also affects precipitation and temperature on Vancouver Island (Patterson et. al. 2013). The AL and NPH are also responsible for the changes in ocean currents near Vancouver Island. Fresh water outflow from the Fraser River also affects currents near the island (Masson and Cummins 1998). Full understanding of the drivers behind PDO and ENSO is not available at this time. The climate of Vancouver Island has undergone changes in the past and the current climate change is affecting the island in adverse manners. The teleconnections of PDO and ENSO require more research and examination prior to accurate generation of projections regarding climate change for the future.

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