BC Storm Surge Forecasting System

2021-22 Storm Surge Almanac

Climate outlook and tidal elevations for fall/winter 2021

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	PHONE	TWITTER	WEB
Author: Scott Tinis, Ph.D.	250.886.5640	@SurgeBC	www.stormsurgebc.ca

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Executive Summary

The 2020-21 storm surge season was characterized by frequent early season high intensity low pressure systems. Many of these events occurred during neap tides and/or overnight when tides were generally low. Storm frequency diminished in January followed by periods of colder arctic air, outflow winds and snow. The weather last year was influenced by moderate La Niña conditions in the Pacific basin. **This year, the 2021-22 season is under a La Niña Watch with weak La Niña conditions expected through the winter of 2021.**

The strongest wind storm last year occurred on November 17th, 2020, and brought a peak surge of 71 cm which ranked 32nd out of the last 58 years (Table 1). **The current weak La Niña conditions are normally associated with a weaker than normal jet stream and a storm track that is displaced north of its normal winter location.** Early fall wind events this year have been mainly associated with fronts predominantly sweeping down from the north coast.

The Pacific Decadal Oscillation has been in the process of turning negative since last year after being predominantly positive since 2014. Current seasonal coastal sea surface height (SSH) anomalies are near zero at the coast, but somewhat elevated (10-15 cm) in the north Pacific.

Annual coastal flooding risk is greatest during the seasonal perigean spring tides, which generate extreme high tidal levels during the winter months. This winter (2021-22) the highest tides for the Lower Mainland are concentrated in the first weeks of December, January and February. For Victoria, the highest tides occur early-November, mid- and late-December and late-January.

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Table 1. Rank of annual maximum storm surge at Point Atkinson (out of the past 58 years) ***for years since 1997****. Reference year represents the year at the start of the winter season. Last season is indicated in red.*

Year	Rank (out of last 58 years)	Surge (m)	ENSO Phase (red El Nino, blue La Nina)	PDO Phase (red positive, blue negative
1998	1	1.03	moderate-strong	moderate
2015	3	0.95	very strong	strong
2006	5	0.91	weak	weak
2002	8	0.89	moderate	strong
2016	9	0.85	moderate-strong	moderate
2011	11	0.84	weak	strong
2005	14	0.82	weak	weak
2018	16	0.81	moderate	weak
2007	21	0.79	weak-moderate	moderate
2014	24	0.77	neutral	strong
2001	27	0.74	neutral	weak
2009	31	0.72	moderate	weak
2020	32	0.71	moderate	weak
2012	36	0.68	neutral	moderate
1997	38	0.66	very strong	strong
2010	41	0.65	moderate-strong	moderate
2019	47	0.58	neutral	neutral
2004	48	0.57	weak	weak
2003	51	0.57	neutral	weak
2017	52	0.55	neutral	weak
2013	53	0.55	weak	weak
1999	55	0.53	strong	strong
2000	56	0.46	weak	weak
2008	58	0.44	moderate	strong

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Overview

This document provides a summary of the current and expected meteorological and oceanographic conditions for southern British Columbia as they relate to the 2021-22 winter storm season. The focus is on total water level (tide plus surge), and the risk of total water level approaching or exceeding the historical maximum observed values at Point Atkinson (Vancouver) and Victoria.

Fall weather has been intermittently wet and dry accompanied by occasional wind events related to frontal systems. The summer was dry and fall rains have been slow to raise water levels in most rivers and reservoirs to normal flows and volumes. Storm surge can be a confounding factor during late-fall and winter storms when streams are full and hydro reservoir levels are near capacity. The additional barrier of high tide and surge at the mouth of rivers can back up flow in unmanaged streams and adversely influence the ability to shed water in managed rivers at the time when discharge is most required.

The main factors that contribute to extreme marine coastal water levels are seasonal high tides ("king tides"), storm intensity (high wind velocity and low atmospheric pressure) and positive 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 in the following sections.

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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 influenced by the larger scale atmospheric and oceanographic conditions that are often described in terms of select climate indices. Two indices of significance to the west coast of North America are the Pacific Decadal Oscillation (PDO) and the El Niño/Southern Oscillation (ENSO)(Table 2). 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.

Table 2. Monthly Pacific Decadal Oscillation (PDO) and multivariate ENSO index values from 2017-present.

