December 17, 2012 Stanley Park

Storm Surge Almanac for Southwestern British Columbia: Fall/Winter 2013-2014

Pre-season discussion of tidal and climate conditions affecting extreme water levels on the BC coast

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Prepared for Fisheries and Oceans Canada and the British Columbia Ministry of the Environment

Scott W. Tinis, Ph.D.

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Executive Summary

Current conditions in the tropical Pacific Ocean are categorized as *ENSO neutral* and are predicted to remain neutral over the winter of 2013-2014. There are no ENSO-related impacts expected for the west coast of Canada, which should experience an average number of extra-tropical storms and no north/south shift of the winter storm track. In contrast to major El Niño and La Niña events, ENSO neutral conditions are not highly correlated with persistent positive sea-surface height anomalies at mid-latitudes. Last year (2012-13) saw similar conditions and experienced normal storm conditions and near-zero persistent coastal sea surface height anomalies. Many of the strong wind events last season were the result of weather fronts passing over the coast. Such systems have large atmospheric pressure gradients and associated strong winds, but do not normally bring a low-pressure component to the storm surge. One notable exception to this was a severe closed-low pressure storm that brought strong temporally shifting (rotating) winds and low pressure to the lower mainland on December 17, 2012 within hours of one of the highest predicted tides of the year. That storm caused considerable damage when westerly winds at the tail end of the storm struck at high tide and flooded or eroded foreshore areas of Ambleside, Stanley Park and Kitsilano Beach.

Flooding risk is greatest during the seasonal perigean spring tides, which correspond to times of extreme high tidal levels during the winter months. This year the highest tides for the Lower Mainland are expected in the first weeks of December, January and February; for Victoria the highest tides are expected in the first and last weeks of December, and the final week of January.

As in the fall of 2011 (but unlike the fall of 2012), storms arrived early in 2013. The storm of September 30, 2013 brought very high winds and heavy rain to southwestern BC and surge levels of 71 cm were measured at Point Atkinson (55 cm at Victoria). The storm was described as an extra-tropical remnant of Typhoon Pabuk. This year it is difficult to speculate on the expected strength and frequency of storms due to ENSO neutral conditions, coupled with a weakly negative (cool) phase of the Pacific Decadal Oscillation. As cautioned last year, constant monitoring is imperative this season so that stakeholders are not surprised by storm events that run counter to the seasonal forecast.

Overview

This document provides a summary of the meteorological and oceanographic environment of southern British Columbia as it relates to the 2013-2014 winter storm season. Focus is on the risk of water levels approaching or exceeding the historical high observed at Point Atkinson (Vancouver) and Victoria.

The main factors that contribute to extreme water level are seasonal high (king) tides, storm intensity (wind velocity and sea-level pressure), and coastal sea level anomalies (departures from the long-term mean) due to basin-scale ocean climate phenomena such as the El Niño/Southern Oscillation (ENSO). Each of these risk factors is discussed below.

Climatological Factors

Large-scale climatological phenomena affect both the weather and climate. The statistics of synoptic scale meteorological conditions in a given year may be impacted by the larger scale atmospheric and oceanographic conditions that can be described by the current state of a number of climate indices. Two such indices that have a great impact on the west coast of North America are the Pacific Decadal Oscillation (PDO) and the El Niño/Southern Oscillation (ENSO). A description of these phenomena and a discussion of their potential impact on the winter storm surge statistics for British Columbia are included in the Appendix.

In 2000, the PDO shifted from the multi-decadal warm phase (1977-2000), to what has been a predominantly a cold phase over the last 12 years. Last year's minimum PDO (-2.21) was the second lowest observed during the current multi-year cold phase. Winter high winds in 2012-2013 were mainly due to passing fronts early in the season, followed by a very intense closed-low pressure storm in mid-December 2012. **The current PDO index (as of August 2013) is -1.04.** This weakly negative value of the PDO is in concert with ENSO neutral conditions.

The NCEP Climate Prediction Center (CPC) provides regular updates of the state of ENSO in the Pacific Ocean. As of September 5, 2013, the ENSO alert system is not active. Consensus model forecasts published by CPC (Fig. 1) all point to ENSO neutral conditions that are expected to continue into spring 2014. The complete commentary is available at:

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.pdf

From the CPC commentary of September 5, 2013:

"ENSO-neutral conditions persisted during August 2013, as reflected by near-average sea surface temperatures (SSTs) across much of the equatorial Pacific, with below-average SSTs in the eastern Pacific… The low-level and upper-level winds were near average across the equatorial Pacific. Convection continued to be enhanced over Indonesia and suppressed in the central and eastern Pacific. Collectively, these atmospheric and oceanic conditions reflect ENSO-neutral…. Similar to last month, the forecast consensus favors ENSO-neutral (60% chance or greater) through December – February 2013-14."

