# Tracking Climate Trends in Puget Sound in Real-time: The Puget Sound Environmental Metrics Dashboard

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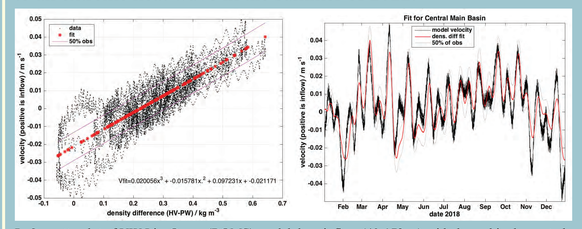
## 1. Summary

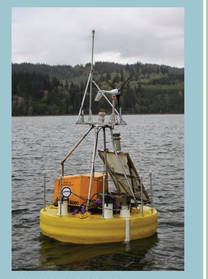
Since 2021 the University of Washington has been tracking a set of environmental metrics that monitor water mass changes in Puget Sound with a **web-based, graphical dashboard**. These metrics, which are updated bi-weekly and use real-time mooring, weather station, tide station and river gauge observations as input, were developed to inform resource managers, scientists, health officials, and others on how key climate and ocean factors are influencing the present state of Puget Sound and to put current conditions in the context of past observations. Several of the metrics have taken the critical step of providing insight into *why* the observed changes are occurring. The metrics include **estuarine flow changes**, **temperature changes from surface heat fluxes, salinity changes from rivers and rain, water column dissolved oxygen,** and **ocean boundary conditions**. These metrics have enabled greater understanding of recent water mass and circulation anomalies in Puget Sound, including the response to periods of drought or heavy rainfall, atmospheric heat waves, and persistent atmospheric patterns. One major finding from this work has been that temperature and salinity anomalies in the top ~60 m of Puget Sound are largely driven by anomalies in local surface heat fluxes and river flow respectively, with changes in T-S properties of oceanic water flowing into Puget Sound playing a lesser role.

## 2. Estuarine Flow Changes

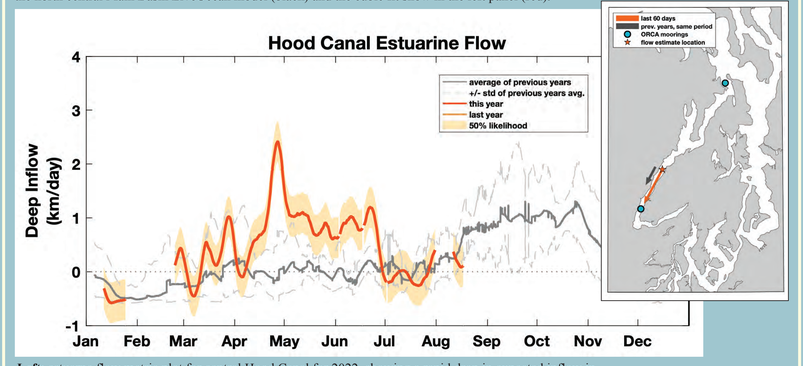
This metric is based on robust empirical relationships between lateral density differences and estuarine flow in Puget Sound. The lateral density differences are calulated from measured profiles at UW-NANOOS ORCA moorings and the flow between these sites is inferrred. This metric highlighted significant flow changes as a response to an extreme heat wave in the summer of 2022.




**Left**: scatterplot of UW LiveOcean (ROMS) model deep inflow (40-172 m) mid-channel in the central Main Basin (Y-axis) vs. model depth-averaged deep density differences between the ORCA Hansville and Point Wells locations (X-axis), with density lag-adjusted by 1 day. A cubic fit is shown in red: sse=0.53, $r^2$=0.75, rmse=0.0079. **Right**: time series plot of 7-day smoothed, deep inflow (40-172 m) mid-channel in the north central Main Basin LiveOcean model (black) and the cubic fit show in the left panel (red).