Year	2017		2018		2019		2020		2021	
Index	PDO	ENSO	PDO	ENSO	PDO	ENSO	PDO	ENSO	PDO	ENSO
Jan	0.77	-0.06	0.70	-0.62	0.45	0.08	-0.19	0.30	0.11	-1.2
Feb	0.70	-0.06	0.37	-0.73	0.16	0.52	-0.41	0.30	-0.27	-0.9
Mar	0.74	-0.08	-0.05	-0.50	0.30	0.77	-0.86	0.2	-0.89	-0.8
Apr	1.12	0.77	0.11	-0.43	0.76	0.33	-0.62	-0.1	-0.81	-1
May	0.88	1.46	0.11	0.47	0.97	0.26	0.25	-0.2	-1.04	-1.1
Jun	0.79	1.05	-0.04	0.47	0.95	0.35	0.14	-0.7	-1.00	-1.1
Jul	0.10	0.46	0.11	0.08	1.28	0.24	-0.17	-1	-1.28	-1.5
Aug	0.09	0.03	0.18	0.13	0.92	0.30	-0.44	-1	-0.22	-1.3
Sep	0.32	-0.45	0.09	0.51	1.03	0.20	-0.14	-1.2		
Oct	0.05	-0.55	0.18	0.41	-0.22	0.30	0.28	-1.2		
Nov	0.15	-0.28	0.13	0.26	0.44	0.50	-0.75	-1.1		
Dec	0.50	-0.58	0.39	0.13	0.75	0.40	-0.20	-1.2		

Pacific Decadal Oscillation

In 2000, the PDO shifted away from a multi-decadal warm phase (1977-2000), to what had been a predominantly a cold phase (negative PDO) until 2014. PDO values recorded between January 2014 and December 2019 were strongly positive, but have begun to give way to largely negative values over the past two years. **The current PDO index value as of August 2021 is -0.22.**

El Niño/Southern Oscillation

The NCEP Climate Prediction Center (CPC) provides regular updates of the state of ENSO in the Pacific Ocean. The September 9, 2021 bulletin from the ENSO alert system indicates a La Nina Watch. **The current ENSO MEI level (as of August 2021) is -1.3,** with consensus model forecasts published by CPC (Fig. 1) suggesting a 70-80% chance of La Niña conditions developing through the fall/winter of 2021. 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 9, 2021 (figure references in the quoted text are for the commentary at the link above):

"In the last month, ENSO-neutral continued with near-to-below average sea surface temperatures (SSTs) persisting in the central and eastern equatorial Pacific… Negative subsurface temperature anomalies (averaged from 180-100°W) remained steady in August [Fig. 3], reflecting below-average temperatures that extended from the surface to ~250m depth in the eastern Pacific Ocean… Tropical convection was suppressed near and west of the Date Line and enhanced over Indonesia [Fig. 5]. Given these conditions, the ocean-atmosphere system reflected ENSO-neutral, but is edging toward La Niña.

The IRI/CPC plume average of forecasts for the Niño-3.4 SST region from the last month favored borderline or weak La Niña during the fall and winter 2021-22 [Fig. 6]. The forecaster consensus this month, however, favors the latest predictions from the NCEP CFSv2 and the North American Multi-Model Ensemble, which suggest higher chances for the emergence of La Niña."

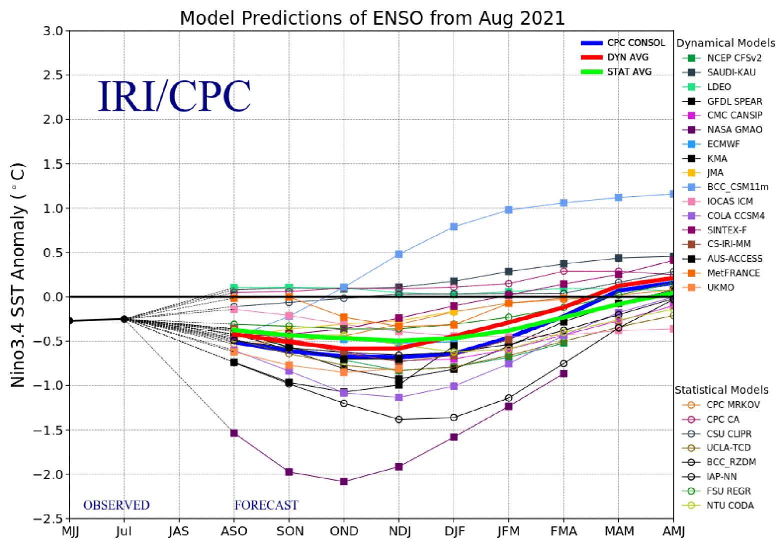

Figure 6. Forecasts of sea surface temperature (SST) anomalies for the Niño 3.4 region (5°N-5°S, 120°W-170°W). Figure updated 19 August 2021.