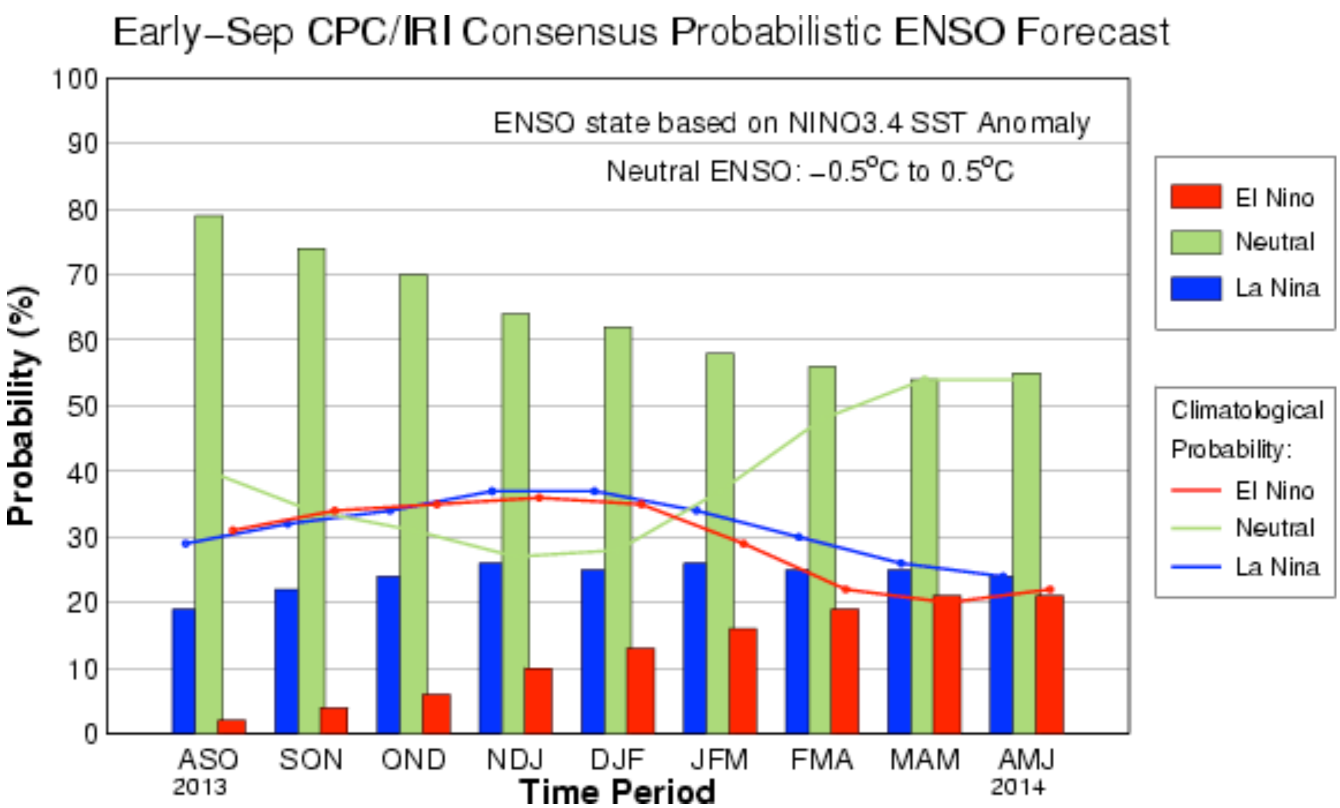

Figure 1: CPC numerical model consensus forecast for ENSO conditions for Fall 2013 to Spring 2014.

Eichler and Higgens (2006 - referred to hereafter as EH) compared North American extratropical storm activity to ENSO phase based on the NCEP reanalysis period of 1950-2002 and the European ECMWF 40-year reanalysis data from 1971-2000. They categorized years based on an ENSO Intensity Scale (EIS) equal to twice the "Oceanic Niño Index" (see Table 1).