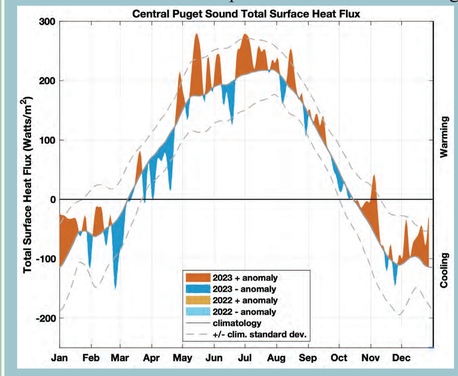
A UW-NANOOS ORCA winched profiling mooring in Hood Canal.

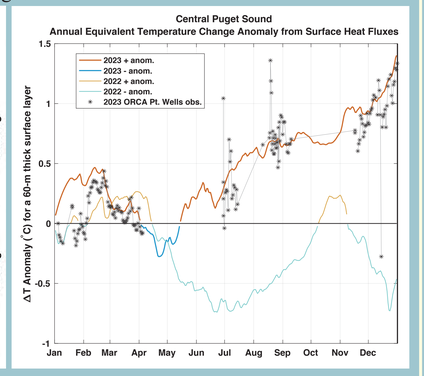



**Left**: estuarne flow metric plot for central Hood Canal for 2022, showing a rapid drop in expected inflow in late June associated with rapid freshening of the mouth of Hood Canal due to anomalously high river flow from meltwater associated with an extreme regional heat wave. **Right**: a metrics website plot from June 2022 graphically depicting the anomously strong deep inflow in central Hood Canal prior to the heatwave.

## 3. Temperature Changes from Surface Heat Fluxes

This metric uses directly-measured and calculated surface heat fluxes at various locations in Puget Sound to place current and past conditions in the context of climatologies and to track the role of these fluxes on water temperature/heat content changes.

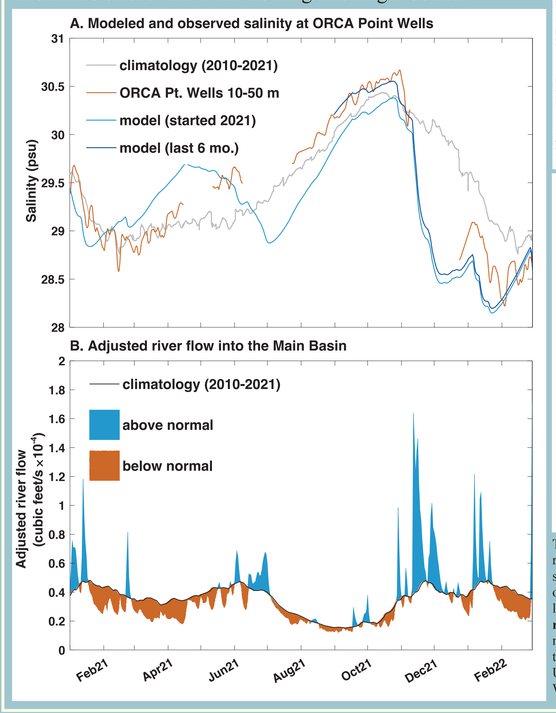


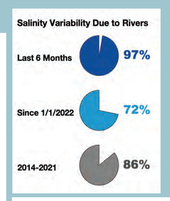



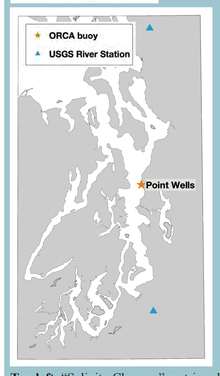

**Left**: Total surface heat flux anomaly plot for 2023 for Central Puget Sound with positive anomalies in orange and negative in blue. All values above the "zero" line are positive fluxes into Puget Sound, acting to warm the water (and vice-versa for values below zero). **Right**: The expected influence of the surface heat fluxes anomalies on water temperature anomalies compared to ORCA mooring observations, showing that the ~1.5 $^{o}$C warm water anomaly at the end of 2023 was largely due to surface heat flux anomalies.

