Factors affecting San Juan Channel and Puget Sound water properties during fall 2014

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Pelagic Ecosystem Function Apprenticeship
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ABSTRACT

Estuarine density gradient circulation patterns depend on seasonal and tidal temperature and salinity shifts. Changes to these properties affect the residence time and flushing of each fjord-like basin. Abnormal temperature and river discharge measurements in the Puget Sound in the fall of 2014 provided an interesting context to study the seasonal fall transition features from upwelling to downwelling. Using a CTD over the 7 week sampling period we looked at temperature and salinity in the San Juan Channel as well as October 23-31 in the Strait of Juan de Fuca (SJF) and Puget Sound basins. The Fall Transition occurred October 12th; our data showed evidence of the shift a week later in the San Juan Channel. External factors such as extensive freshwater input and abnormal SST off the coast interfered with typical temperature and salinity dynamics after the fall transition. Surface waters sampled in the SJF were much higher than predicted. The combination of seasonal and global climate forcing caused temperatures to be warmer after the transition with depth in the SJF and Hood Canal. San Juan Channel measured 1 - 2^{o}C warmer than the 10 year Pelagic Ecosystem Function baseline, and was 1 - 2^{o}C cooler than measurements throughout Puget Sound.

I. INTRODUCTION

Puget Sound (PS) is an estuarine body of water comprised of 5 interconnected basins of water: Admiralty Inlet (AI), Main Basin (MB), Whidbey Basin (WB), Hood Canal (HC) and South Sound (Fig.1). It is located at 48° N, 123° W inland Washington State, U.S.A. and Victoria, B.C. Water exchanges with the Pacific Ocean mainly by crossing over the Victoria Sill and through the Strait of Juan de Fuca (SJF), a 160 km long shallow and wide thoroughfare. The SJF splits northward, leading to the Strait of Georgia, and southward into AI. From there water is further divided at the Triple Junction into MB, WB and HC. A double sill mixes water between the SJF and AI. MB then branches into HC to the southwest, compartmentalized by a sill at the entrance, and WB to the northeast. SJF water is exchanged directly with WB, but Deception Pass Sill is shallow and less freshwater mixes in from there compared to from Admiralty Inlet. Main Basin has the lowest residence time, whereas Whidbey Basin and Hood Canal experience longer residence times for water.

The presence of sills interrupts the 2-layered estuarine circulation of the SJF and PS. Dense ocean water influxes via the deep water, and light brackish water exits on top. Besides interacting at sills, and the local climate forcing, the water column can remain fairly stratified between the top and bottom layer, creating unique residence times for the top and bottom layers of each basin. Water flow over sills cause mixing of the temperature and salinity layers, creating a more homogeneous water column, whereas farther away from mixing areas, stratification occurs, having different features at different depths (Fig. 4). The dynamics between fresh, well oxygenated surface water and deep nutrient rich waters make this area a productive habitat for a diverse ecosystem. Dominant influences of physical oceanography are temperature and salinity features throughout the PS and are characterized by semi-diurnal tides as well as local climate influences from river freshwater input and wind stress.

Tides

Tidal type (spring and neap) and amplitude determine the volume of water entering and exiting the SJF throughout each semidiurnal cycle and impact the estuarine dynamics. Each week alternates between spring or neap tides. Spring tides are characterized by stronger fluxes of water and current speed, caused by a larger difference in tidal height. Neap tides are characterized by weak fluxes of water and current speed, resulting in less change in tidal height and therefore induce less water movement. Independently, the amplitude of the tides changes roughly on a 28 day scale. The height or amplitude of any given tide characterizes the currents and overall volume of deep water introduced to the system during the flood portion of the tide. The volume of oceanic water increases when high spring flood tides align with high amplitude in tidal height. During this part of the tidal phase, larger amounts of deep water move into the SJF. However, there is vigorous mixing at sills, and 2-layered stratification disappears. When weak tidal mixing occurs during neap tides, the oceanic water layer is pushed over sills and is less disturbed by mixing, and is able to intrude further into other basins, seaward surface water flow is also highest during neap tides (Griffin and LeBlond 1990). This creates a pattern of deep water intrusion and renewal. This in turn can help describe the difference in water residence times in each basin. This cycle typically replenishes deep water on a monthly basis. Tidal straining also occurs, making waters more stratified on neap tides, and less during flood tides, however depending on the position in an estuarine channel, the effects of tidal shear can be enhanced (Simpson 1990, Burchard 2012). A flood brings in saltier water in the SJC, whereas a neap can bring in water originating from the Fraser River (Fig.3).

River Discharge

River discharge forcing can increase stratification (Simpson 1990) and drive more surface layer water seaward. This process drives horizontal and vertical salinity gradient mixing, but larger discharges can inhibit deep water intrusions (Lavelle 1991). Beginning in September, river input into PS watersheds increases sharply as the Aleutian Low (AL) pressure cell settles into the Pacific Northwest. Right before this seasonal shift, very little river discharge flows into the system, which corresponds with higher salinity levels in the SJF, and a low salinity gradient change. Each year the AL manifests itself differently, and less intense ones create wetter winter conditions until March, whereas a mellow ones cause dryer winter conditions (Moore, 2008). When PS river discharge increases, Fraser River generally decreases after peaking in July (Fig. 5). The Skagit River in WB is responsible for over half of the river forcing in the Puget Sound (Marine Waters Report 2013), which is tightly coupled with the salinity in the SJF (Fig. 6). As fall progresses and PS freshens, the water circulations patterns between the basins change.

During the fall, exchange between WB and AI increases, and AI and MB decreases (Babson 2006).

Depending on the river, snowpack and precipitation drive the amount of freshwater discharge. The main watershed affecting the SJC is the Fraser River, which typically has one peak in discharge in June due to snow melt (Fig. 5). For Puget Sound there are many river inputs, but the Skagit River accounts for over half of the discharge, into WB which is precipitation and snow melt driven (Moore 2008).

Wind

Each fall in PS, the wind plays an important role on the seasonal shift from upwelling to downwelling by redirecting surface water transport and assisting with stronger mixing surface water. Between October and November, the dominant wind direction reverses from Northwesterly to Southeasterly. As the AL pressure cell replaces the North Pacific High pressure system, SE wind prevails. This shift in wind regimes corresponds to the direction of water transport off the coast from upwelling to downwelling; this is also known as the fall transition. Upwelling occurs when colder and saltier oceanic water moves upward to replace water blown away from the surface water by NW winds. Warmer and fresher surface ocean water is blown towards the coast during downwelling, creating a pressure gradient that pushes pre-existing surface water downwards in the water column. Changes in wind forcing off the coast are generally observed to affect currents and water features in SJF 3 - 10 days later, and calculated to be seen in the bottom water by the AI sill 7.25 days after wind event changes (Cannon 1990). After the transition, the water column throughout PS is warmer and fresher, with storms and higher winds decreasing stratification. In addition to initiating upwelling, SE wind direct water north, including brackish Fraser River influenced water, away from the SJC and PS, and Columbia River water to the entrance of the SJF. 2-3 times a month during the winter the winds can revert back to Northwesterly, and these storms lasting a couple days can revert downwelling briefly back to upwelling (Thomson 1994). Cross sill salinity gradient differences can also affect the magnitude of deep water intrusions into the SJF (Cannon 1990). Models have demonstrated that winds can reposition freshwater on the surface and alters the salinity gradient over sills in such a way that encourages intrusions (Lavelle 1991).

This Study

To understand how PS water interacts with tides, rivers and wind, plotting temperature and salinity with depth creates clear snapshots of the water column conditions in a specific timespace. Temperature and salinity determine the density of the water. Density gradients are proportionally 5:1 more influenced by salinity over temperature, with salinity changes responsible for much of the density driven circulation. Implementing tide, river, and wind data enhances our sampled data, and it is possible to better understand where the water originated from (Fig. 3).

Many studies have previously looked at density gradient changes on deep water intrusion, and wind stress and river influence on deep intrusion (Leonov 2009, Deppe 2014, Cannon 1990). What is generally accepted is that salinity variability in the SJF is a more accurate proxy to see seasonal variability than river input (Moore 2008, Babson 2006).

As has been shown in previous research by Pelagic Ecosystems Functions Apprenticeship (PEF), winds, rivers and tides affect the salinity at in the SJC, and that salinity gradient changes can be measured to gauge the seasonal shift from upwelling to downwelling (Thomas 2013, Thompson 2011, Kull 2008).

However large ocean temperature anomalies have not been studied in the SJC and compared to the PS. My objectives are to answer: (1) What are the Fall 2014 water temperature and salinity properties at PEF North and South stations? (2) How do ocean condition, river input, tides, and wind affect water properties at North and South stations during fall 2014 ? (3) How do late October 2014 PEF conditions compare to those in Puget Sound and the Strait of Juan de Fuca?

METHODS

SJC

Data

PEF program collected the 2014 SJC data aboard the *R/V Centennial* cruises. We conducted weekly cruises September 30th - November 10th, 2014. Friday Harbor Laboratory's SEACAT SBE-19 *Conductivity-Temperature-Depth* (CTD) was used to measure water temperature, salinity and density with depth. The CTD was deployed from the surface to 5-10 m above the seabed at North Station (N; 48° 35'. 00N, 123° 02.50'W) and South Station (S; 48° 25.20'N, 122°56.60'W); the CTD collected all oceanographic data. N is situated south of Jones Island. The location of S is southwest of Cattle Pass outside of the San Juan Channel. We used temperature, salinity, and density values obtained on the downcast to assess later. After each cruise, we exported data from the *R/V Centennial's* computer in HEX files and converted those to CNV files using the *SBEDataProcessing* program.

National Oceanographic and Atmospheric Administration (NOAA) Upwelling Index

Daily data compiled on this index was downloaded into Excel to determine major upwelling and downwelling events. All data for the 48 N 123 W index were used September 20th - November 10th, 2014.

Fraser River Discharge

Fraser River discharge rates (m^3/s) relative to our 7 weeks study were obtained via http://wateroffice.ec.gc.ca/ (Fig.5,6) . Average discharge values were assessed taking 12 hour interval values for the three days leading up to the cruise.

Friday Harbor Weather Station

All information regarding wind speed and direction was compiled from FHL Weather Station (http://depts.washington.edu/fhl/wx.html). For each cruise, 8 day wind profiles were downloaded and graphed to determine conditions leading up to and during the cruise. 10 bins were then created for each wind direction: North, South, East and West. Measurements from the website were in degrees from true north (0°). 315° - 45° for North, 45°-135° for West, 135° to 225° for South and 225° - 315° for East.

R/V Thompson G. Thompson Cruise

Data

We selected temperature, salinity and density data at stations P 22, P 21 AD1, P8, P6, and P4 for this study to allow for spatial and depth uniqueness (Table. 1).

In addition to the stations mentioned, PRISM data between October 23-26th was utilized to understand the water properties off the coast and along the SJF (Table 2).

With the *Puget Sound Regional Synthesis Model* team (PRISM), we gathered Puget Sound water property data October 29th - October 31st, 2014 aboard the *R/V Thompson G. Thompson* using a SeaBird Electronics, Inc. model SBE911plus with dual SBE3 (temperature) and SBE4 (conductivity). Table 2 includes all the stations visited.

Wind Stress

Measurements from October 22 to 31st, 2014 were obtained from the NANOOS website from the Pt Townsend weather station. The same bins to categorize wind stress and magnitude in the SJC were used (see section A.d.).

Skagit River Discharge

Graphs provided by the United States Geological Survey (USGS). Daily discharge (ft^3/s) and mean values were compiled on a graph (http://www.usgs.gov/water/) were downloaded.

Northwest Association of Networked Ocean Observing Systems (NANOOS)

All previous PEF and PRISM research used in this paper were accessed (http://www.nanoos.org/). To align data from different regions during the same point in time, *NANOOS* allowed us to effectively compare each region in the PS's interannual trends.

National Atmospheric and Oceanic Administration's (NOAA) Pacific Fisheries Environmental Laboratories (PMEL) Upwelling Index

Data downloaded from the PMEL website (http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html) allowed us to see specific upwelling and downwelling events from the index on a daily basis.

III. RESULTS

SAN JUAN CHANNEL

Salinity

North Station

Salinity remained well mixed cruises 3, 4, 5, and 6, while 1 and 2 had light surface stratification, and cruise 7 experienced high amounts of freshwater stratification (Fig.8). Cruise 2 experienced higher salinity at the bottom. Salinity values at the surface ranged from 28.5 to 31

PSU, whereas with depth varied between almost 31 and 31.25 PSU. The saltiest cruises were 3 and 4, while the freshest were cruises 1 and 7.