Figure 1: [CPC Figure 6] CPC numerical model consensus forecast for ENSO conditions for Fall 2021 to Spring 2022. The consensus is for a 70-80% chance of La Niña conditions through winter 2021.

Eichler and Higgens (2006 - referred to hereafter as EH2006) compared North American extratropical storm activity to ENSO phases 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 3).

Table 3: (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,

EIS > 3	strong El Niño	1958, 1966, 1973, 1983, 1992, 1998, 2003
		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, EH2006 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 3), 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 EH2006 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 winter forecast for 2021-22 is for a weak La Niña.**

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.

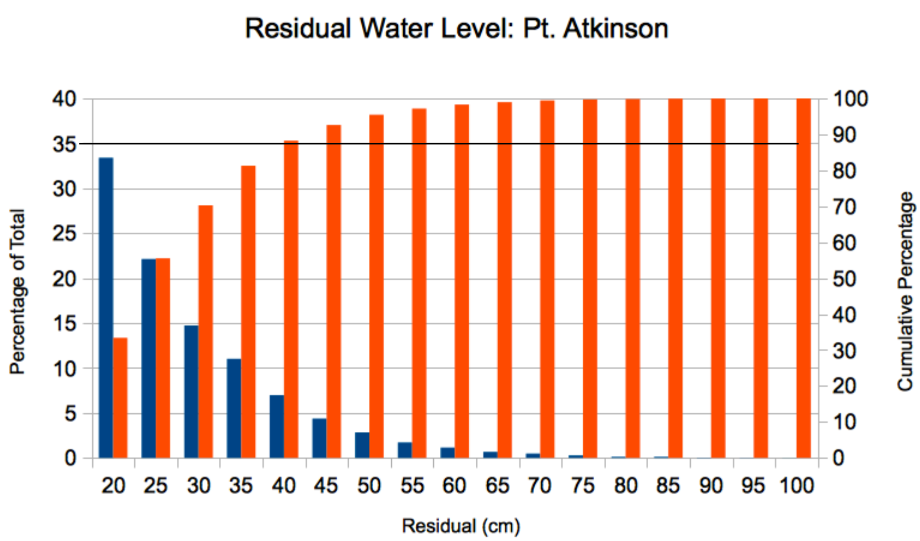

Figure 2. Residual water levels at Pt. Atkinson (>20 cm) in 5-cm bins as a percentage of the total number of residuals >20 cm (blue) based on hourly observations. The cumulative percentage at each bin level is shown in orange. Residuals >45 cm lie within the 90th percentile (black line) of all residuals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

