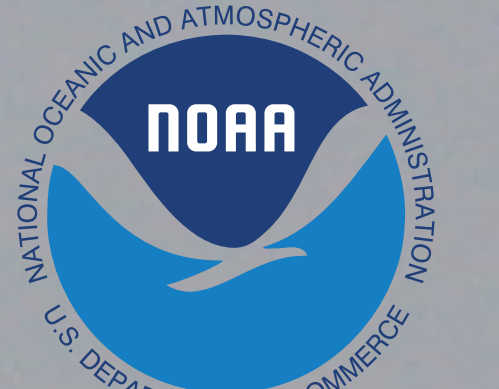# The Response of Puget Sound to the 2014–2015 North Pacific Warm Anomaly
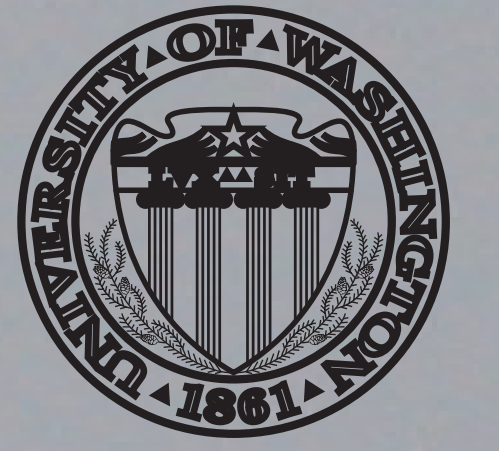
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Abstract

The flow of the unprecedentedly-warm upper-ocean North Pacific "Blob" water into Puget Sound, Washington, caused local extreme water property anomalies that extended from the arrival of the water inshore in the fall of 2014 through 2015. Here we report on moored observations from Puget Sound, where temperature was more than 2 standard deviations above the 10-year climatology for much of the year with maximum temperature anomalies at depth and at the surface +2.5 °C and +7 °C respectively. In Hood Canal, a branch of Puget Sound, the low density of the oceanic warm "Blob" water resulted in weak deep water flushing in the fall of 2014, which combined with a lack of wintertime flushing to result in anomalously-low dissolved oxygen (DO) concentrations at depth. Late-summer 2015 DO values were the lowest in a decade of mooring observations and more than 2 standard deviations below climatology. The anomalously low density of the deep basin water allowed a very early onset of the annually-occurring, late-summer intrusion, which first entered Hood Canal at the end of July compared to the usual arrival in early to mid-September. In late August this intrusion conspired with an early fall storm to lift the very low DO deep water to surface at the south end of Hood Canal, causing a significant fish kill event.