South Station

Overall, the strongest salinity stratification occurred from cruises 1 to 3, and the weakest during cruises 4 through 7 (Fig.9). There was no stratification on cruises 5 and 6. The most stratification occurred in the water column during cruise 3.

Temperature

North Station

Temperature measurements in degrees Celsius (C) at N remained well mixed mostly with depth, with some surface cooling during cruises 2 and 7, and warmer surface stratification during cruise 4. Cruise 2 had much cooler water at the bottom 10 m. Temperature cooled with respect to time cruises 1through 4, and then increased 5 - 7, with cruise 6 having the warmest average temperature throughout the water column.

South Station

During the 7 week study, temperature stratification increased to cruise 3 and then diminished with time after cruise 3. Cruises 4, 5, and 7 showed the weakest stratification, whereas cruise 6 showed almost none (Fig. 9). Cruises 6 and 7 were cooler at the surface.

Tides

North Station

We sampled N during 3 peak floods, 2 late floods, 1 slack and 1 late ebb (Fig. 10, 11). The late ebb and slack tide, cruises 2 and 6, were the lowest tidal heights. Cruises 3, 4, and 5 water was sampled during peak floods of similar tidal heights, however the tidal exchange was strongest during cruise 5, and weakest during cruise 4. Cruises 2, 4, and 6 were sampled during neaps, all progressively weaker throughout the sampling time frame.

South Station

Water sampling for South Station occurred during 3 early ebbs, 1 peak ebb, 1 late ebb, 1 peak flood, and 1 late flood. Greatest tidal height exchange was during cruises 3, 5, and 7 experienced the greatest tidal exchange, and cruises 4 and 6 the weakest (Fig. 10,11). Cruise 2 was the only late ebb sampled, and during a neap cycle was a fairly weak tidal height change. The only flood sampling for South station was during cruise 6.

Rivers

When averaging daily discharge rates, the Fraser River increased 25 m^3/s per day throughout our study (Fig. 12). The annual calculated mean for this season, based on historical data is closer to 2025 m^3/s. 2014 data surpassed the mean after cruise 3, eventually increasing to nearly 3 times the mean by cruise 7. The temperature linearly dropped throughout the survey, from 15.25º to 8º (Fig. 7).

This survey period the Skagit River showed a similar trend (Fig. 13). The first 3 cruises the water discharge was lower than the daily median, with the last 4 surpassing mean discharge values.

Winds

Wind stress remained fairly mixed throughout the sampling period. Cruises 1 – 3 remained predominantly northwesterly influenced. During this time the North, West and South wind magnitudes remained constant (Fig. 14). After cruise 4 the West wind diminished significantly and the South wind tripled in magnitude. During cruises 4 and 5 the North wind magnitude was higher than previous weeks, however that decreased slightly during 6 and 7 sampling periods.

The 7 days before and day of cruise 7 wind stress flipped to northwesterly, and so, November 6th showed higher SE influence. Daily wind stress November 5th - November 10th comprised of North and West with low South and East wind input.

Puget Sound

October 23 - 25 2014

Temperature

While surface temperatures measured at PRISM stations from off the coast to Puget Sound varied from 10.6^o – 15.5^oC, deep water temperatures only varied from 7.5^o - 10.5^o C. Surface temperatures cooled moving east, and temperatures increased with depth. At station P 381 temperature was dramatically cooler with depth, with stratification from 15.5^o to $10.5^o C$ 20 m to depth. The warmest temperatures were directly outside of the SJF to 80 m in depth.

Salinity

Surface salinities for each station varied 1 PSU; moving east into the Strait became saltier. Depth salinity values reversed, freshening moving east. The highest salinities were present at the deepest stations, P 105 and P 120.

October 29-31st, 2014

Temperature

Temperature throughout the Puget Sound ranges from 10.5^o to nearly 13^o. Stratification occurred at each station except for North Station and AD 1, yet they varied by almost a degree. The Strait of Juan de Fuca (P 22) and Whidbey Basin (P 4) had the highest temperatures. P 22 remained close to $13^o C$ the first 20 m and then cooling occurred with depth, whereas WB had a unique depth profile, where there was a temperature spike below the surface. Main Basin is the third warmest and was stratified to 55 m then well mixed with depth.

Salinity

Salinity stratification spatially varied (Fig.15). High surface stratification was present at in Main, Whidbey and Hood Canal. Similar depth stratification appeared at South Station and at P 21, right before the sill. P 22 had well mixed salinity, however, there was a fresh indent 0 to 20 m.

Admiralty Inlet was the homogeneous respective to density. At AD 1 it had the highest density at 23.4 kg/m^3. Further south, in between the sills was slightly more stratified but relatively well mixed, with temperature only slightly higher and salinity slightly fresher.
Hood Canal had cooler and fresher water at the surface, however Whidbey Basin and Main Basin were warmer and fresher at the surface. Whidbey showed the most stratification, followed by Main Basin and Hood Canal.

Skagit River Discharge and Puget Sound Wind Stress

Discharge rates for the Skagit followed similar mean trends for this year. Late September to early October the discharge rates at Mt. Vernon station remained close to the median daily statistic (Fig. 13). Mid October the discharge rate exceeded the median daily flow by 800 - 2000 ft^3/s. The Wind stress during this period was predominantly SE (Fig. 16).

III. DISCUSSION

We expected some freshwater stratification before the fall transition at N, and cooler and fresher properties after at South Station. Those properties were observed, however due to the anomalous temperature and Fraser River discharge increase, there was salinity stratification cruise 7, opposite of what tidal data might predict.

The density discrepancy usually found at South Station between the surface and depth diminished quicker and more so than other years. This was especially apparent when comparing

PEF interannual data before the fall transition, with 2014 having the 2nd warmest October in the 11 year baseline (Fig. 17, 29). After downwelling began (Fig. 18), S station clearly warmed and freshened beyond the average, even compared to other El Nino years (Fig. 23).

Water properties at South Station were distinctly warmer and fresher after the fall transition, directly influenced by the NE Pacific temperature anomaly (Fig. 20,30). S warmed and freshened after the fall transition, but to a more extreme degree compared to the 11 year PEF record (Fig. 22). We observed warmer waters at depth at South Station and Hood Canal. While this temperature structure with depth happens after the fall transition in Hood Canal (Fig. 27), it may be anomalous since this behavior coincided with South Station's anomalous temperature.

Relative to PS data gathered, SJC was the cooler and saltier. PS was 1° to 2° warmer throughout compared to N and S. Water property features seen in 2014 in the SJC and Puget Sound compared to other years were spatially affected differently by the temperature anomaly. Conditions in Hood Canal during late October of 2014 appeared similar to December temperature stratification in 2009 (Fig. 26). P 22 temperature varied with surface temperature more than other years, however the salinity at P 22 was comparable to other years. Whidbey Basin also appeared to have typical fall salinity stratification, however temperature differed with depth compared to 2010 data. 2010 basin comparison of SJF and Whidbey Basin showed more discrepancy between temperatures and had a 2° difference throughout the water column. 2014 temperature data between P 22 and P 4 temperatures varied less than 0.5°.

Date	Station	Depth	Location
29-Oct	P 4	83	Skagit Bay
30-Oct	P 8	135	Hood Head
30-Oct	AD 1	55	Admiralty Inlet
30-Oct	P 21	90	Buoy SA
30-Oct	P 22	95	Eastern Bank
31-Oct	P 6	119	Useless Bay

Table 1. Details regarding PRISM October 29-31st, 2014 cruise

Date	Station	Depth	Location
24-Oct	P 381	93	ChaBa Buoy site off La Push
25-Oct	P105	319	Strait of Juan de Fuca 1
25-Oct	P 120	284	Strait of Juan de Fuca 4
25-Oct	P 132	174	Strait of Juan de Fuca 9
25-Oct	P 136	151	Strait of Juan de Fuca 11
25-Oct	P 21	84	Buoy SA
21-Oct	S	86	South Station

Table 2. Date and locations of PRISM stations visited October 23 – 26th, 2014. South Station was sampled during PEF cruises 4

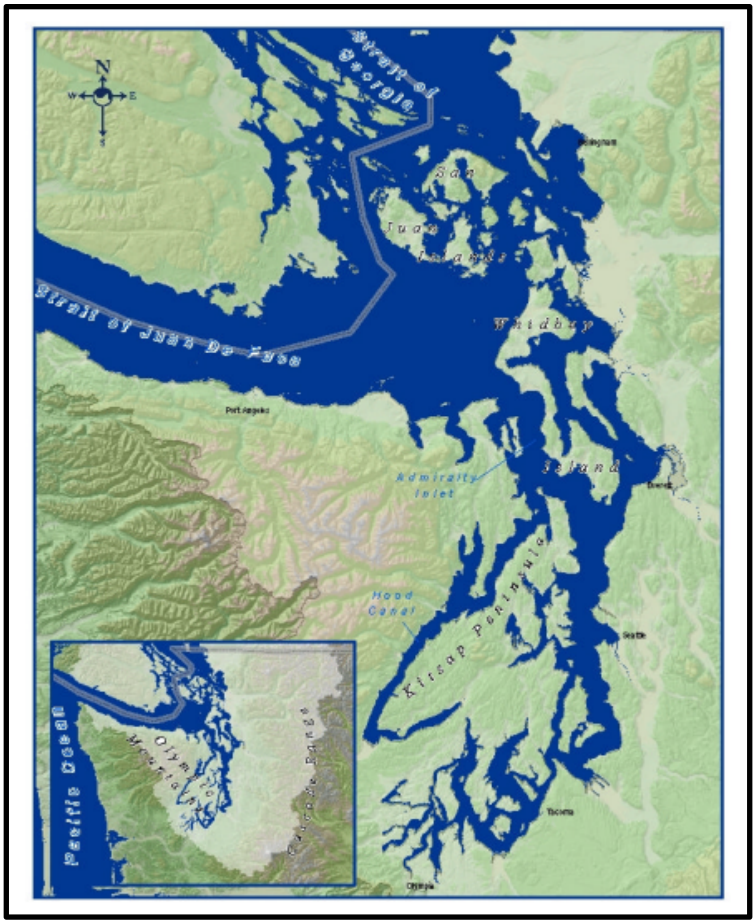


Fig. 1. A map of the Pacific Coast, the Strait of Juan de Fuca, the San Juan Archipelago and Puget Sound.

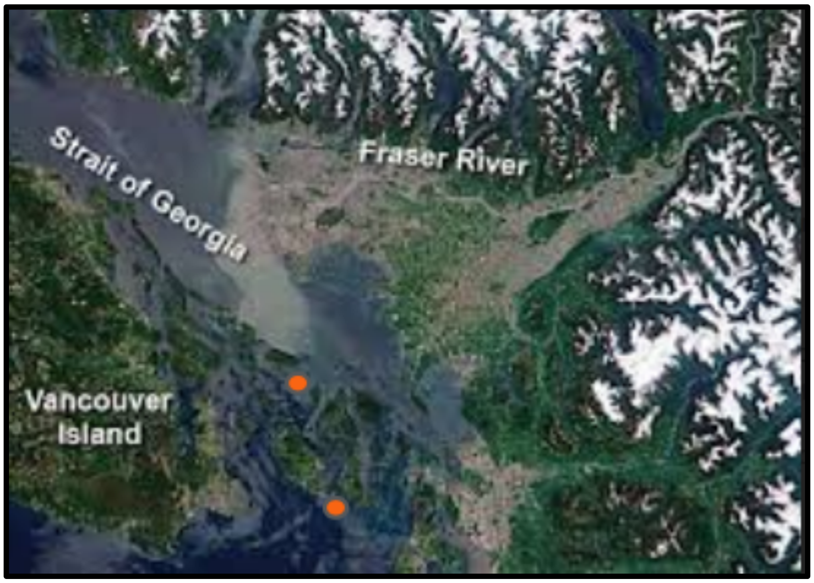


Fig. 2. This satellite image shows the proximity to the San Juan Archipelago to the Fraser River and the southbound freshwater plume.