Victoria

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

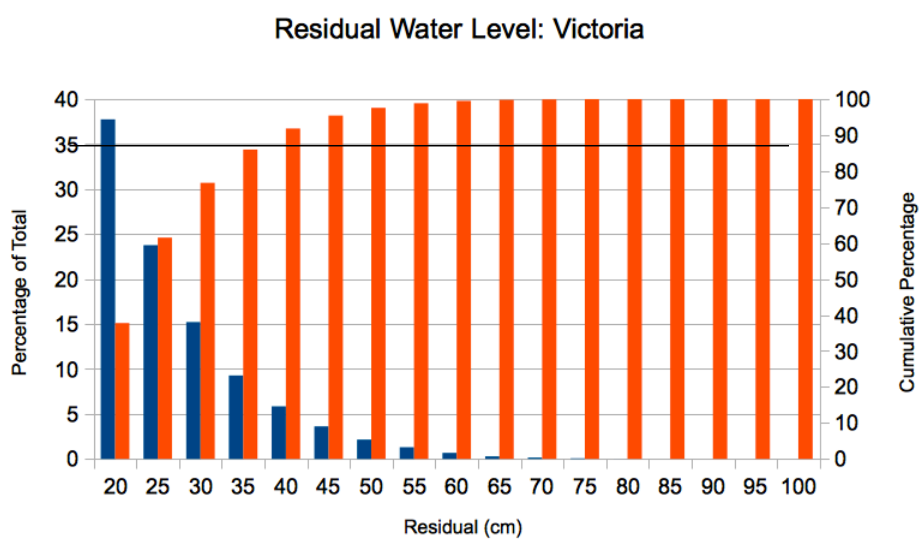

Figure 3. Residual water levels at Victoria (>20 cm) in 5-cm bins as a percentage of the total number of residuals >20 cm (blue) based on hourly observations. The cumulative percentage at each bin level is shown in orange. Residuals >40 cm lie within the 90th percentile (black line) of all residuals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

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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 respectively. Water levels of this magnitude leave coastal areas vulnerable to flooding by storm surge. To illustrate the importance of these periods of extreme tidal height, a moderate storm surge of 0.6 m (1.3 year return period) concurrent with peak winter tides (5.0 m) would cause a total water level equivalent to the 1982 record high at Point Atkinson (and the 2003 record high at Victoria), even without the presence of El Niño-induced elevated coastal sea levels.

Point Atkinson Tide Calendar

The historical recorded highest 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 highest 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 exceed 4.7 m relative to station datum at Point Atkinson; these periods offer broad windows during which a moderate or high 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 m above chart datum are shaded red. **The periods where predicted tide exceeds 4.9 m at Point Atkinson occur from December 5-10, January 3-8 and January 31-February 4**.

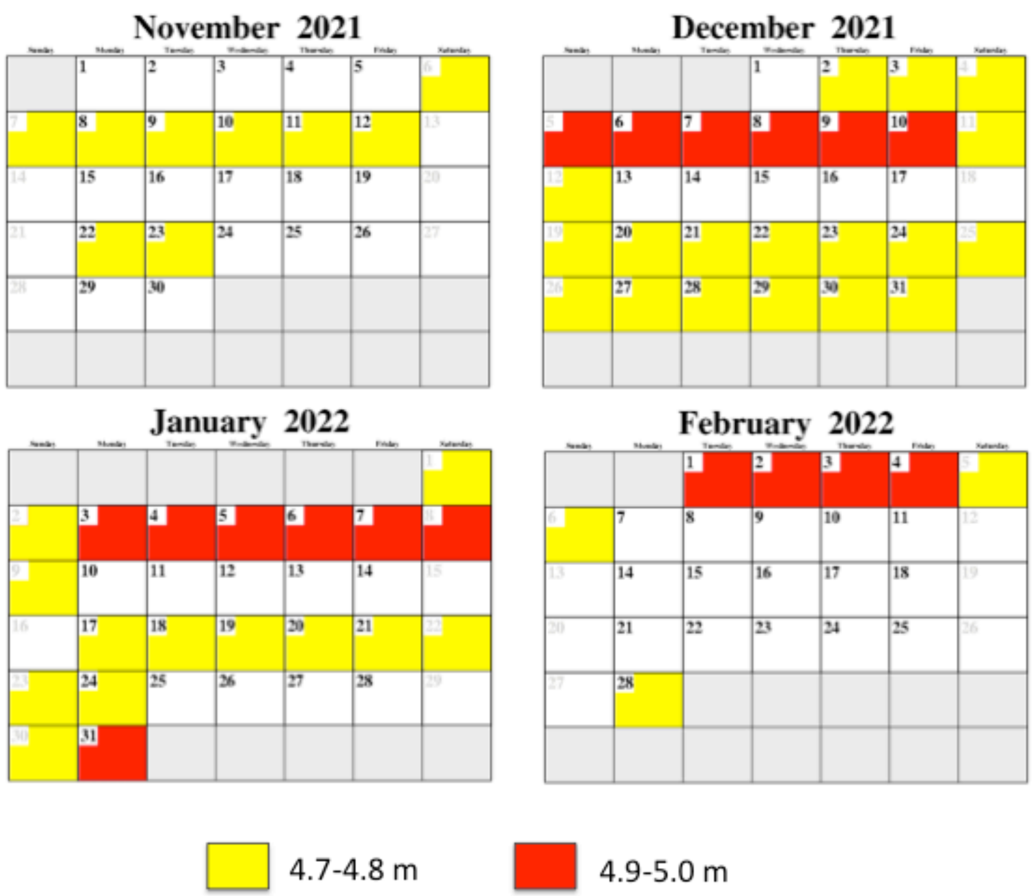

Figure 4. 2021-22 calendar dates for tides exceeding 4.7 m at Point Atkinson.