## 4. Salinity Changes from Rivers and Rain

A simple salt conservation model tracks expected salinity changes solely due to river input into Puget Sound. The only model input is USGS river flow observations with model salt influx only dependent upon the difference between modeled salinity and a constant outside (oceanic) salinity. Significant model skill when compared to ORCA mooring observations indicates that salinity anomalies within Puget Sound are largely due to anomalies in river flow and not anomalies of oceanic water flowing into Puget Sound.



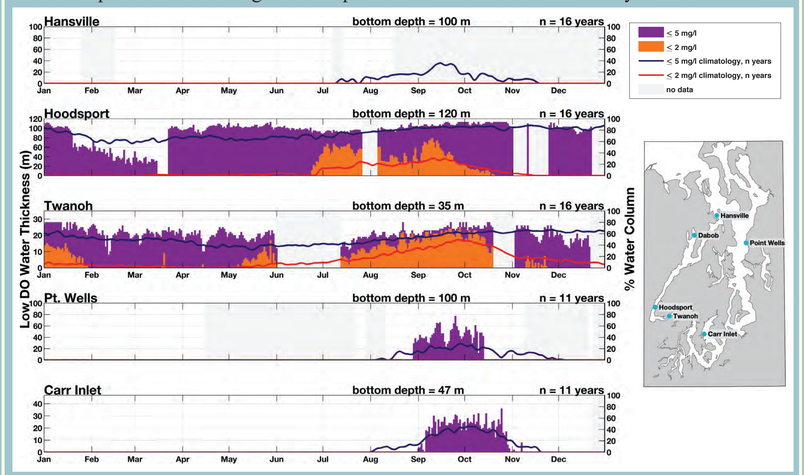




**Top left**: "Salinity Changes" metric salt budget model results for Central Puget Sound from 1/2021 to 1/2023 showing that anomalously salty conditions in the spring of 2021 and fresh conditions in the winter of 2022 were largely due to river flow anomalies (**lower left**). **Top right**: percent variance described by the salt budget model compared to Pt. Wells ORCA mooring observations for this period. **Lower right**: Locations of the USGS river flow stations used as model input and the Pt. Wells ORCA mooring.

## 5. Water Column Dissolved Oxygen

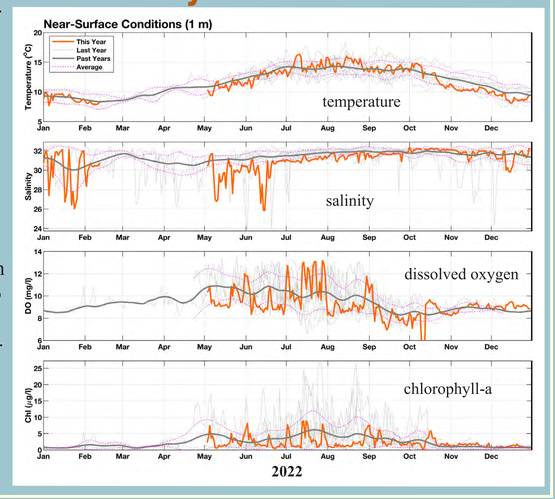
Using the profiling ORCA mooring observtions, this metric tracks the water column percentage and equivalent "thickness" of dissolved oxygen concentrations of different classes (hypoxic: ≤ 2 mg/l, and low: ≤ 5 mg/l) and places these measurements in the context of climatologies created from ORCA observations. This metric allows a more complete understanding of the impact of low-DO water on the ecosystem and biota.




**Left:** Dissolved oxygen water column thickness and percentage for 2022 at various ORCA mooring sites (map, **rignt panel**). The Hoodsport and Twanoh locations saw significantly greater amounts of hypoxic water than climatology for extended periods of time for much of the year, likely adding to environmental stress for a number of species.

## 6. Ocean Boundary Conditions

The influence of changes in the properties of oceanic water flowing into Puget Sound is tracked using observations from the UW-NANOOS Cha'Ba mooring located on the Washington Shelf near the entrance to the Strait of Juan de Fuca. Significant changes in T-S properties on the shelf will propagate into Puget Sound, as was the case during the North Pacific Blob years 2014, 2015).




## www.nanoos.org/products/ps_metrics

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