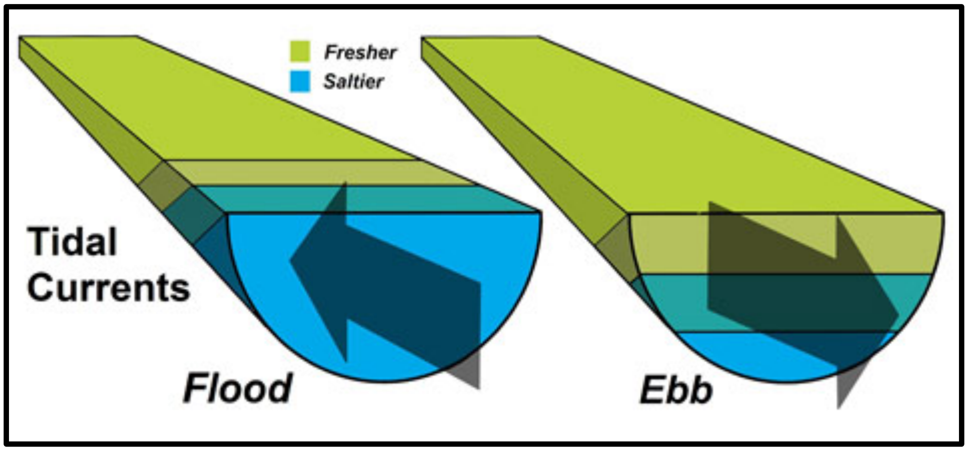


Fig. 3. This figure illustrates the tidal difference seen in an estuary depending on the tide. This can explain the cruise by cruise variations in north station.

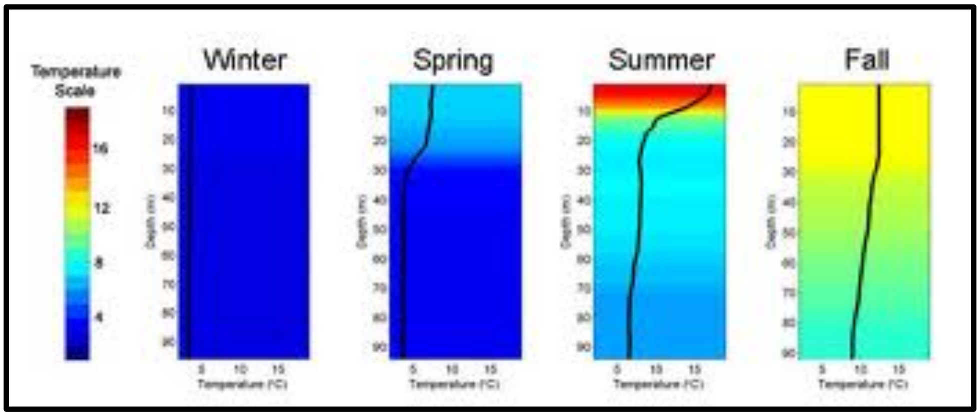


Fig. 4. Temperature profiles from the Gulf of Maine (credit: http://serc.carleton.edu/eet/phytoplankton/primer.html) depicting stratified (spring and summer) and non stratified (winter).

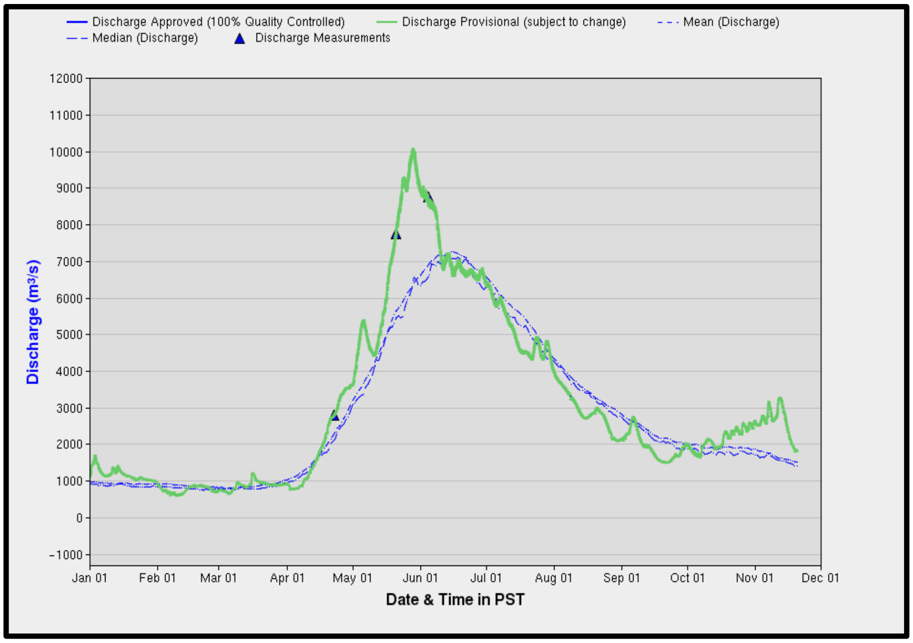


Fig.5. Annual Fraser River Discharge pattern (blue) and 2014 data (green). Generally one annual peak occurs in June and tapers off in fall. The anomalous second peak began in October and sharply decreased in later November.

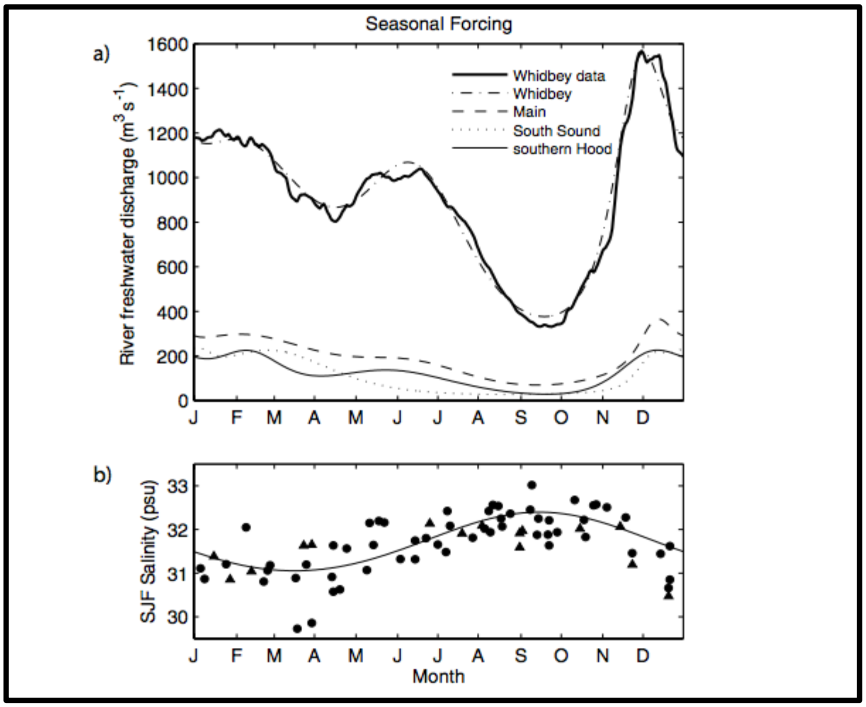


Fig. 6. An idealized model courtesy of JEMS of the annual cycle of freshwater input from Puget Sound Basins (a) and SJF salinity (b). From Babson 2006.

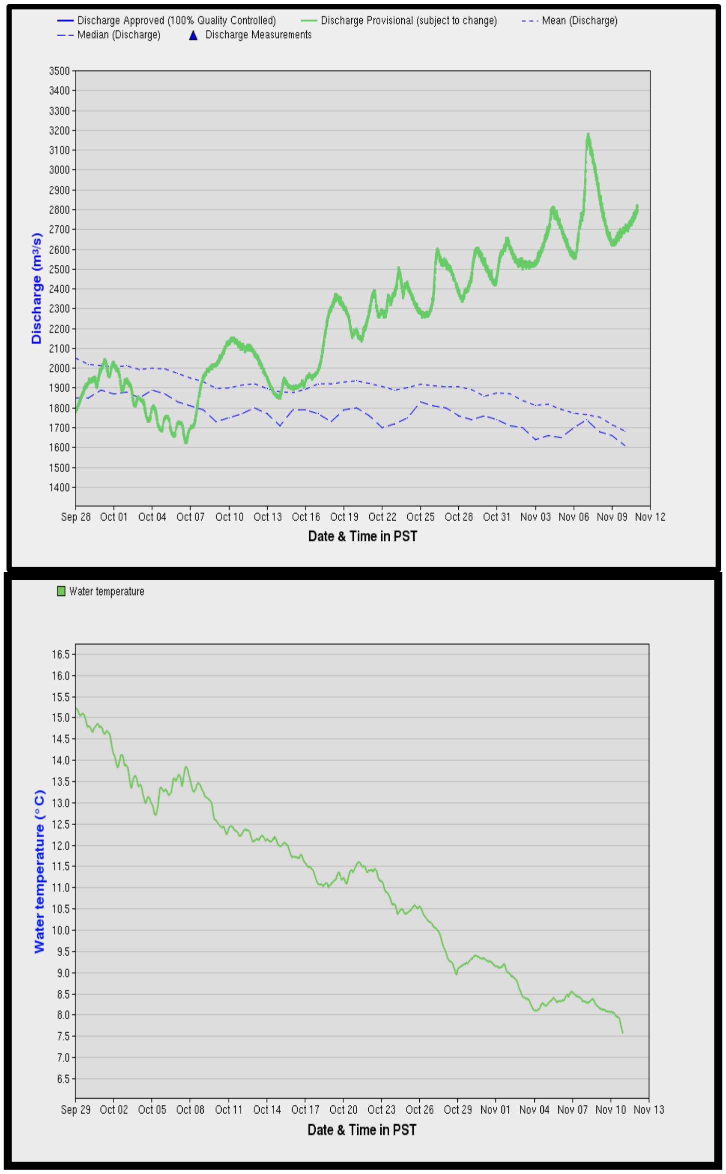
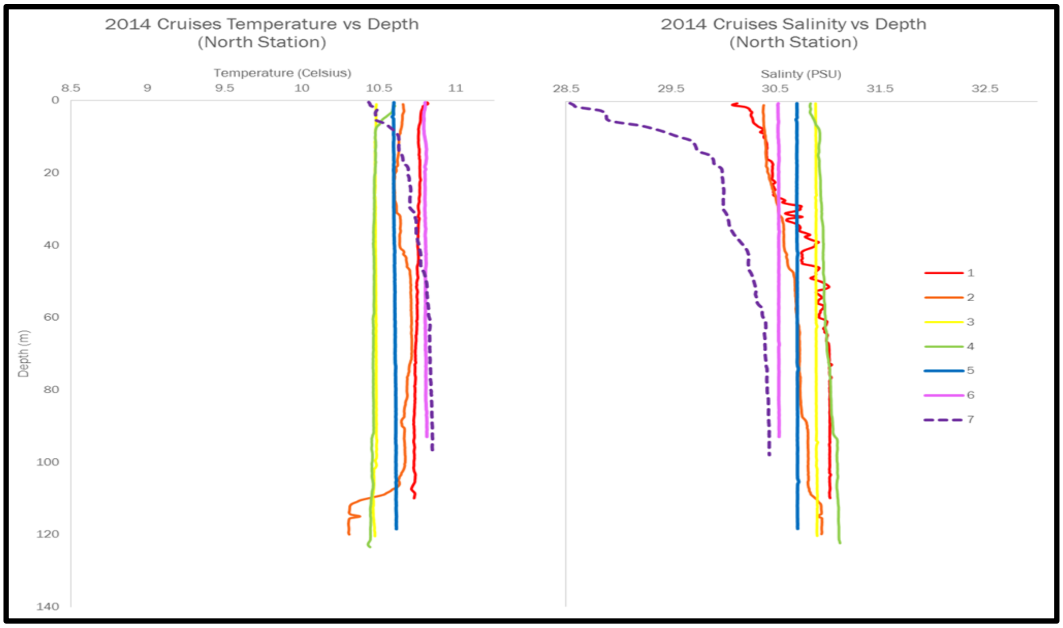


Fig. 7. Depicted on this graph is the discharge rate of the Fraser River on top (m^3/s) and discharge temperature (ºC) with respect to the 7 week PEF project (September 30 to November 10th, 2014). The Fraser River progressively increased throughout our sampling time frame when it typically decreases.


2014 Cruises Temperature vs Depth (North Station)

2014 Cruises Salinity vs Depth (North Station)

(Fig. 8) Temperature (ºC) and salinity (PSU) with depth at North Station, SJC, September 30 to November 10, 2014. Well mixed compared to South Station.