Table 1: (From Eichler and Higgens (2006) Table 1)

EIS > 3	strong El Niño	1958, 1966, 1973, 1983, 1992, 1998, 2003
0 < EIS < 3	weak/moderate El Niño	1964, 1969, 1977, 1978, 1987, 1988, 1995
EIS = 0	Neutral	1952, 1953, 1954, 1959, 1960, 1961, 1963, 1967, 1970, 1979, 1980, 1981, 1982, 1986, 1990, 1991, 1993, 1994, 1997, 2002
-3 < EIS < 0	weak/moderate La Niña	1951, 1955, 1957, 1962, 1965, 1968, 1971, 1972, 1975, 1984, 1985, 1996, 2001
EIS < -3	strong La Niña	1950, 1956, 1974, 1976, 1989, 1999, 2000

Over the entire reanalysis period, EH provide an average seasonal frequency of the number of storms in the northeast Pacific that impact the southern coast of British Columbia; results show an average of three storms in the period spanning October to December (OND) and four in the period from January to March (JFM). When the storms were binned by ENSO phase (as described in Table 1), the JFM storm track frequency was shown to be highest (four or more) during a moderate or strong La Niña phase and during a strong El Niño phase. The lowest storm frequency in the region (4 or less) occurs, on average, during ENSO neutral or moderate El Niño conditions. This analysis was not done for the OND period so it is not clear from the discussion of EH whether or not the storms have shifted earlier in the season, but it is assumed that the weakening of storm frequency in JFM during ENSO neutral to moderate El Niño occurs in all seasons.

The Pacific Ocean is currently in a persistent ENSO neutral phase. Atmospheric and oceanic conditions are all ENSO neutral and are expected to remain that way into the northern hemisphere winter. **Based on the forecast of ENSO neutral conditions, combined with a weakly negative PDO, the winter storm track is not expected to be shifted relative to normal. An average number of extra-tropical storms is predicted, whose strength and timing are uncertain.**

Surge Statistics

Residual sea level (water level - tidal height) statistics for southern British Columbia are examined for Point Atkinson and Victoria from 1980 to present. This time period was chosen because it represents a modern era in the gauge data. One drawback of using this period is that the beginning coincides with the start of the 23-year PDO warm phase (1977-2000), and therefore may include climatological biases (weighted towards warm PDO conditions). The tides were calculated for both tide gauge stations and subtracted from observed water levels. The resulting water level residuals were binned in 5 cm bins; all residuals greater than 20 cm were retained for the analysis.

Point Atkinson

The maximum residual water level measured (1980-present) at Pt. Atkinson is **1.03 m in March, 1999**. For residuals > 20 cm, the 90th percentile corresponds to residuals >45 cm. The percentage and cumulative percentage represented for each 5 cm bin are shown in Fig. 2.

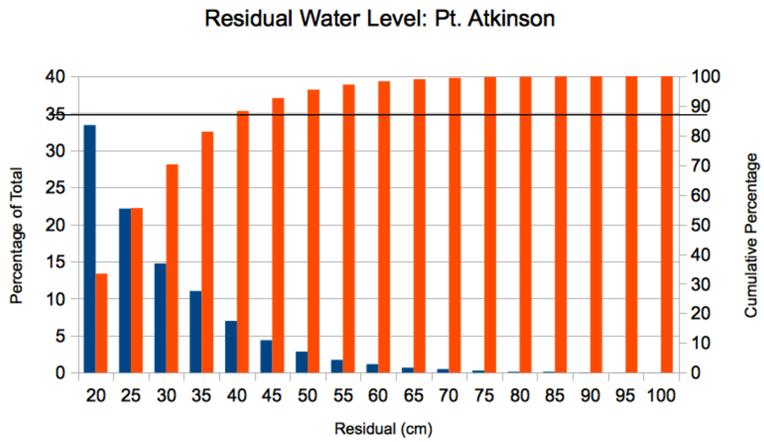

Figure 2. Residual water levels at Pt. Atkinson (>20 cm) in 5 cm bins as a percentage of the total number of residuals > 20 cm (blue) based on hourly observations. The cumulative percentage at each bin level is shown in orange. Residuals >45 cm lie within the 90th percentile (black line) of all residuals > 20 cm.

Victoria

The maximum residual water level measured (1980-present) at Victoria is **0.80 m in January 1983**. The 90th percentile includes all residuals >40 cm. The percentage and cumulative percentage represented for each 5 cm bin are shown in Fig. 3.

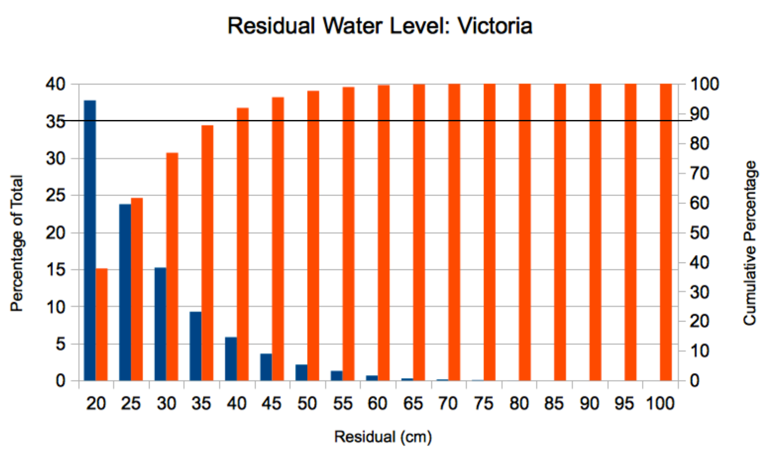

Figure 3. Residual water levels at Victoria (>20 cm) in 5 cm bins as a percentage of the total number of residuals > 20 cm (blue) based on hourly observations. The cumulative percentage at each bin level is shown in orange. Residuals >40 cm lie within the 90th percentile (black line) of all residuals > 20 cm.