Victoria Tide Calendar

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 and during a moderate El Niño.

Figure 5 highlights the dates when peak tides exceed 2.8 m relative to station datum (dates where tides >3.0 m are shaded red). 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, **the highest predicted tides (>3.0 m) occur during November 6-7, December 2-6, December 30-January 2 and January 27-February 1.**

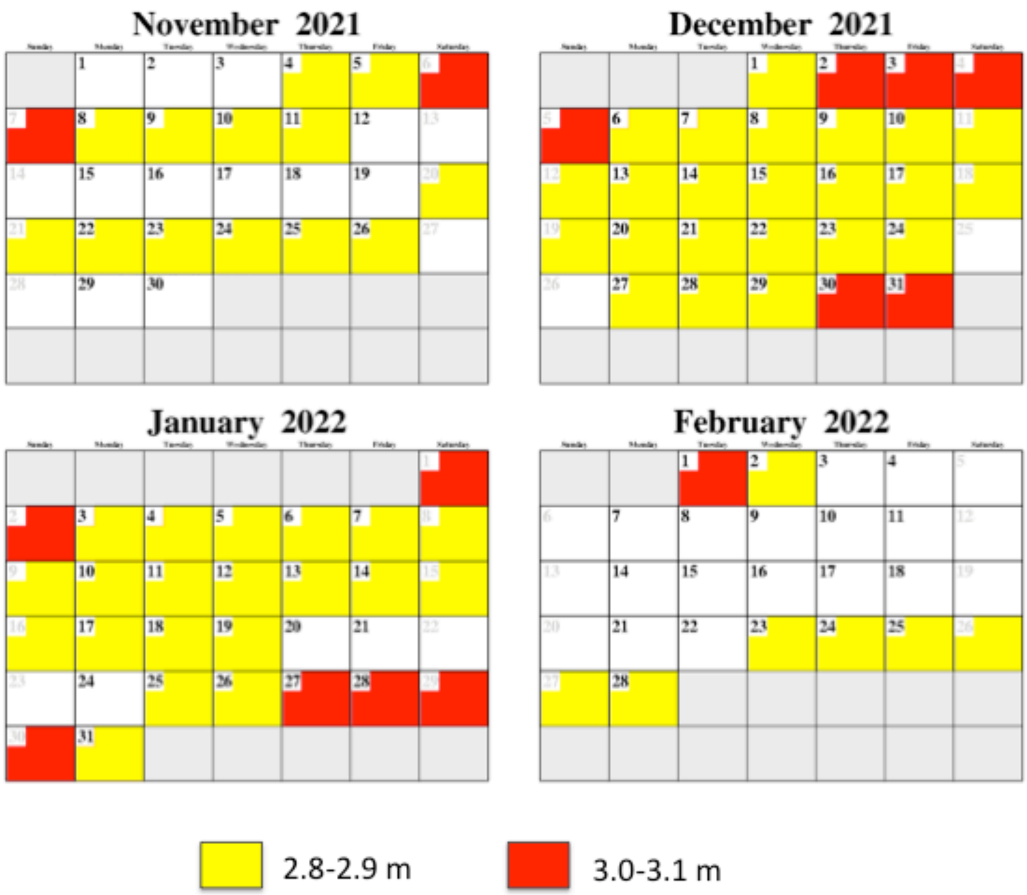

Figure 5. 2021-22 calendar dates for tides exceeding 2.8 m at Victoria.

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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. The anomalies show the interannual variability of SSH after the mean and seasonal signals and the trend have been removed. The SSH anomalies are used to highlight large scale spatial trends, often caused by climatological phenomena such as ENSO.

The ENSO-neutral conditions of summer 2021 are transitioning to weak La Niña conditions. Near equatorial SSH anomalies are negative, and forecasts are for developing La Niña conditions through spring 2022. Currently, SSH anomalies are near zero all along the North American west coast (Fig. 6), but a strongly positive anomaly (10-15 cm) remains in the north Pacific; unlike past years the positive SSH anomaly appears uncorrelated to surface temperature anomalies in the region.