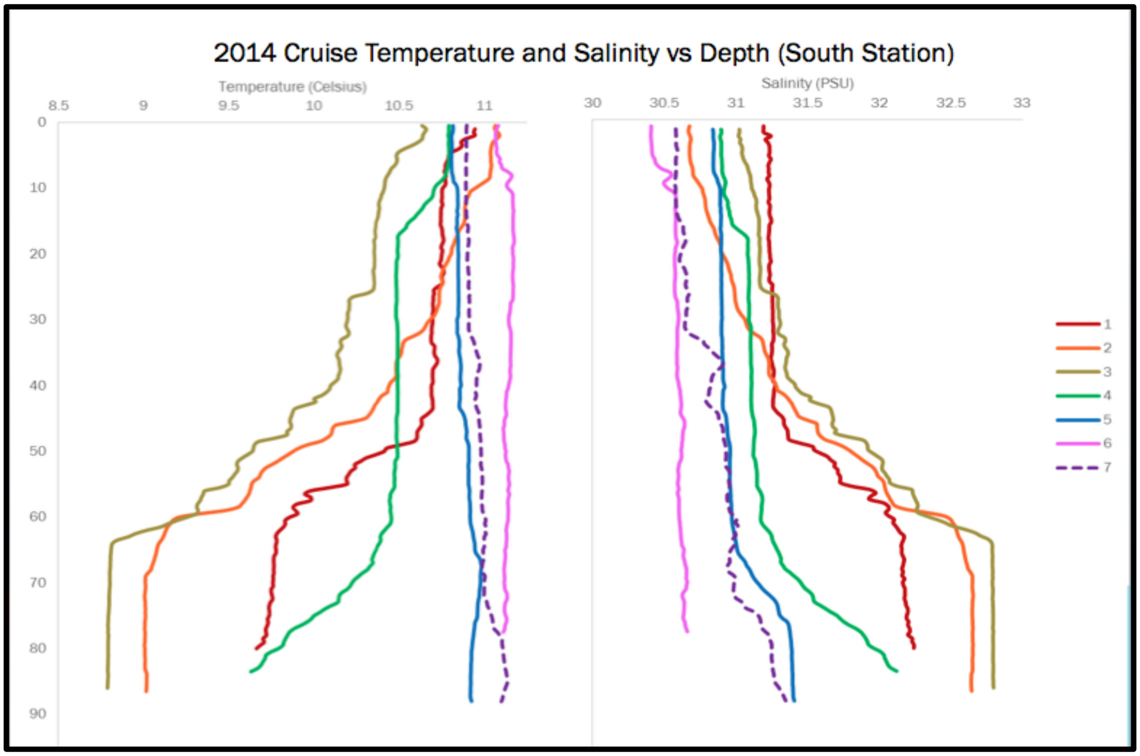

2014 Cruise Temperature and Salinity vs Depth (South Station)

Fig. 9. Temperature (ºC) and salinity (PSU) vs Depth (m) data for R/V Centennial *cruises 1- 7 for South Station during fall 2014.*

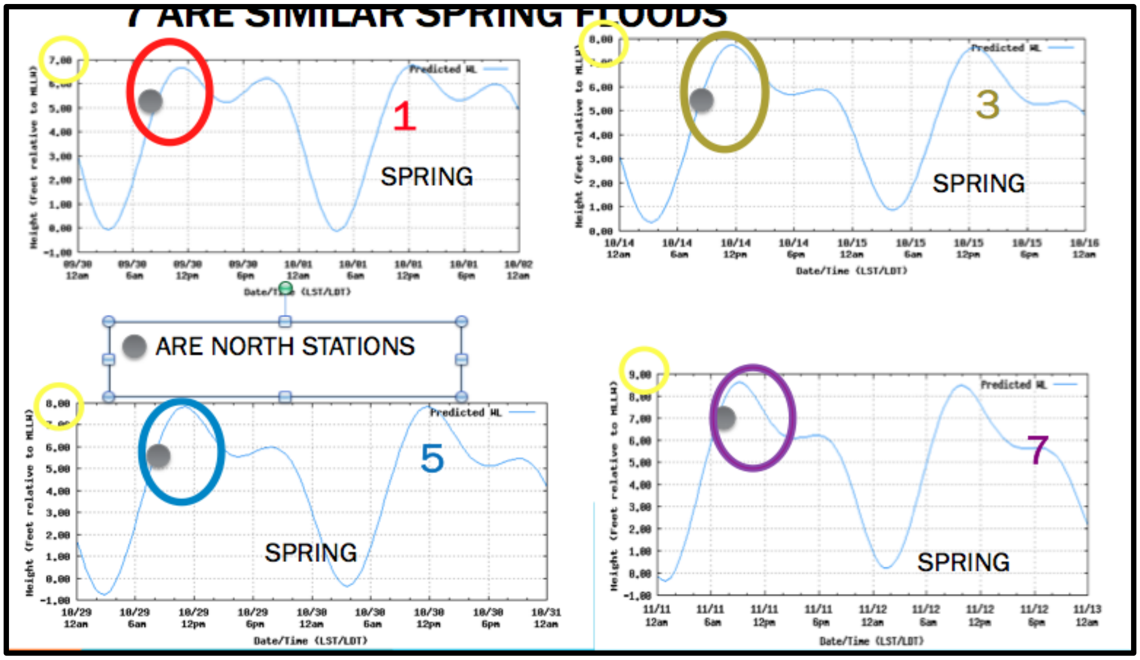


Fig. 10. Spring flood tides and sampling times for North station during cruises 1, 3, 5, and 7.

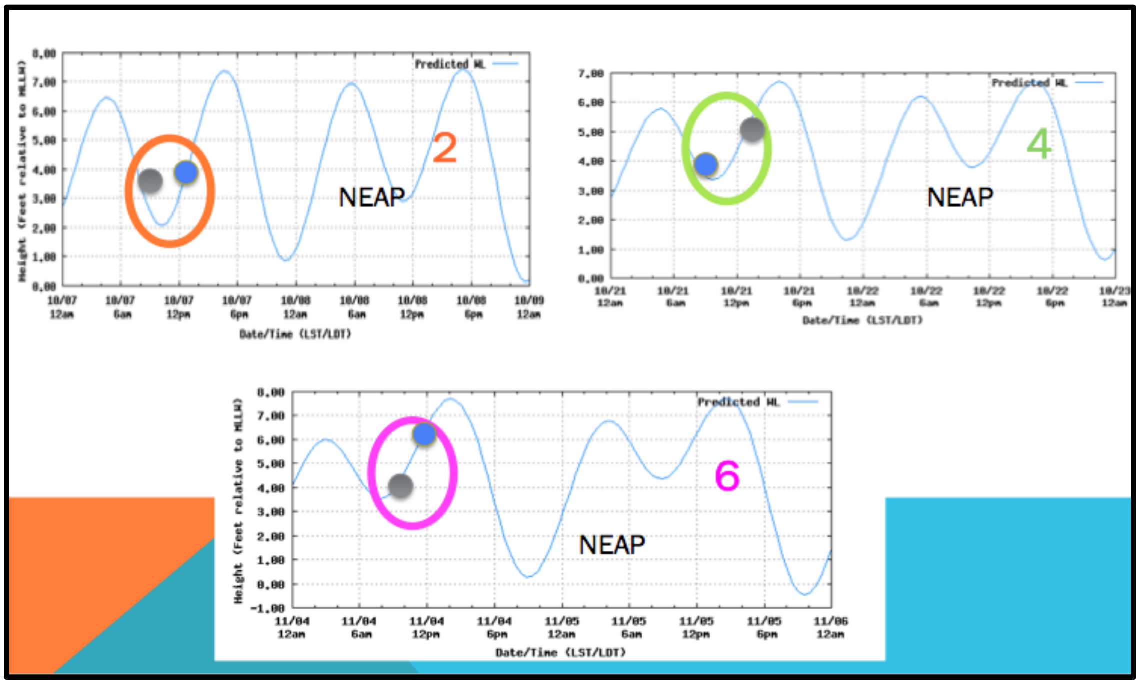


Fig. 11. Neap tides sampled during PEF cruises 2, 4, and 6. The black dots correspond with the north sampling time.

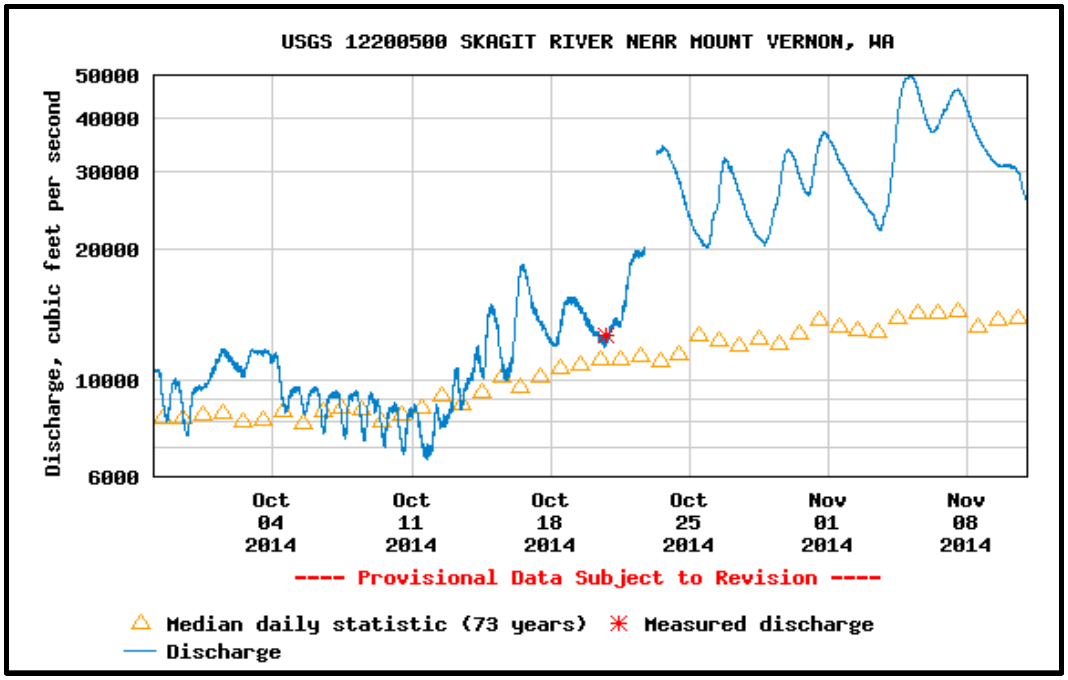


Fig. 13. Skagit River discharge (ft^3/s) with respect to time (September 30 to November 10, 2014). The Skagit River surpassed the mean statistic this period similar to the Fraser River.

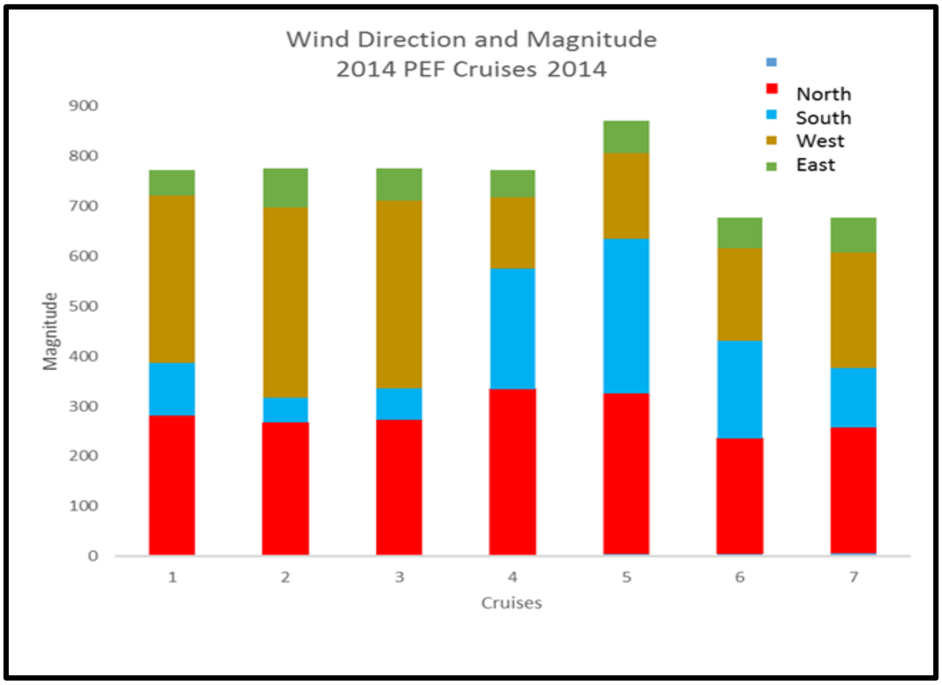


Fig. 14. Wind direction and magnitude with respect to each PEF cruise. There was a notable shift between 3 and 4.