Tides

The highest tides of the year, known as the perigean spring (or "king") tides, occur near the summer and winter solstices. High tides during this period reach (or slightly exceed) 5.0 m at Point Atkinson and 3.1 m at Victoria. Water levels of this magnitude leave coastal areas extremely vulnerable to flooding by storm surge. To illustrate the importance of these periods of extreme tidal height, a concurrent storm surge of 0.6 m (1.3 year return period) would cause a total water level equivalent to the 1982 record at Point Atkinson (and the 2003 record at Victoria), even without the presence of El Niño-induced elevated coastal sea levels.

Point Atkinson

The historical recorded high water level at Point Atkinson occurred on December 16, 1982 when the water gauge measured a total water level of 5.61 m (4.71 m tide + 0.90 m anomaly). The factors that led to the historical high water level were a combination of high seasonal tide, strong winds, low atmospheric pressure and a coastal sea-level height anomaly of approximately 0.2 m driven by one of the most intense El Niño events on record.

Figure 4 highlights the dates when peak tides may exceed 4.7 m relative to station datum at Point Atkinson; these periods offer broad windows during which a moderate storm surge could result in extreme water levels. Days with predicted tides in the range of 4.7-4.8 m are shaded yellow, while those with tides in the range of 4.9-5.0 m above chart datum are shaded red. The periods to watch occur during the first weeks of December, January and February.

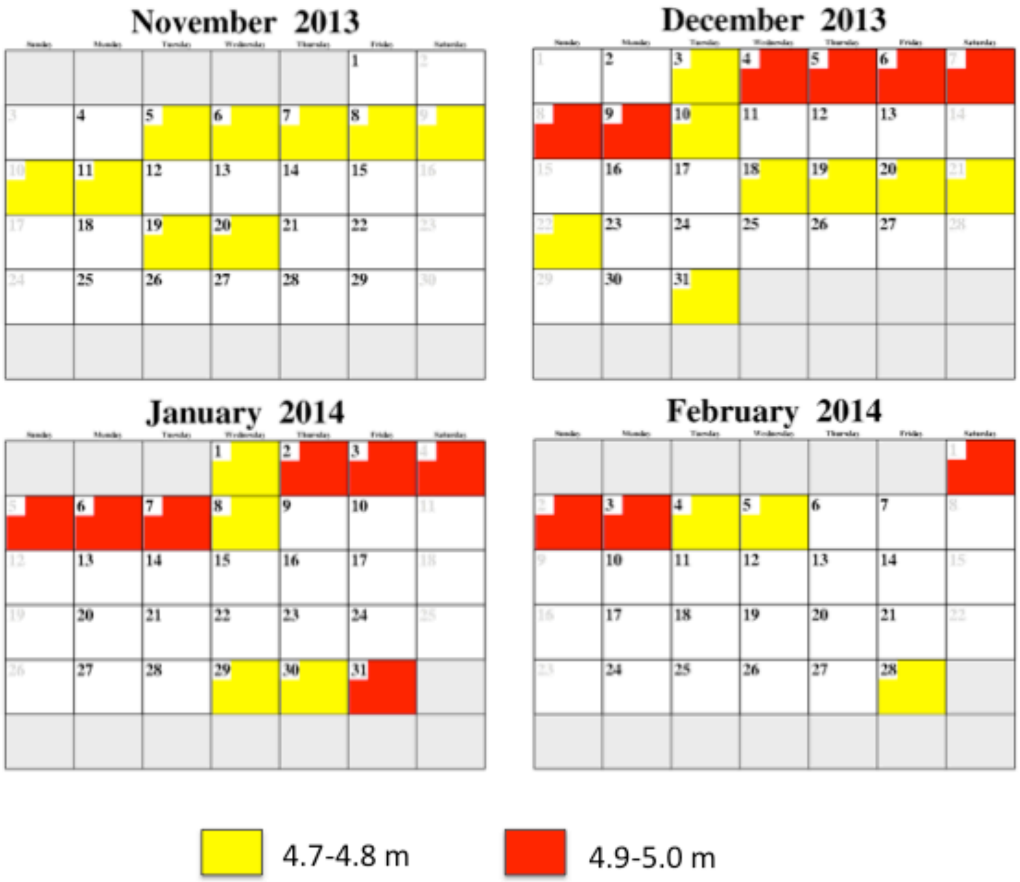

Figure 4. Calendar of dates for the winter of 2013-2014 with tides exceeding 4.7 m at Point Atkinson. The highest tides during this four month period occur during the first weeks of December, January and February.