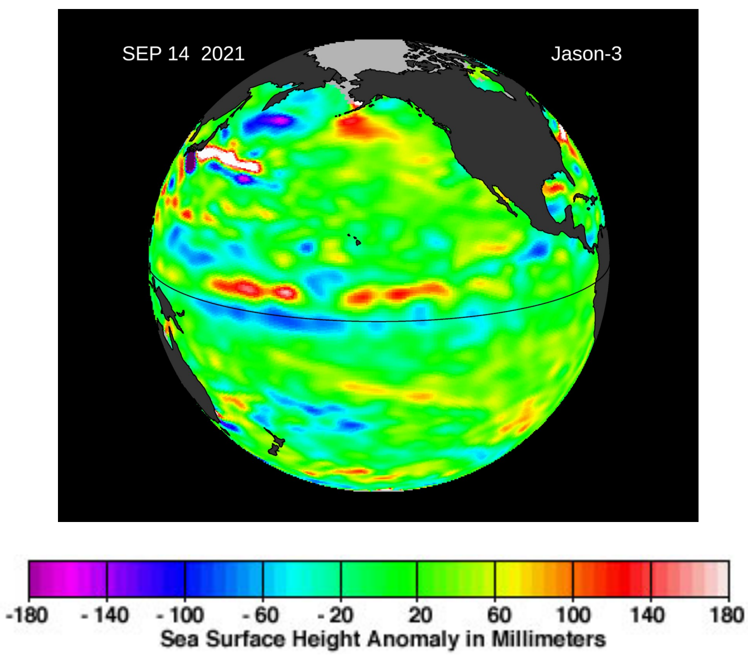

Figure 6. JPL image of 10-day averaged SSH anomalies over the Pacific Ocean on September 14, 2021. Equatorial SSH Anomalies are consistent with weak (emerging) la Niña conditions.

The latest seasonal (July-October) SST anomaly (Fig. 7) published by the Earth System Research Laboratory (ERSL/NOAA) shows residual warming in the central Pacific but near zero anomalies in the North and Equatorial Pacific. There is little indication yet in the SST signature of the developing La Niña conditions near the Equator.

