BC Storm Surge Forecasting System

2014-15 Midseason Update
Storm season and climate index update

January 8, 2015
Conditions in the tropical Pacific Ocean remain categorized as *ENSO neutral*, as in the pre-season guidance. However, an El Niño Watch remains in place for the winter of 2014-2015 with a 50-60% chance of El Niño developing in the next two months. Potential El Niño impacts include an increase in the number of extra-tropical storms and a possible southward shift of storm tracks associated with the strengthening of the Aleutian Low.

Early December saw a series of strong storms with surges in the Strait of Georgia reaching 70-80 cm on three consecutive days (December 9, 10 and 11). The surges accompanied very high rainfall that caused flooding, particularly in Port Alberni and Courtenay/Campbell River. Several rivers experienced 1:50 and 1:100 year flow events, and BC Hydro was unable to control discharge from several Vancouver Island dams, allowing high river flow to occur coincident with high marine water levels.

The 5-10 cm sea surface height (SSH) anomaly off the west coast of British Columbia seen in the JPL Topex altimetry data in September dissipated just prior to November, but returned in the latest image (December 12), possibly reflecting the persistent onshore weather experienced in early December.
Overview and Events Summary

This document provides a summary of the meteorological and oceanographic conditions of southern British Columbia experienced so far during the 2014-2015 winter storm season. A summary of significant events is provided below, as is a summary of changes in climatological factors which can contribute to the storm outlook for the remainder of the season.

Three significant storms hit the west coast of British Columbia on December 9, 10 and 11, causing widespread flooding due to a combination of heavy precipitation and high marine water levels. The storms arrived during spring tide (but two weeks before perigean tides), and the storm surge on December 9 and 10 (both 80 cm) peaked very close to high tide. A third storm (the remnant of a large California storm) brought a surge of 70 cm, but hit at low tide and caused less damage than was originally expected. The observed tides and residuals (surge) are shown in Figure 1 below:

![Observed water levels and residuals at Point Atkinson from December 8-12, 2014.](image-url)
BC Storm Surge Forecasting System

Damage from these storms was widespread and variable, ranging from flooded heritage buildings in Richmond and a collapsed residential seawall in Tsawwassen, to major flooding in Port Alberni and Courtenay/Campbell River due to a combination of extreme high river flow meeting very high estuarine water levels. The river flows were estimated in many cases to 1:50 or 1:100 year high flow events, while the surge and total marine water levels were 1:5 and 1:3 year events respectively.
Climatological Factors Update

Large-scale climatological phenomena affect both the weather and climate. The statistics of synoptic scale meteorological conditions in a given year may be influenced by the larger scale atmospheric and oceanographic conditions that can be related to the current state of a number of climate indices. Two indices that have a significant relationship to 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 relationship to the winter storm surge statistics for British Columbia are included in the Appendix.

As of August 2014, the PDO index was 0.67, and there was an El Nino watch with an estimated 60-65% chance of El Nino developing over the winter months. The current PDO and El Nino states are:

- PDO: increased to 1.72 (November 2014)
- ENSO: El Nino watch still in effect with 50-60% chance of El Nino developing in the next two months

The weather this season has alternated between strong onshore flow (including strong winds and low pressure), and Arctic outbreak conditions (downwelling outflow winds and high pressure). There does not appear to be a consolidation in these conditions in the short term weather forecasts.
Tides

The highest tides of the year, known as the perigean spring 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.

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). Figure 4 highlights the dates when peak tides may exceed 4.7 m relative to station datum at Point Atkinson. 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 most closely occur during the fourth weeks of December and January, and the third week in February.

Figure 2. 2014-2015 calendar dates for tides exceeding 4.7 m at Point Atkinson. The highest tides during this four month period occur near the end of December, January and February, respectively.
Victoria

The historical maximum observed 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 coincided with the time of highest seasonal tide.

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 2014-15), the highest predicted tides occur during the fourth weeks of December and January.

Figure 5. 2014-2015 calendar dates for tides exceeding 2.8 m at Victoria. The highest tides during this four month period occur in late December and late January.
Sea Surface Height Anomaly

Sea surface height (SSH) 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 18, 2014, 5-10 cm anomalies are present off the British Columbia coast (Fig. 6), possibly associated with steric effects associated with the positive sea surface temperature anomaly observed over the same region. These coastal anomalies dissipated in October/November, but anomalies of approximately 10 cm are seen in the latest image (below) from December, possibly associated with the extended onshore flow of a series of storms early in the month.

Figure 6. JPL image of 10-day averaged SSH anomaly over the Pacific Ocean on December 20, 2014.
BC Storm Surge Forecasting System

Summary

As of December 2014, the winter 2014-2015 storm season has been characterized by the following:

1. **Surge Events**: Three storms during the period December 9-11 caused widespread flooding from high rainfall and high surge/tide levels.
2. **ENSO**: currently neutral with a 50-60% chance of El Niño forming in the next two months.
3. **PDO**: turning more positive (1.72 currently) as the winter progresses. Positive PDO generally reinforces the effects of a positive ENSO (El Niño).
4. Remaining Peak tides **Victoria**: fourth week of January.
5. Remaining Peak tides **Vancouver**: fourth week of January and third week of February.
6. **SSH anomalies**: ~10 cm anomalies visible, possibly short term related to a persistent early December storms.

Conditions have alternated between strong onshore flow with high winds, low pressures and high precipitation and Arctic outbreak (cold, outflow winds and high pressure). Weather is currently in between these regimes and storms will be closely monitored as the seasonal high tides return in January and February.
BC Storm Surge Forecasting System

References


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 a 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.
**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.
Midseason Update

BC Storm Surge Forecasting System

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.