Victoria

The historical maximum recorded water level at Victoria of 3.71 m above chart datum (3.14 m tide + 0.57 m surge) occurred on January 2, 2003. This occurred at the time of highest seasonal tide combined with a large surge (98^{th} percentile). Figure 5 highlights the dates when peak tides may exceed 2.8 m relative to station datum. Depending on the predominant wind direction, several regions around Victoria are at risk to storm surge damage including Fairfield (Ross Bay), Oak Bay and Cadboro Bay. This year (winter of 2013-14), the highest predicted tides occur during the first and last weeks of December, and the last week in January, with the 5 days surrounding New Year's Day providing the largest window of peak tides of the winter.

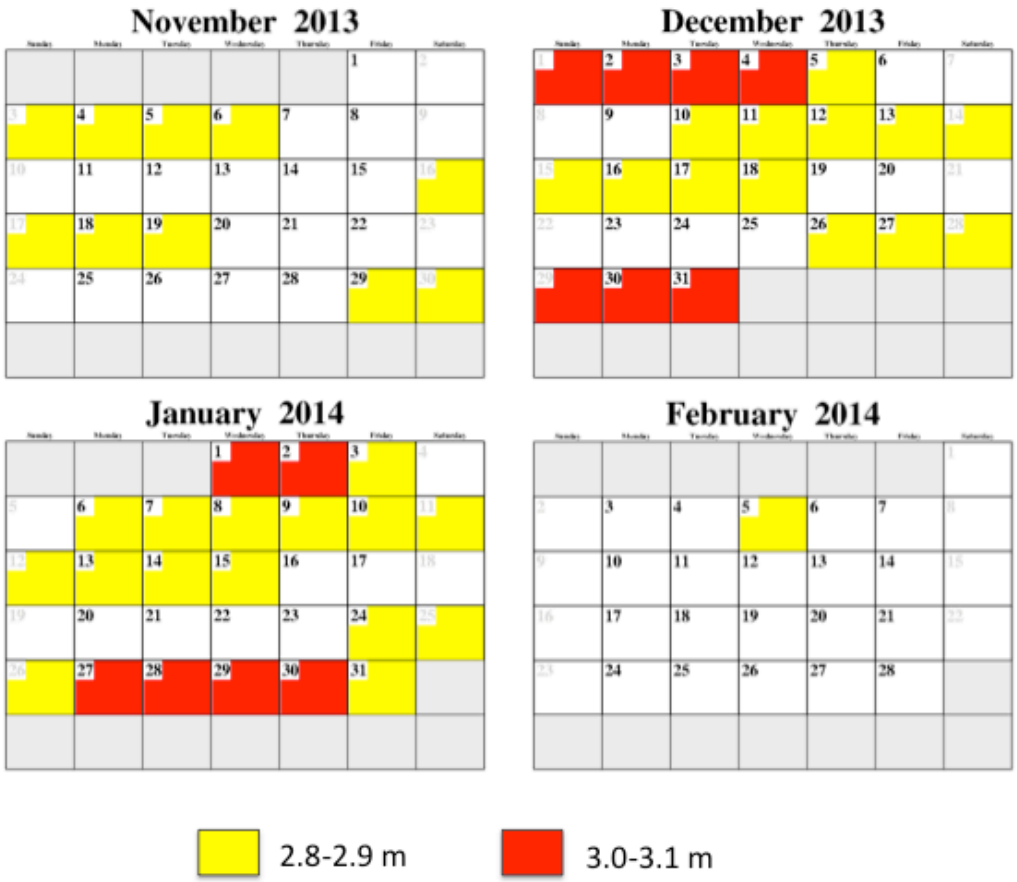

Figure 5. Calendar of dates for the winter of 2013-2014 with tides exceeding 2.8 m at Victoria. The highest tides during this four month period occur in early December and the first and last weeks of January.

Sea Surface Height (SSH) Anomaly

Sea surface height anomalies derived from the JASON radar altimetry satellite are processed by the Jet Propulsion Laboratory (JPL) at the California Institute of Technology to show the interannual variability of SSH by removing the mean and seasonal signals, and the trend. The SSH anomalies can indicate effects of large scale interannual phenomena, such as ENSO. As of September 20, 2013, near-zero anomalies are indicated off the British Columbia coast (Fig. 6). Near-zero anomalies also appear along the entire equatorial Pacific which indicates neutral ENSO conditions; neutral conditions are forecast to remain with a small expectation of a weak to moderate El Niño developing later in the winter (early 2013).