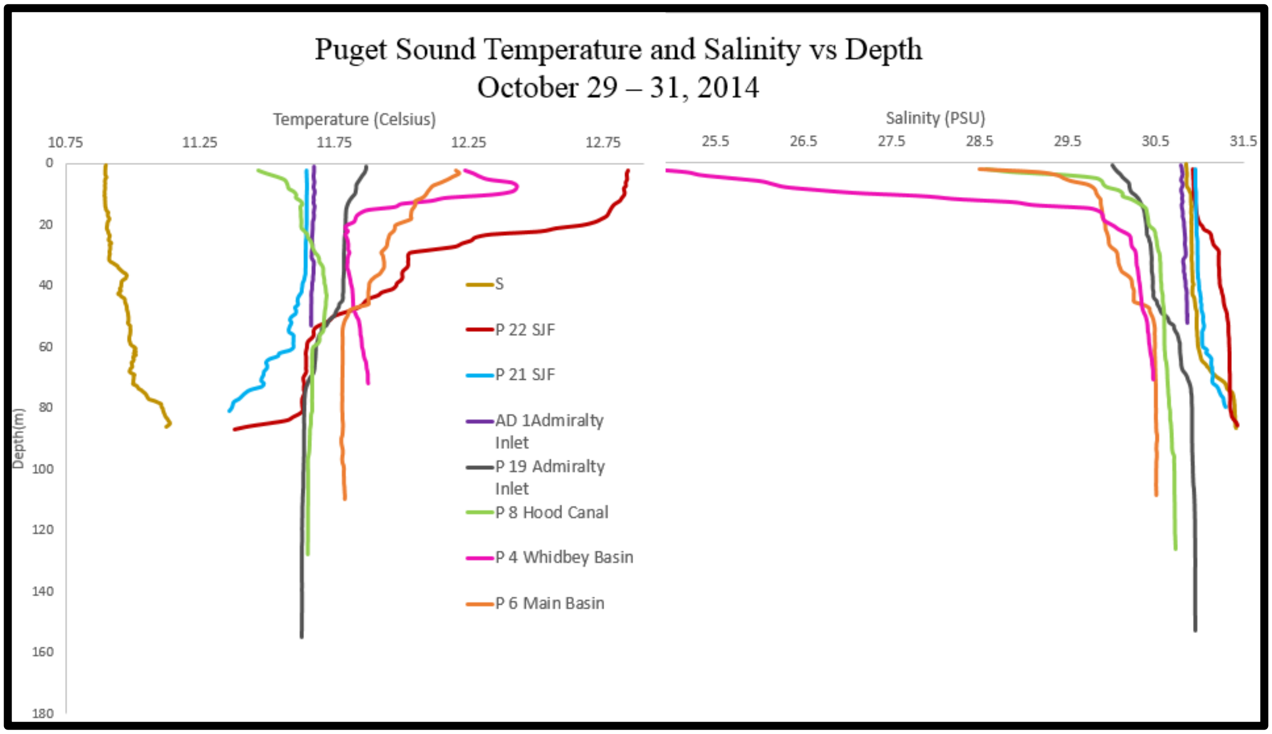


Fig. 15. Puget Sound and SJC temperature (℃) and salinity (PSU) with depth data from October 29 - 31, 2014. Hood Canal (green), Whidbey Basin (pink) and Main Basin (orange) have similar salinity however surface temperature behavior varies.

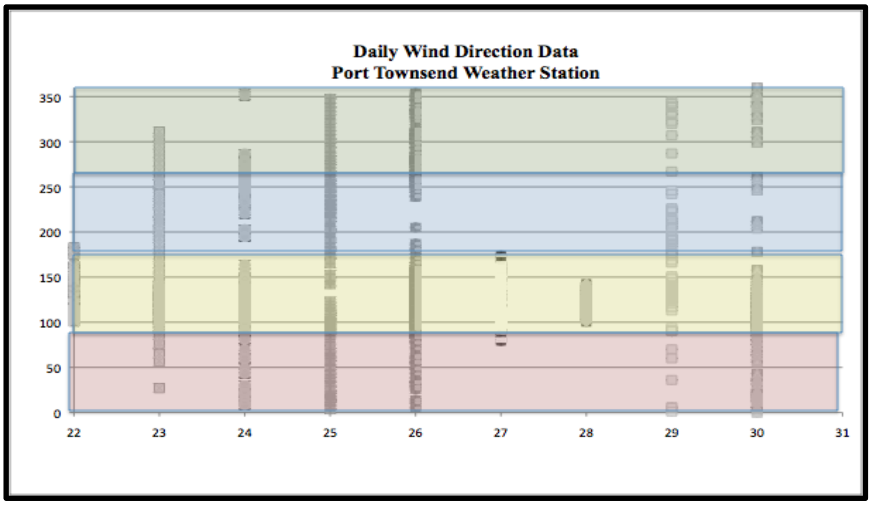


Fig. 16. Wind direction (degrees from 0, true North) from the Port Townsend Station with respect to days (October 22 - 31, 2014). North (red) and West (yellow) dominate October 22, 27 and 28. Stronger South and East wind stress occurred every other day. NW winds cause surface water to be blown SE, and SE winds cause water to be blown NW.

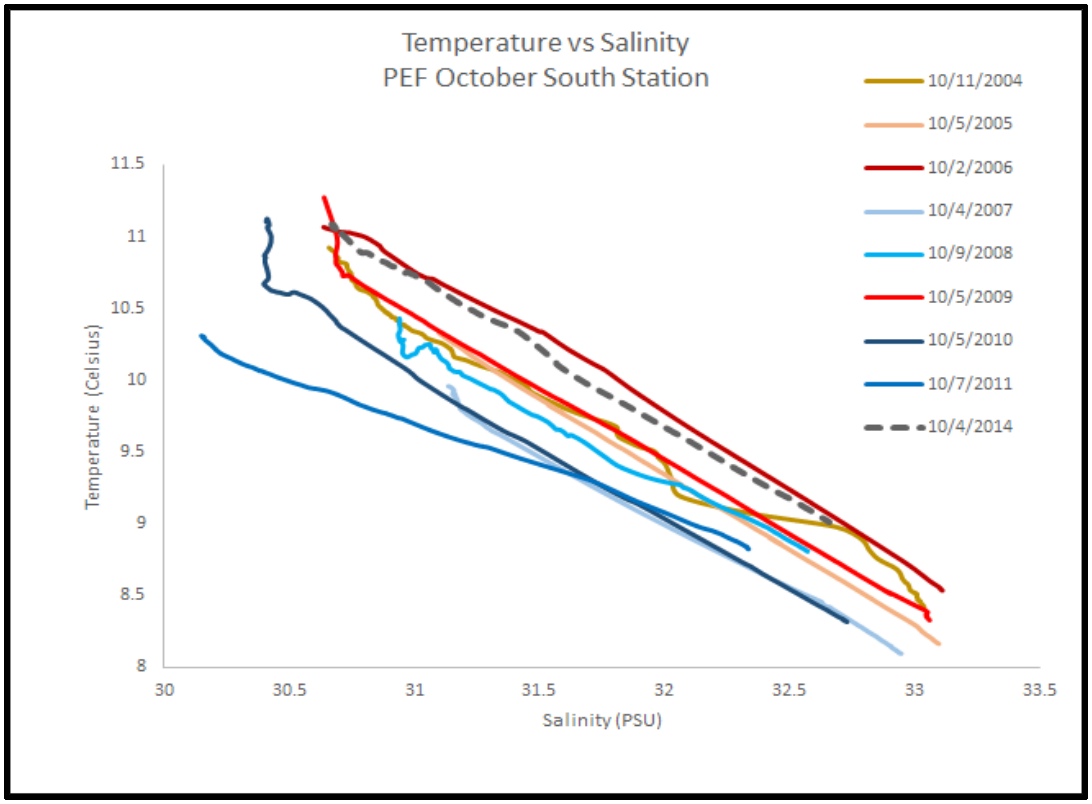


Fig. 17. An interannual comparison of temperature (°C) and salinity (PSU) for early October samples, 2004 to 2011, and 2014 at South Station. 2014 was the second warmest measurement in 10 years before the fall transition.

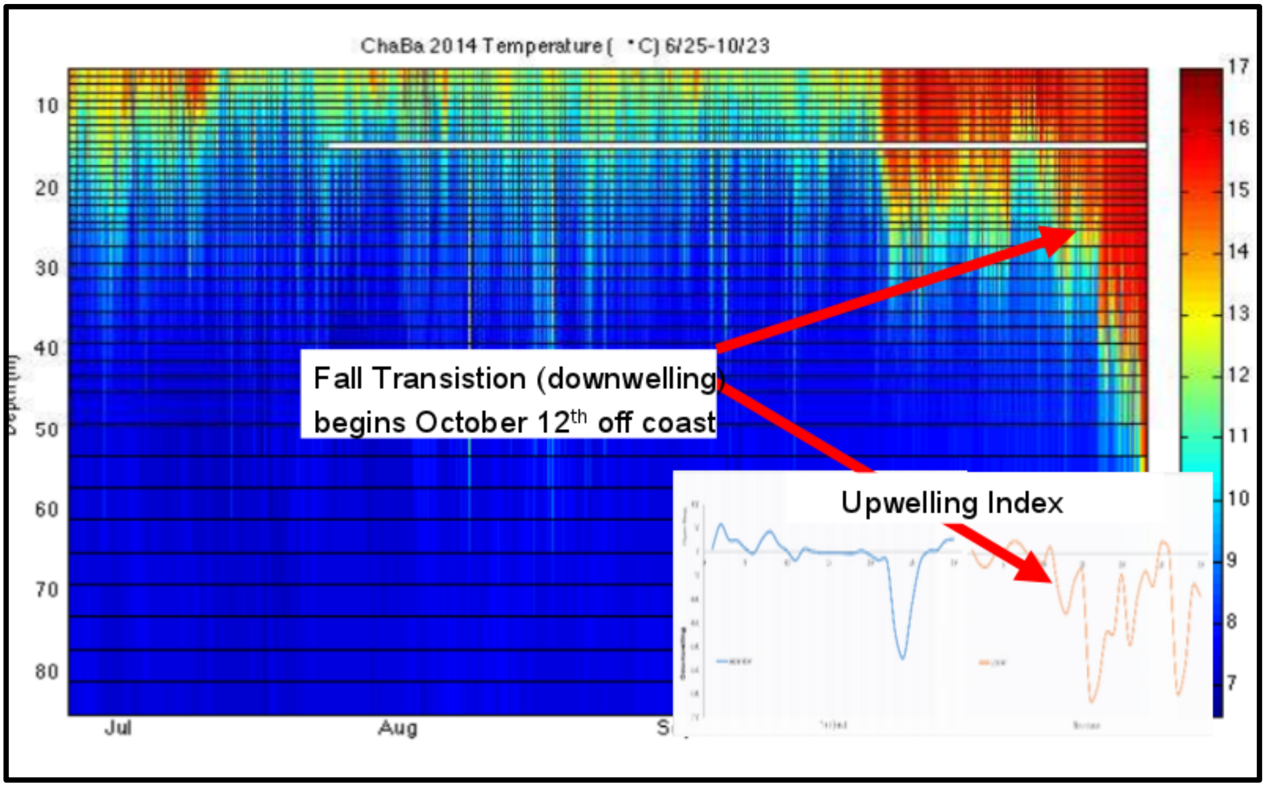


Fig. 18. The colored graph depicts water temperature (ºC) with depth (m) from July to late October 2014 recorded from the ChaBa buoy off the coast of Washington by La Push. The lower right corner shows the NOAA/PMEL Upwelling Index graphed during the same dates September to October with positive numbers corresponding to upwelling, and negative for downwelling. During the upwelling period, water temperature remained cool for most of the water column. After the fall transition, the water column rapidly warms with depth.