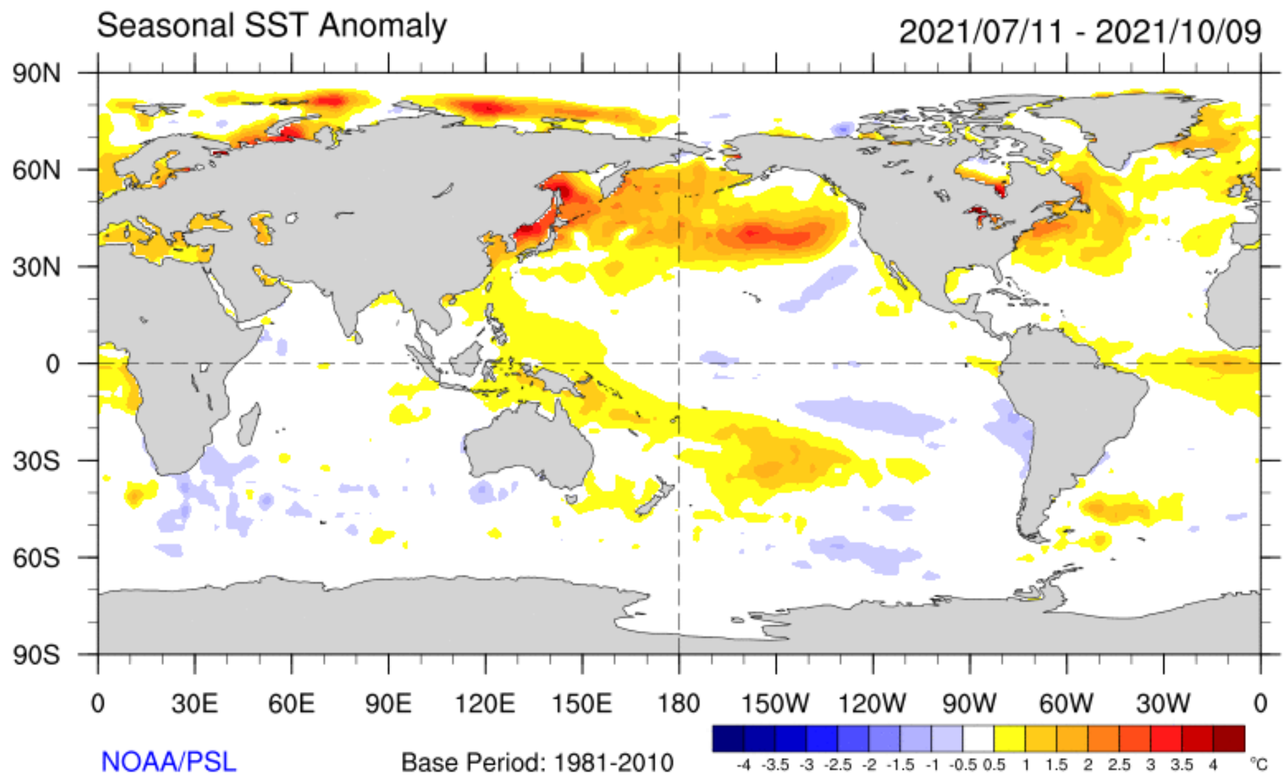

Figure 7. ERSL/NOAA seasonal SST anomaly for July 7-October 9, 2021 (https://psl.noaa.gov/map/clim/sst.shtml).

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Summary

From the information available as of October 2021, the winter 2021-22 storm surge season will be characterized by the following:

1. **ENSO**: weak La Niña conditions developing in early winter.
2. **PDO**: slightly negative and trending downward
3. Peak tides **Victoria**: November 6-7, December 2-5, December 30-January 2 and January 27-February 1.
4. Peak tides **Vancouver:** December 5-10, January 3-8 and January 31-February 4.
5. **SSH anomalies**: Near zero on the coast but positive in the north Pacific.

Mixed meteorological conditions are present early this fall with few strong wind events. La Niña and negative PDO conditions have worked together in the past to generate active storm seasons, but both indices are weak and may have a muted impact on the strength and frequency of storms along the southern British Columbia coast this winter.

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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 a return to the cool PDO phase. **NOTE: the JISAO PDO index is no longer updating as of September 2018; continuing data will be derived from the Japan Meteorological Agency which publishes PDO values derived from a parallel method to the Mantua index.**

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. 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.

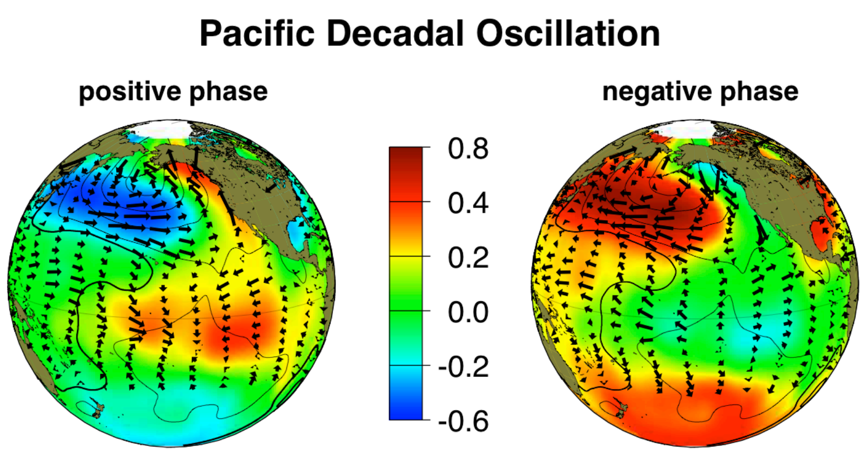

Figure A1. PDO warm and cool phases of sea surface temperature anomaly and associated wind anomaly patterns. Web image from Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington.