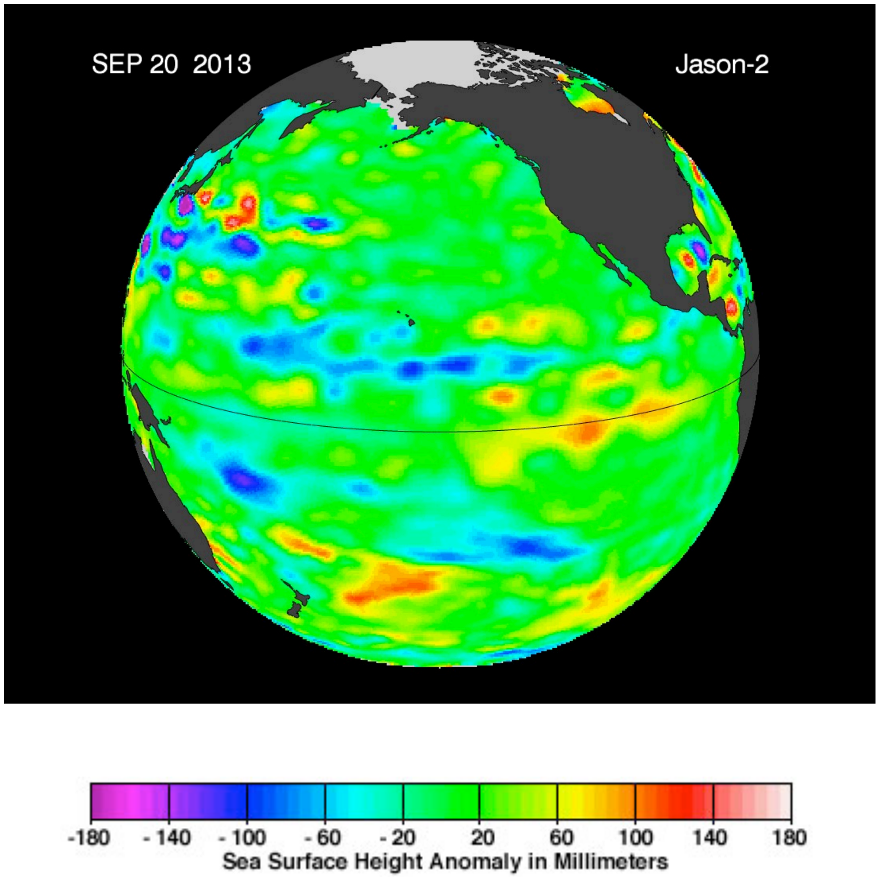

Figure 6. JPL image of 10-day averaged SSH anomaly over the Pacific Ocean for September 20, 2013. The equatorial pattern indicates neutral conditions in the equatorial and mid-latitude northeast Pacific Ocean.

Summary

From the information available as of October 2013, the winter 2013-2014 storm season will be characterized by the following:

1. Peak spring tides at **Point Atkinson** will reach 4.9-5.0 m above chart datum in the first weeks of December, January and February.
2. Peak spring tides at **Victoria** will reach 3.0-3.1 m above chart datum in early and late December, then again in the last week of January.
3. An average number and intensity of winter storms is expected based on historical storm climatology for the predicted neutral ENSO conditions through the winter of 2013-2014.
4. Ambient coastal SSH anomalies are expected to be near zero throughout the winter.
5. The PDO index is presently -1.04, which is weakly cool with no expected impact on storminess.

Early autumn storm activity has been strong on the southern British Columbia so far, similar to 2011. Flooding in November 2011 was widespread throughout the Georgia Basin – a development which led to the creation of a Campbell River storm surge bulletin. In 2011-2012, an arctic high-pressure system dominated the synoptic weather patterns after mid-December, which forestalled high residual water levels. Such an occurrence is not expected (statistically) this year because of the neutral ENSO conditions.

References

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Gershunov, A. and T. P. Barnett. 1998. Interdecadal modulation of ENSO teleconnections. *Bulletin of the American Meteorological Society* 79: 2715-2725

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Appendix

Pacific Decadal Oscillation

The PDO, which represents the principal mode of variability of sea surface temperature in the Pacific Ocean, shifts between a positive (warm) and negative (cool) phase (Mantua and Hare, 2002). During a warm PDO phase, the waters off the west coast of North America exhibit warmer than normal temperatures, and wind velocity anomalies along the outer coast are directed northward (Fig. A1). The opposite is true during the cool phase. The time series of PDO index from 1900 to present (Fig. A2) shows that the oscillation between the warm and cool phase varies with a period of roughly 5-10 years, but can also stay predominantly in one mode for prolonged periods. The shift from a nearly 30-year cool phase to a warm phase in the late 1970s is considered by many to be an oceanic regime shift affecting both weather and biological ecosystems in the Pacific Ocean. After 1998, there was an apparent return to the cool PDO phase.