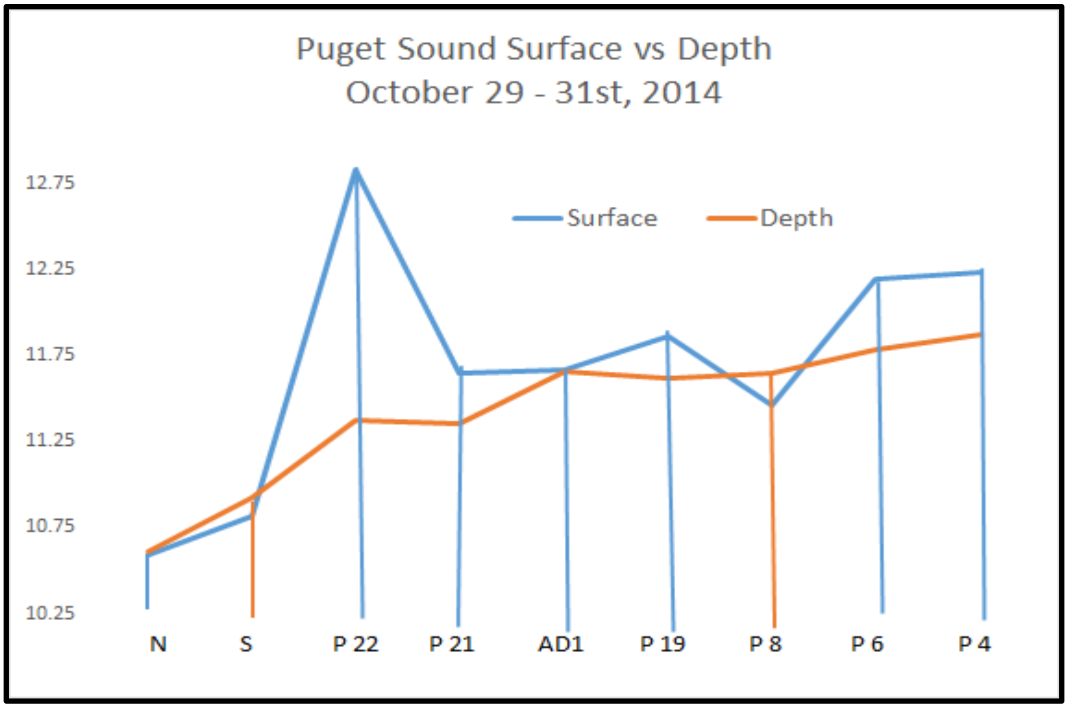


Fig. 19. Temperature(ºC) differences at various Puget Sound PRISM Stations, compared to North (N) and South (S) Station at the far left. Deep water appears warmer at South Station and P 8 (Hood Canal), and surface and depth temperatures equal due to the well mixed nature of N and AD1 stations.

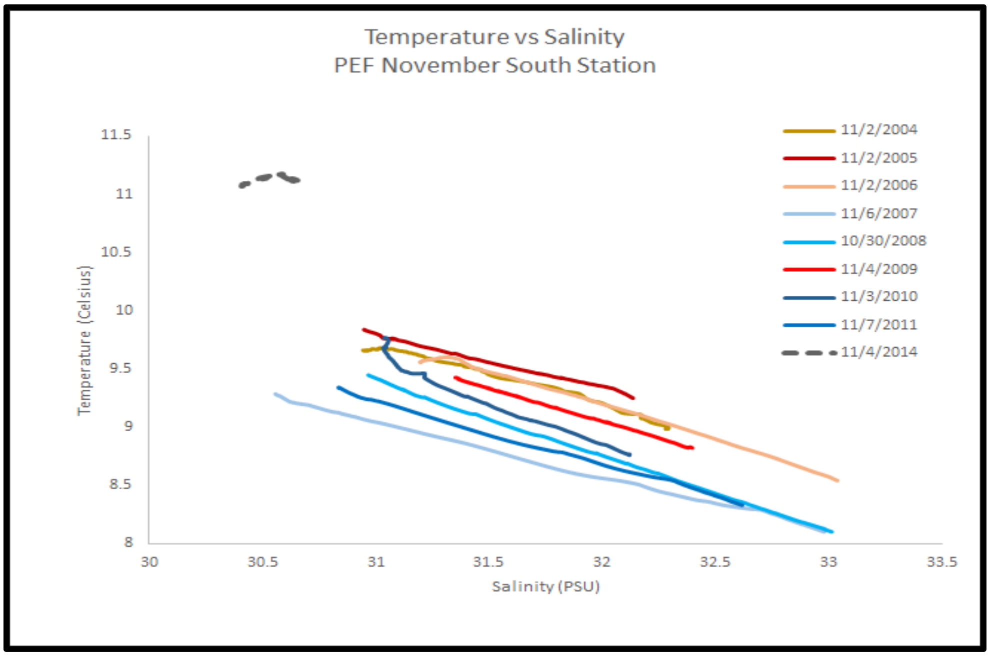


Fig. 20. Interannual comparison of temperature (ºC) and salinity (PSU) at South Station for early November, 2004 to 2011, and 2014 after the fall transition. 2014 behaved like no other year, 2 degrees warmer at depth, and 1 degree warmer at the surface. Salinity was the smallest range of any year in PEF.

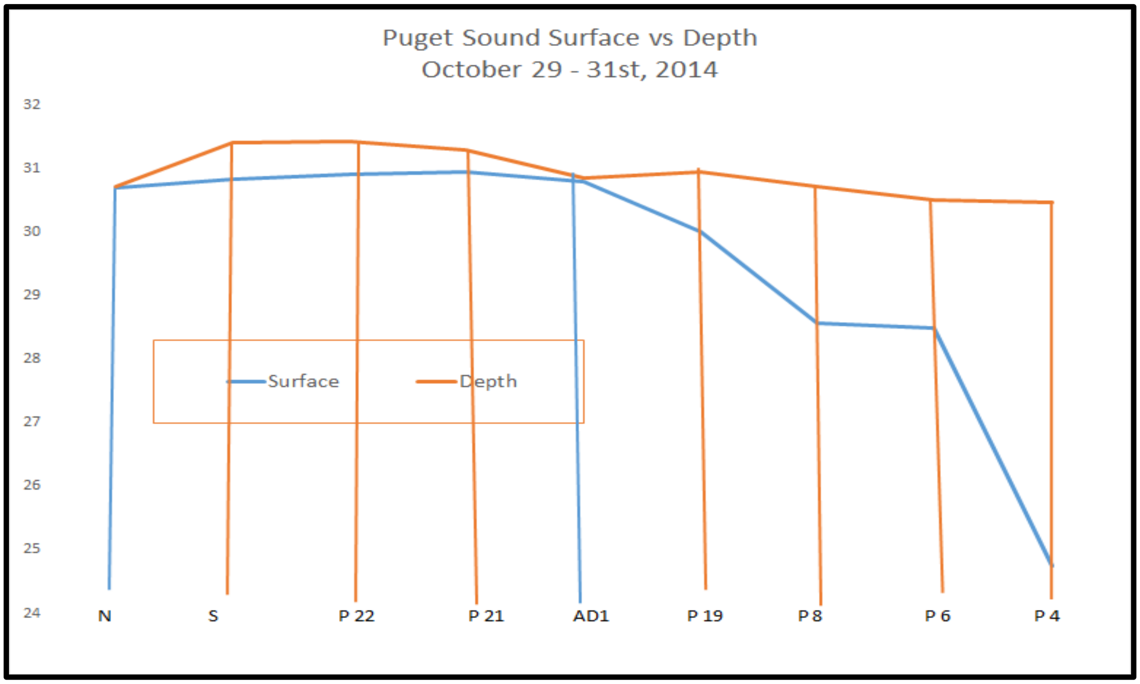


Fig. 21. Late October salinity (PSU) surface and depth measurements from Puget Sound PRISM stations taken compared to North and South stations (far left). Salinity with depth remained consistent, however moving into the Puget Sound Hood Canal; Main and Whidbey Basins surface salinity was highly impacted by freshwater input.

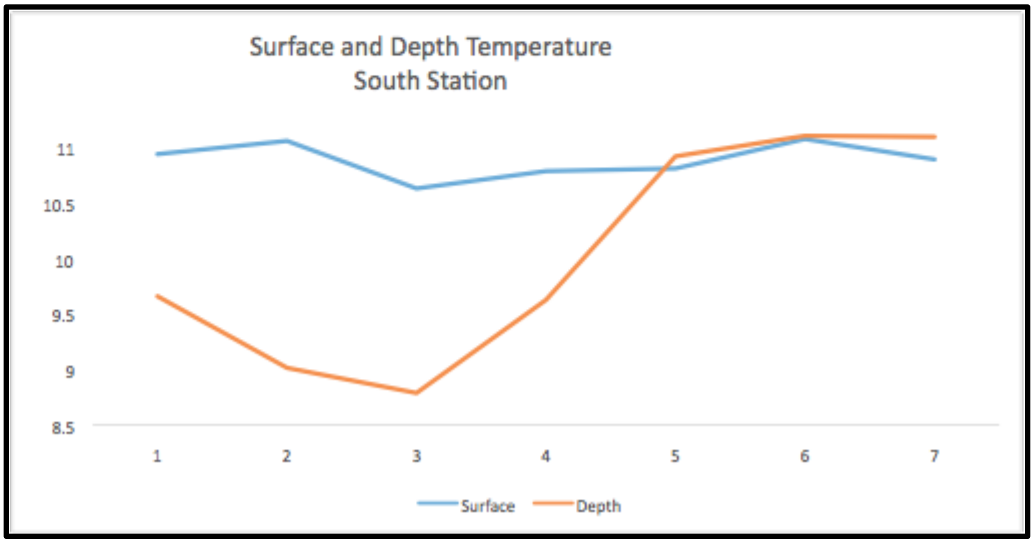


Fig. 22. Surface and depth temperature (ºC) measurements from each 2014 PEF cruise for South Station. There was a distinct switch noticed in the bottom water, but as expected the surface water showed less variation.

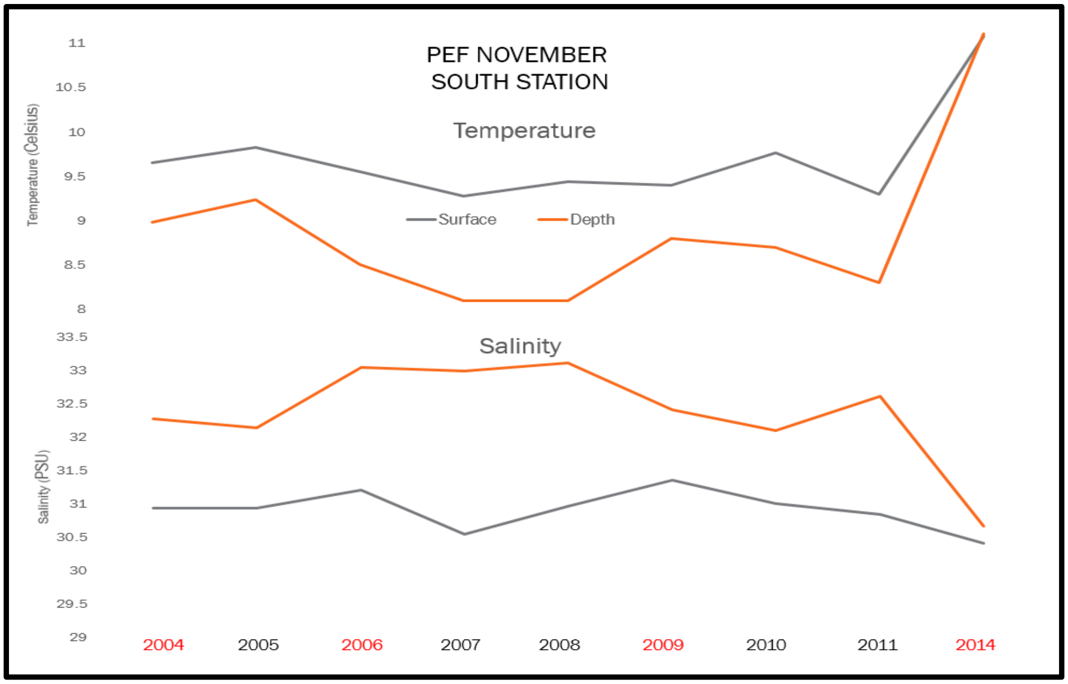


Fig. 23. This graph shows surface and depth temperature (ºC) and salinity (PSU) data for South Station, each year excluding 2012 and 2013. The sharp increase in temperature at depth was mirrored by decreasing salinity in November 2014. Temperature and salinity during El Nino years (red) fluctuate less than a degree or PSU. 2014 November had the lowest salinity and highest temperature at surface and depth.