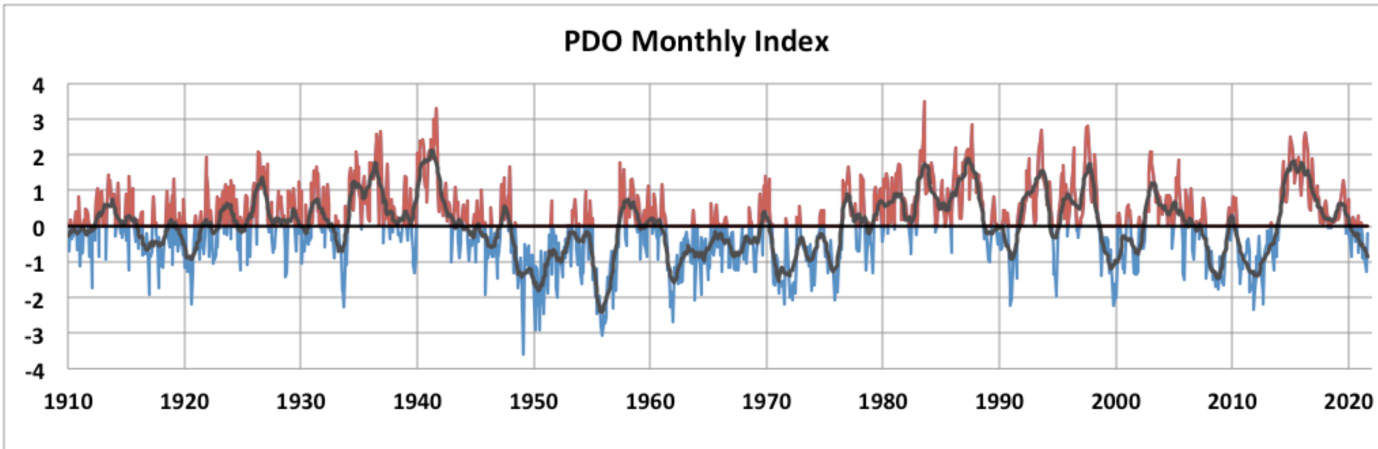

Figure A2. Monthly values of the PDO index from 1910-2021.

El Niño/La Niña

The El Niño-Southern Oscillation is a coupled tropical atmospheric and ocean phenomenon that has extra-tropical 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. Extra-tropical 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.

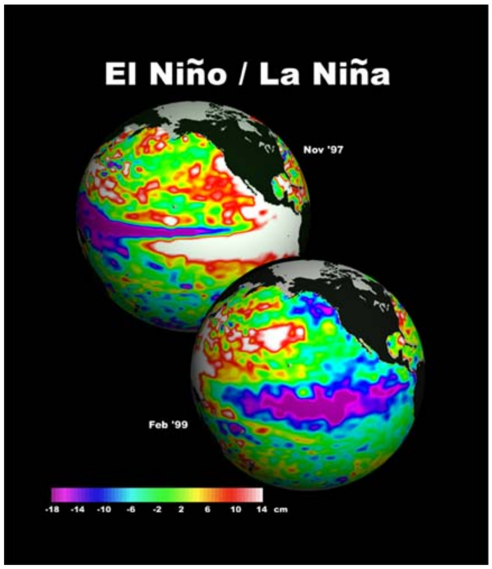

Figure A3. Residual sea surface height during the El Niño winter of 1997 and La Niña winter of 1999 (courtesy Jet Propulsion Laboratory). The positive SSH residual off the BC coast in 1997 is part of a larger feature stretching to the equator, while the negative SSH residual in 1999 is more localized.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

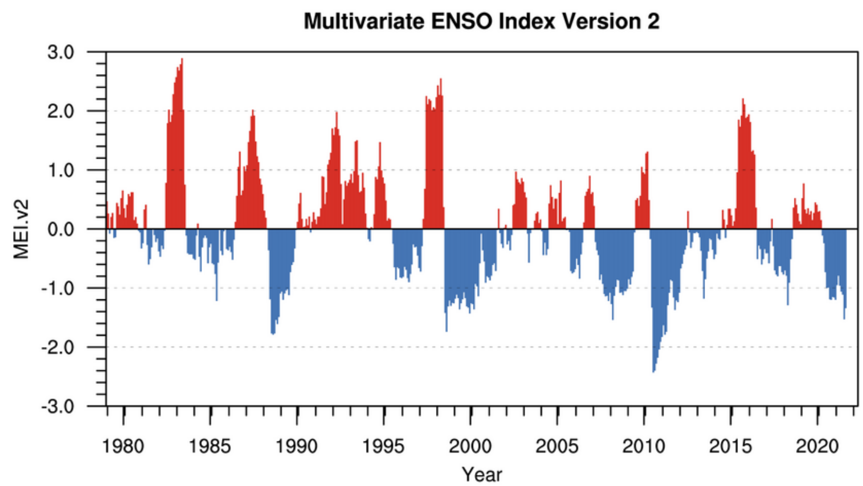

Figure A4. NOAA ERSL multivariate ENSO (version 2) index from 1960 to present. Positive values indicate El Niño conditions, negative values indicate La Niña conditions.