The sea level pressure anomaly associated with the warm phase of the PDO acts to intensify the Aleutian low, and vice-versa during the cold phase. Gershunov and Barnett (1998) provide evidence of modulation of the ENSO signal by the PDO. For example, the climate impacts of El Niño may be intensified during a warm PDO phase since both contribute to a deepening of the Aleutian low pressure system. Conversely, a cold phase PDO could enhance the effects of La Niña over western North America.

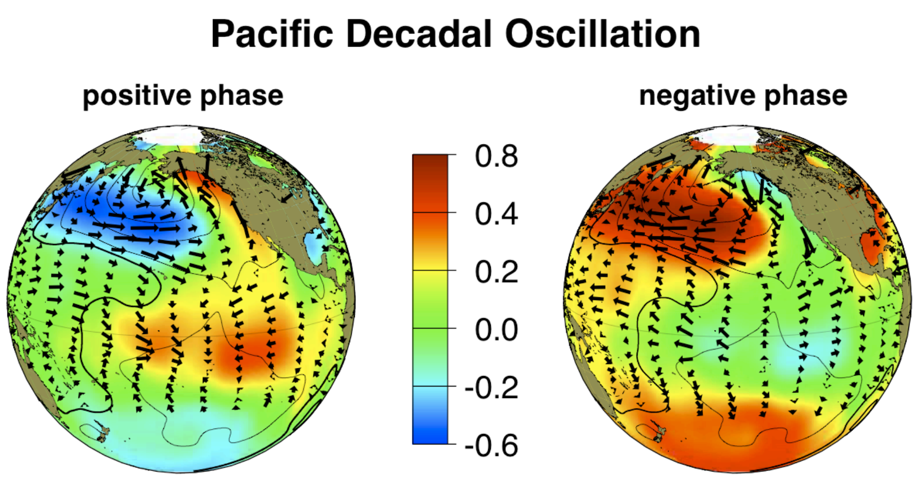

Figure A1. PDO warm and cool phases of sea surface temperature anomaly and associated wind anomaly patterns. Web image from Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington.

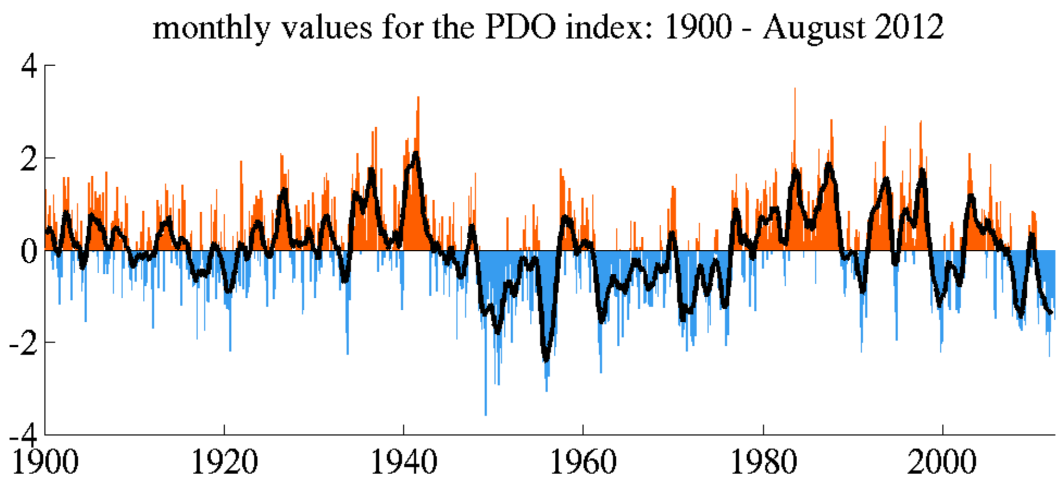

Figure A2. Monthly values of the PDO index from 1900-2012. Image from JISAO website.