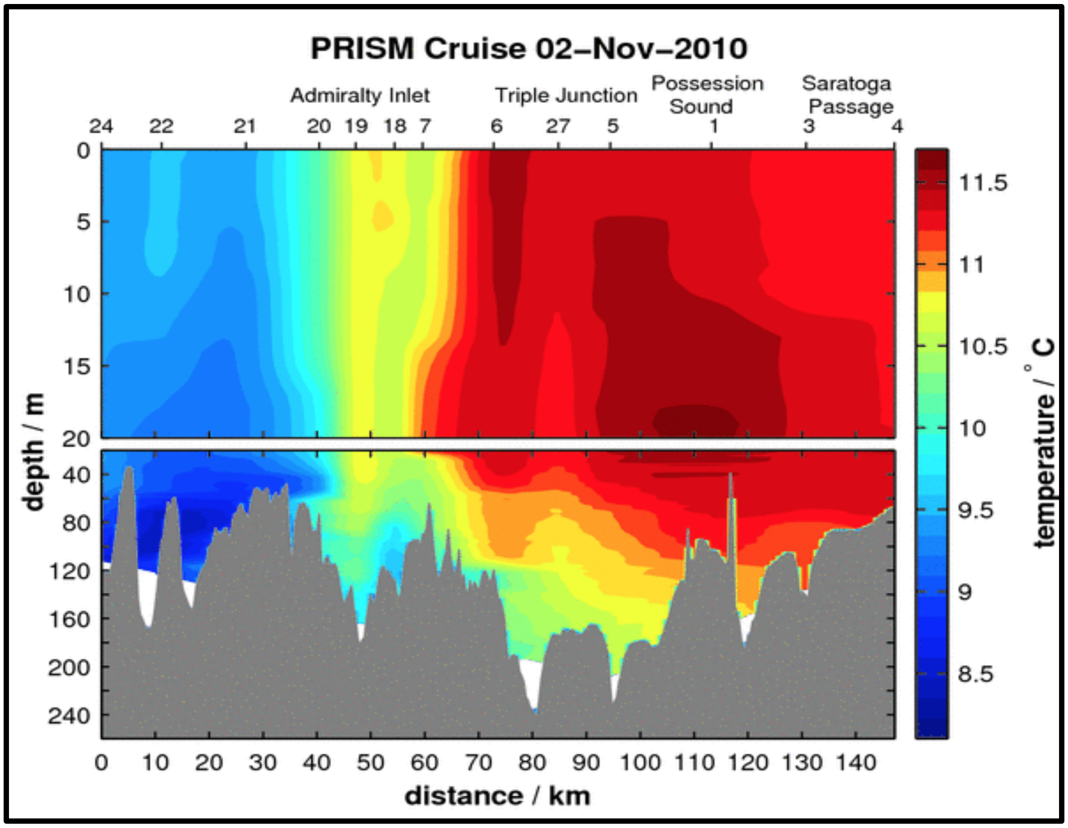


Fig. 24. November 2, 2010 PRISM station temperature (ºC) data throughout Puget Sound. Compared to 2014, P 22 and P 4 were much different. P 22 temperature range was also much smaller in 2010.

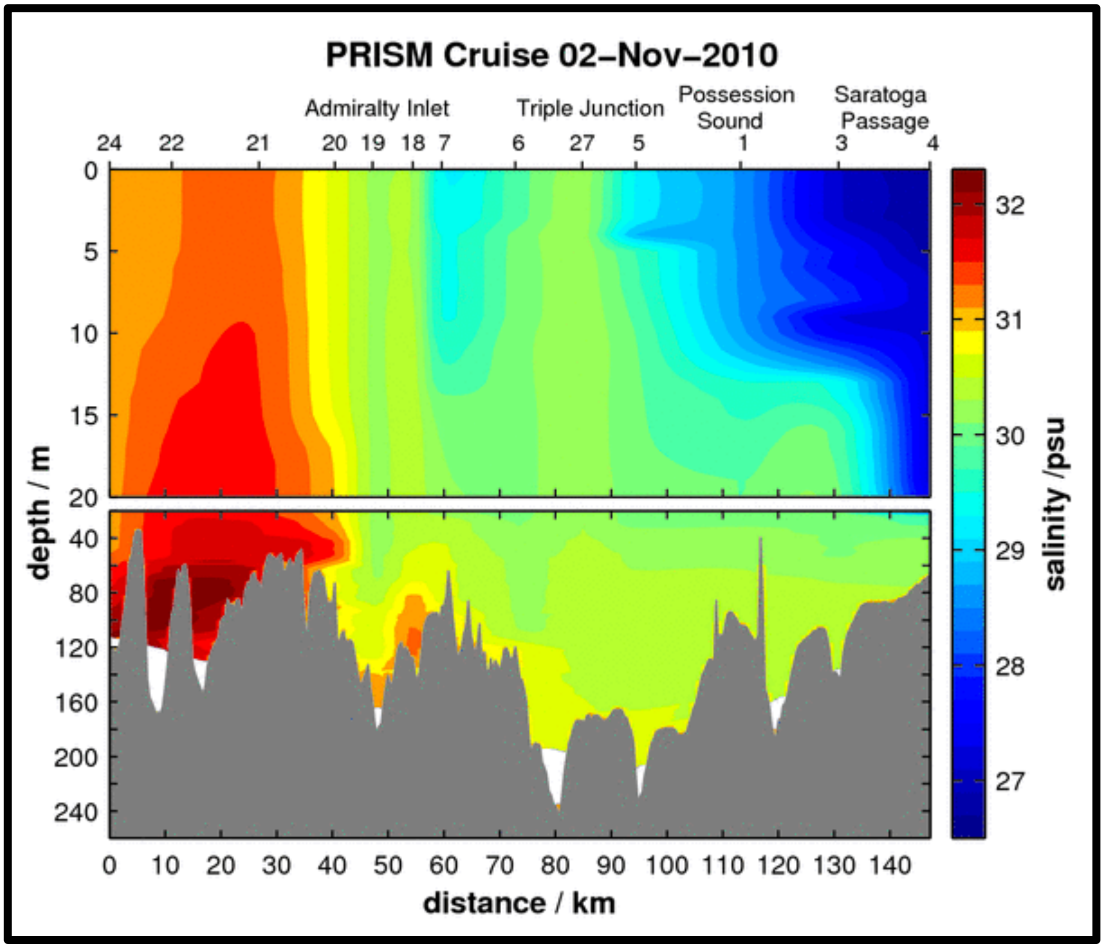
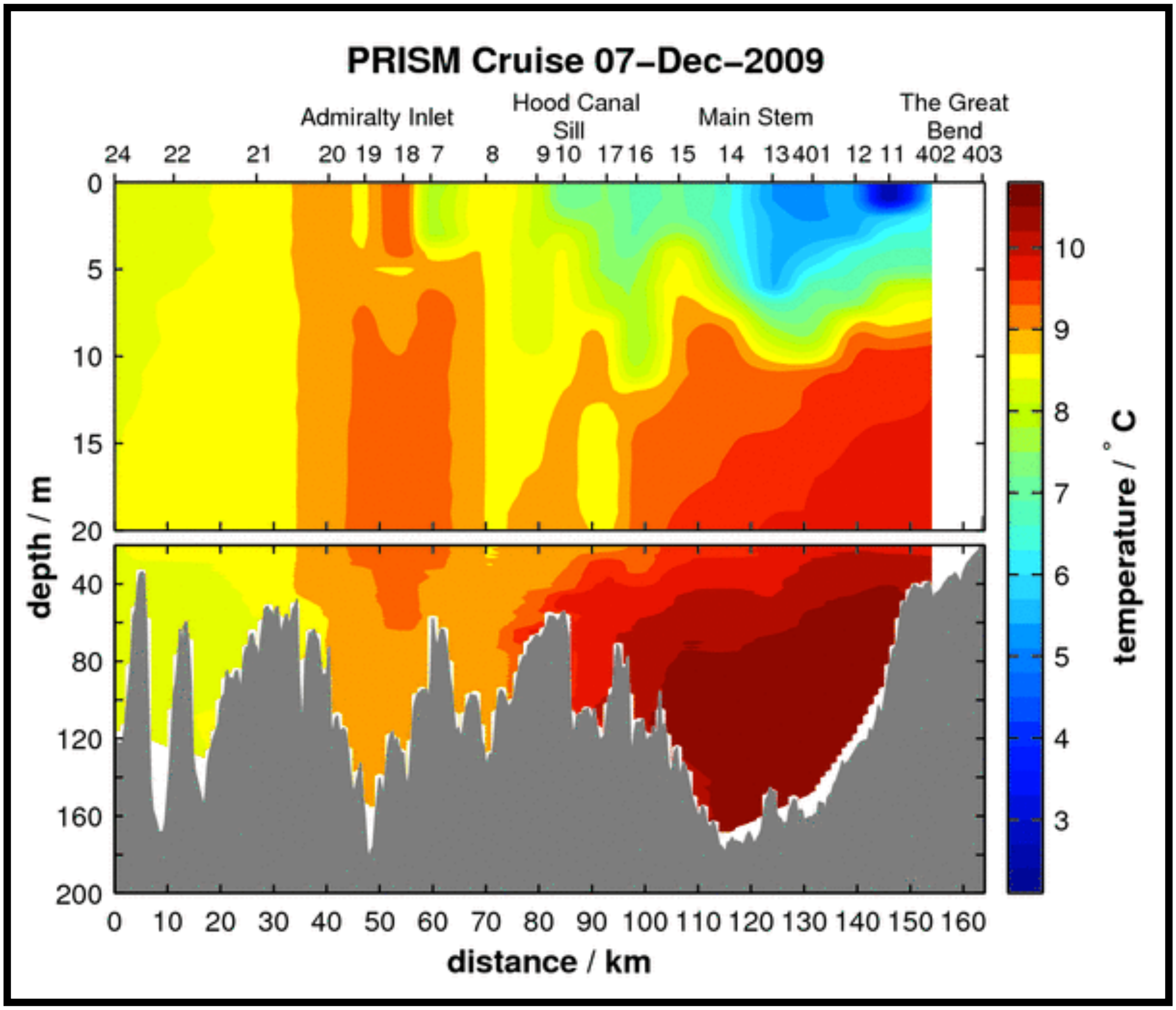


Fig. 25. *PRISM stations in SJF to Whidbey Basin. Salinity and depth are plotted from November 2010 data. This shows typical salinity layout in Puget Sound*


PRISM Cruise 07–Dec–2009
Admiralty Inlet
Hood Canal Sill
Main Stem
The Great Bend
24 22 21 20 19 18 7 8 9 10 17 16 15 14 13 401 12 11 402 403
depth / m
0 5 10 15 20 40 80 120 160 200
distance / km
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
temperature / ° C
3 4 5 6 7 8 9 10

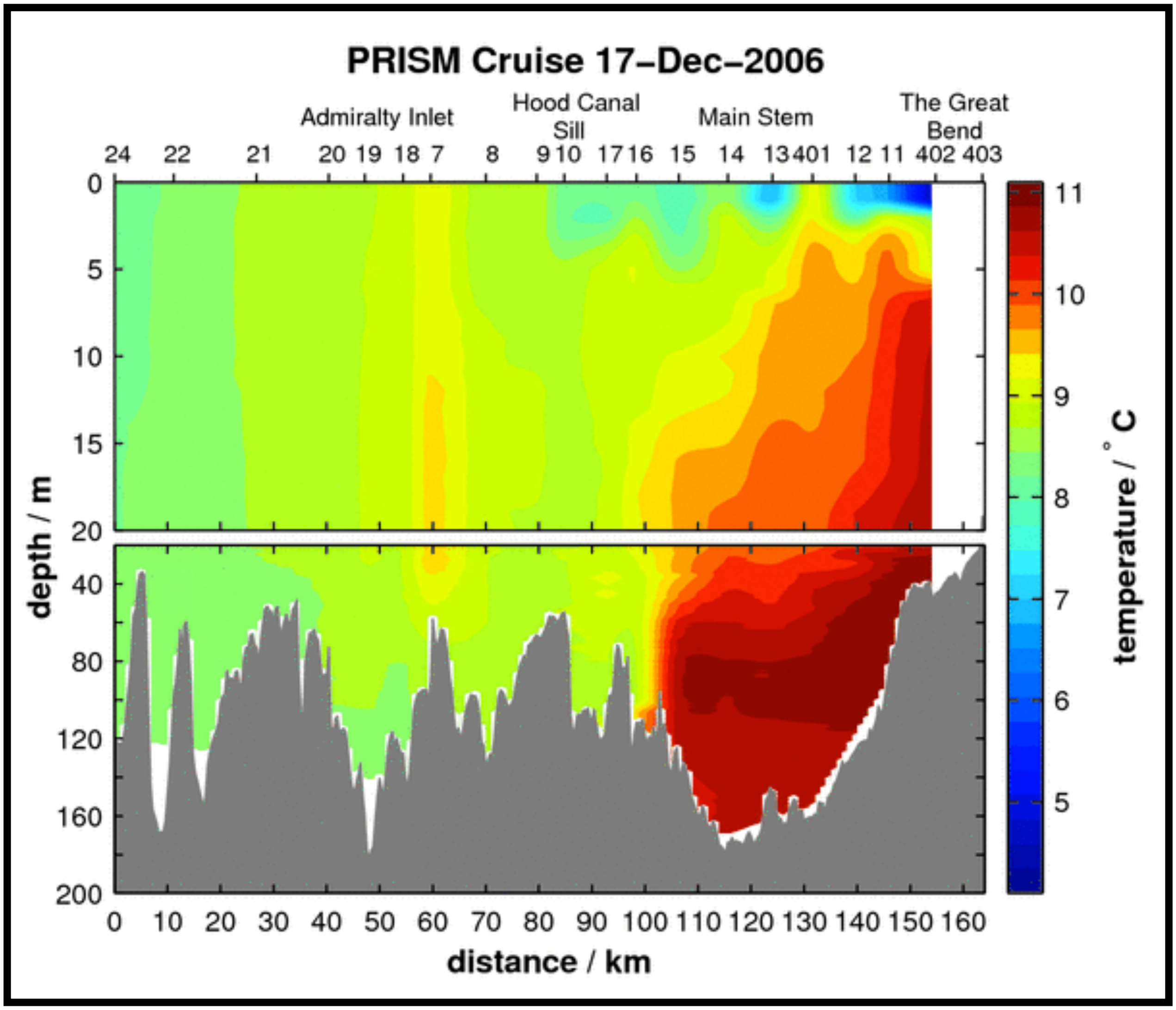


Fig. 26. December 2009 temperature conditions from SJF to Hood Canal.