El Niño/La Niña

The El Niño-Southern Oscillation is a coupled tropical atmospheric and ocean phenomenon that has extratropical influence over weather and oceanographic conditions. The Southern Oscillation is a quasi-periodic fluctuation in the atmospheric sea level pressure measured between Tahiti (central south Pacific) and Darwin, Australia. When atmospheric pressure is lower than normal over Tahiti and higher than normal at Darwin, the Southern Oscillation Index (departures from the mean difference) is negative and the normally easterly trade winds are reduced. This causes the warm water mass normally pushed to the western side of the Pacific Ocean to migrate towards South America. The occurrence of warm water off the coast of Peru is known as El Niño, and coincides with abnormally high coastal sea levels which suppress coastal upwelling and adversely affect marine biota through reduced deep water nutrient supply. Extratropical effects of El Niño include warmer ocean and air temperatures on the west coast of Canada, and more southern storm tracks. The opposite effect (a strengthening of the trade winds) results in La Niña conditions, which can result in colder air, more precipitation and a northward shift of the pacific storm track.

The impacts of El Niño/La Niña on sea levels off the coast of British Columbia can be significant. During the major El Niño years of 1982-83 and 1997-98, coastal sea level anomalies of 10-20 cm persisted for several months and contributed to a high occurrence of potentially damaging surges. La Niña can have the opposite effect (negative anomalies) but the anomalies are often more localized and of shorter duration. Figure A3 shows two images of residual sea surface height under both conditions.

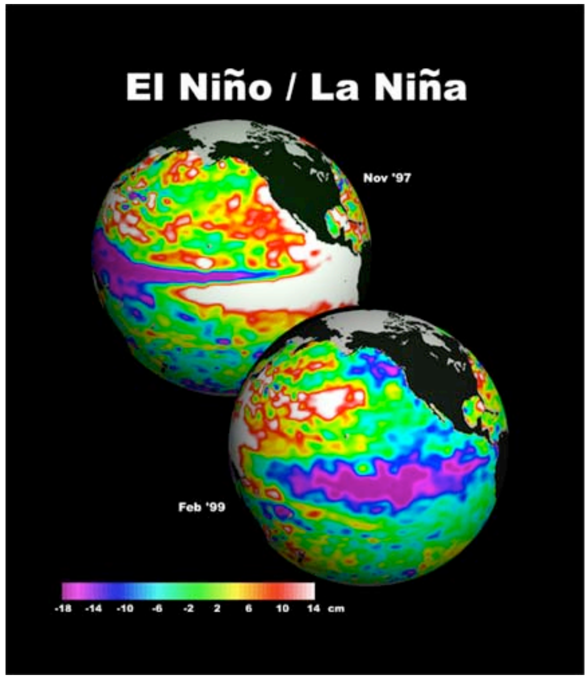

Figure A3. Residual sea surface height during the El Niño winter of 1997 and La Niña winter of 1999 (courtesy Jet Propulsion Laboratory). The positive SSH residual off the BC coast in 1997 is part of a larger feature stretching to the equator, while the negative SSH residual in 1999 is more localized. The magnitude of both is well in excess of 10 cm.

The Earth System Research Laboratory (ERSL) of the US National Oceanic and Atmospheric Administration produces a multi-variate ENSO index based on six oceanic and atmospheric variables: sea surface temperature, wind velocity components, sea level pressure, surface air temperature and cloudiness (Wolter and Timlin, 2011). The result is a monthly time series showing the interannual variability of ENSO strength (Fig. A4).

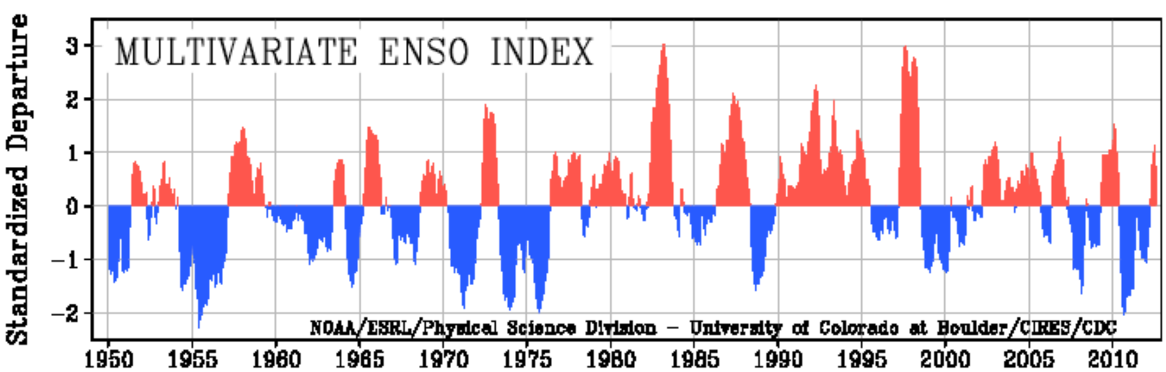

Figure A4. NOAA ERSL multivariate ENSO index from 1950 to present. Positive values indicate El Niño conditions, negative values indicate La Niña conditions.