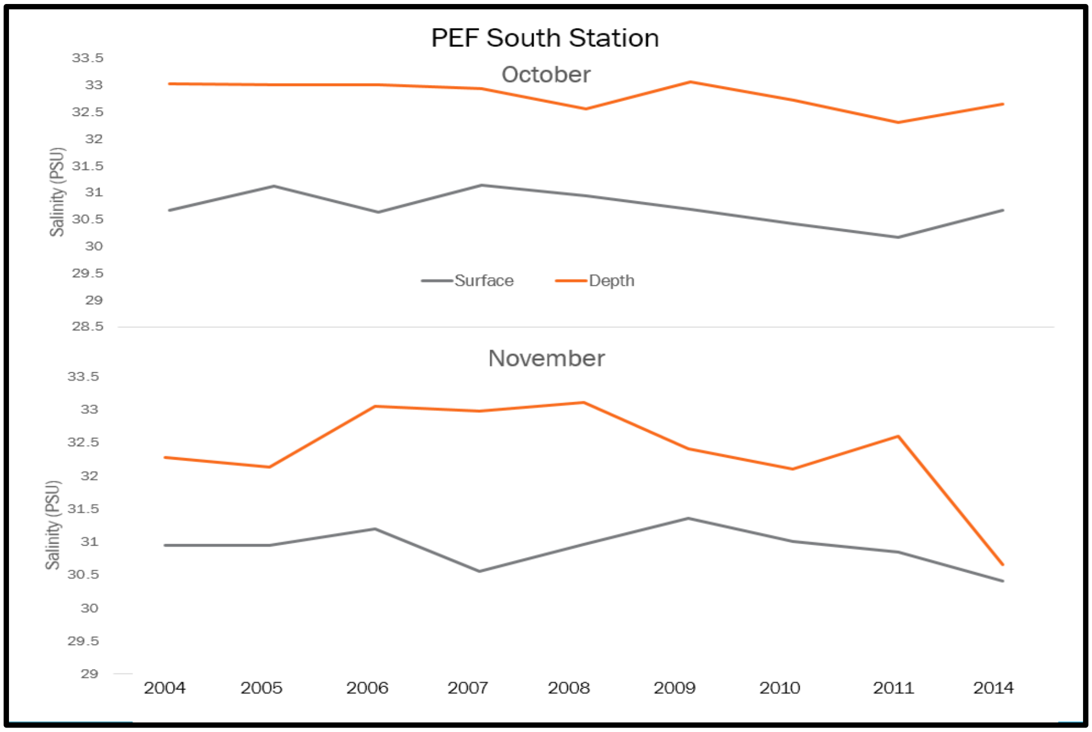


Fig. 27. October Pre-Fall Transition data 2004 to 2014 of South station surface and depth temperature (ºC) and salinity (PSU) measurements. Interannual salinity values in November fluctuate more than October.

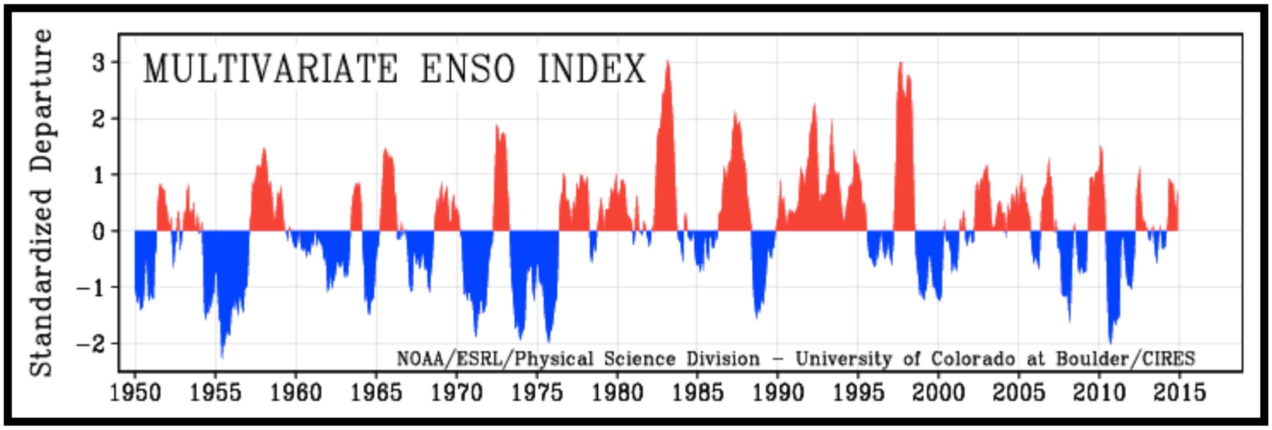


Fig. 28. ENSO Index, showing the later portion of 2014 becoming an El Nino year.

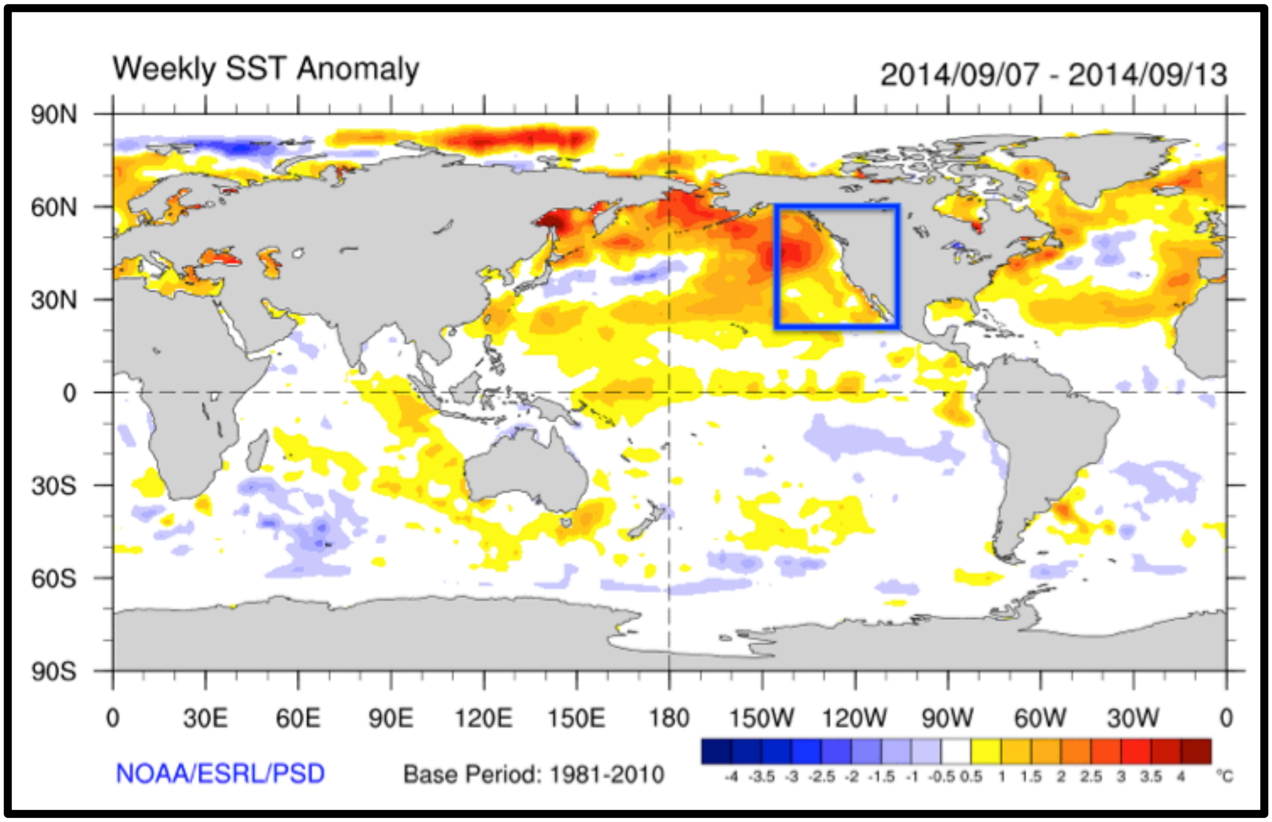


Fig. 29. SST anomalies during upwelling preventing advance of NE temperature "blob" into Puget Sound.

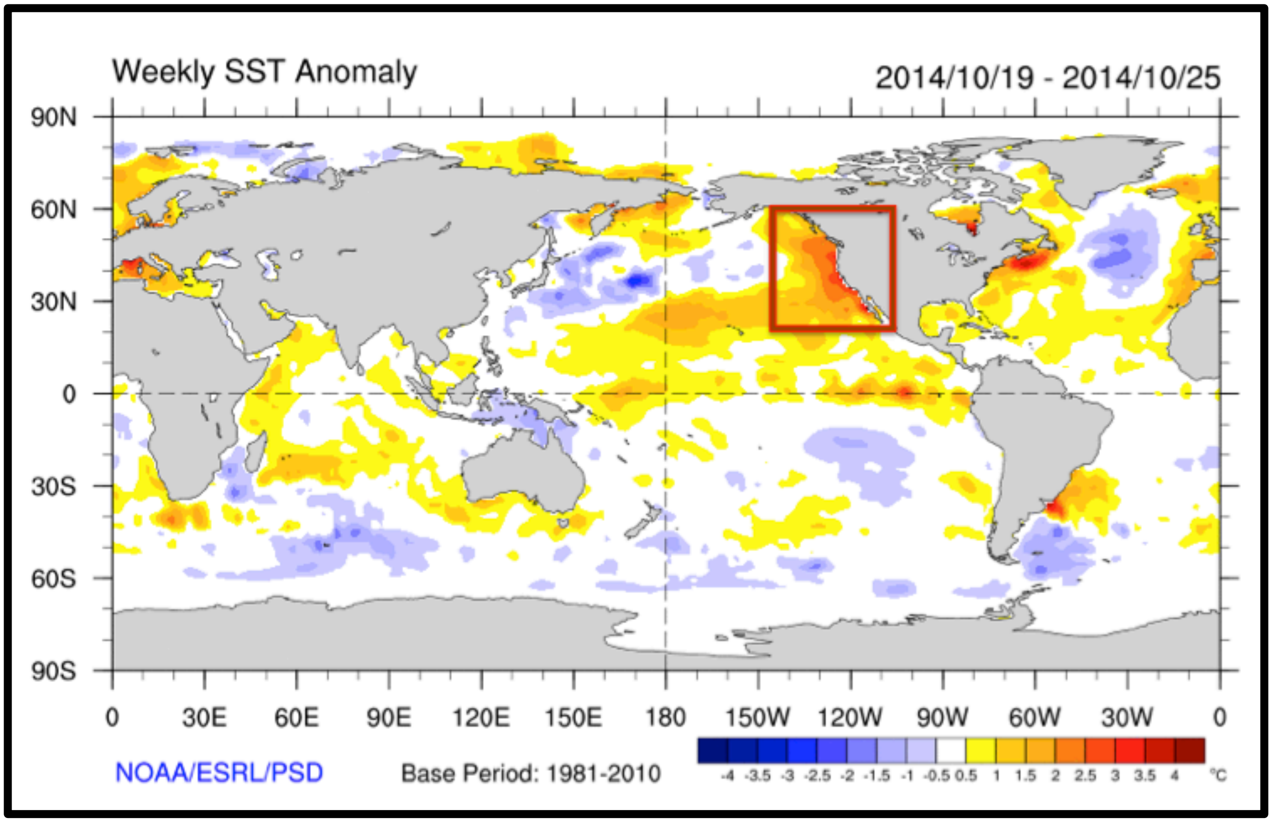


Fig. 30. SST anomalies during downwelling period.

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