Bathymetric map of Puget Sound, Washington (right panel) showing the locations of the ORCA (Oceanic Remote Chemical Analyzer) profiling moorings, which are denoted with magenta triangles. The left panel provides regional context and shows the location of the offshore Cha Ba mooring.
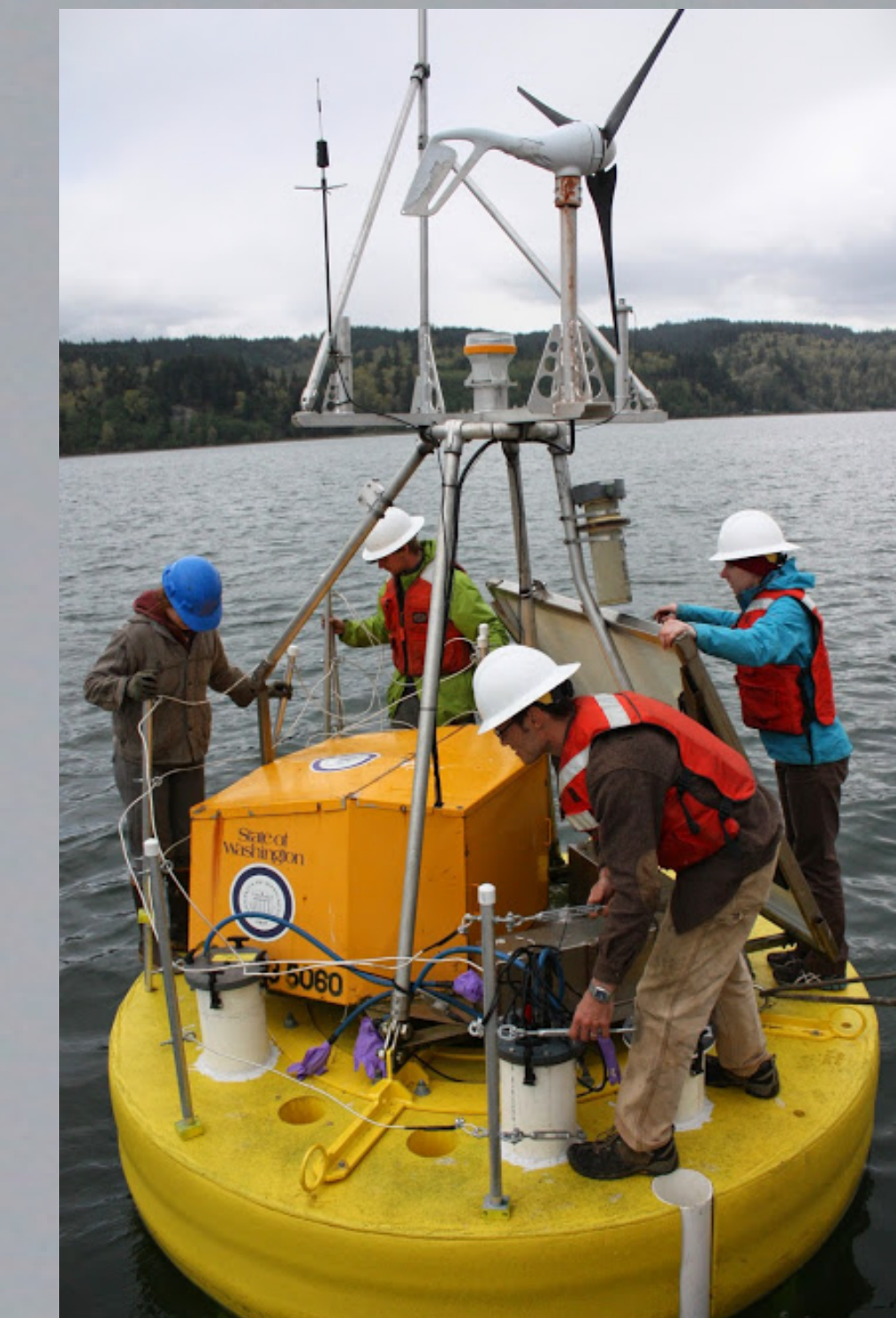
Hoodsport θ-S Diagram
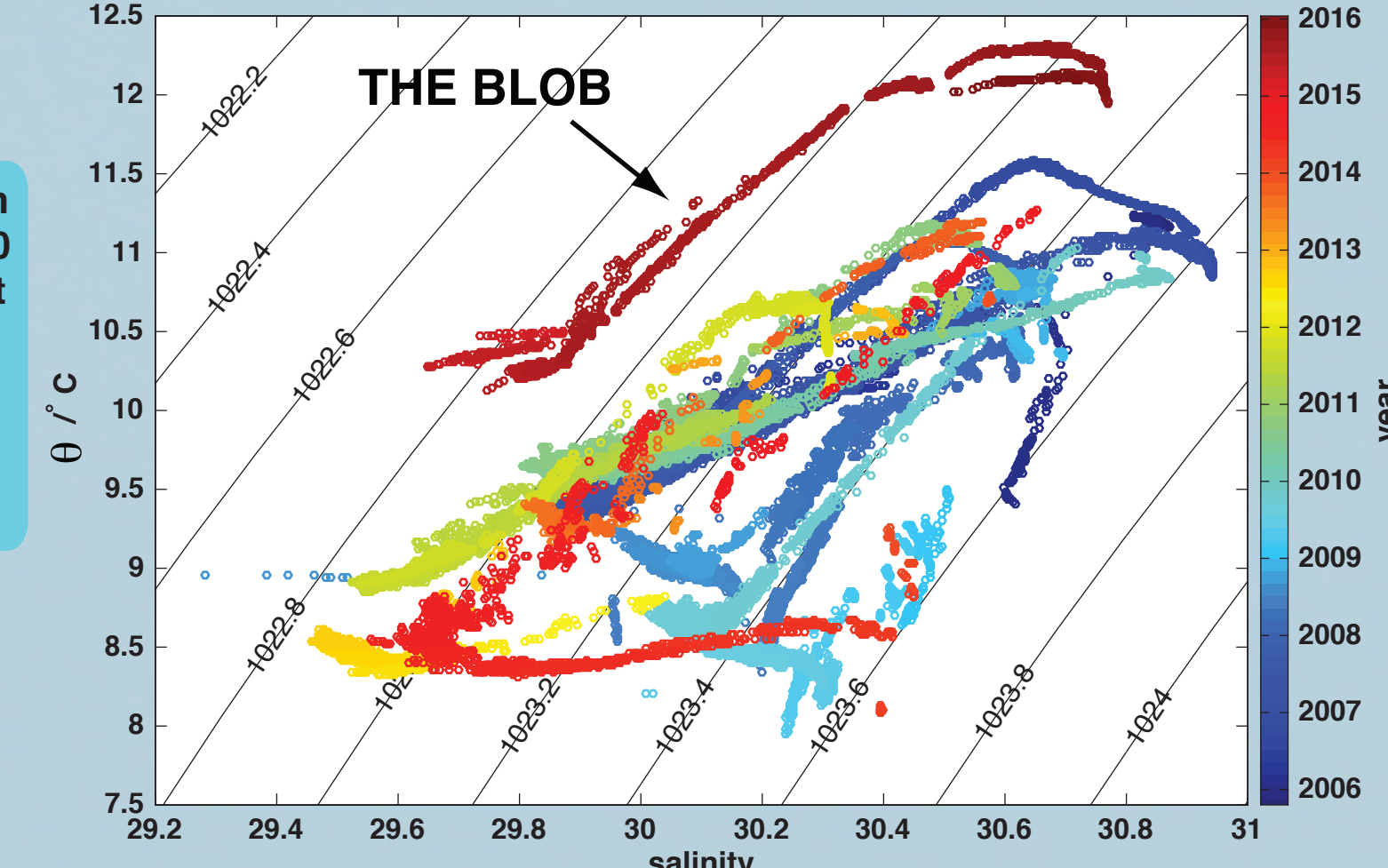
THE BLOB

A potential temperature-salinity diagram at the Hoodsport ORCA mooring (80-100 m) shows the Blob water entering Puget Sound resulted in extreme temperature and salinity anomalies as well as some of the lowest density deep water observed in Hood Canal over a decade of observations.
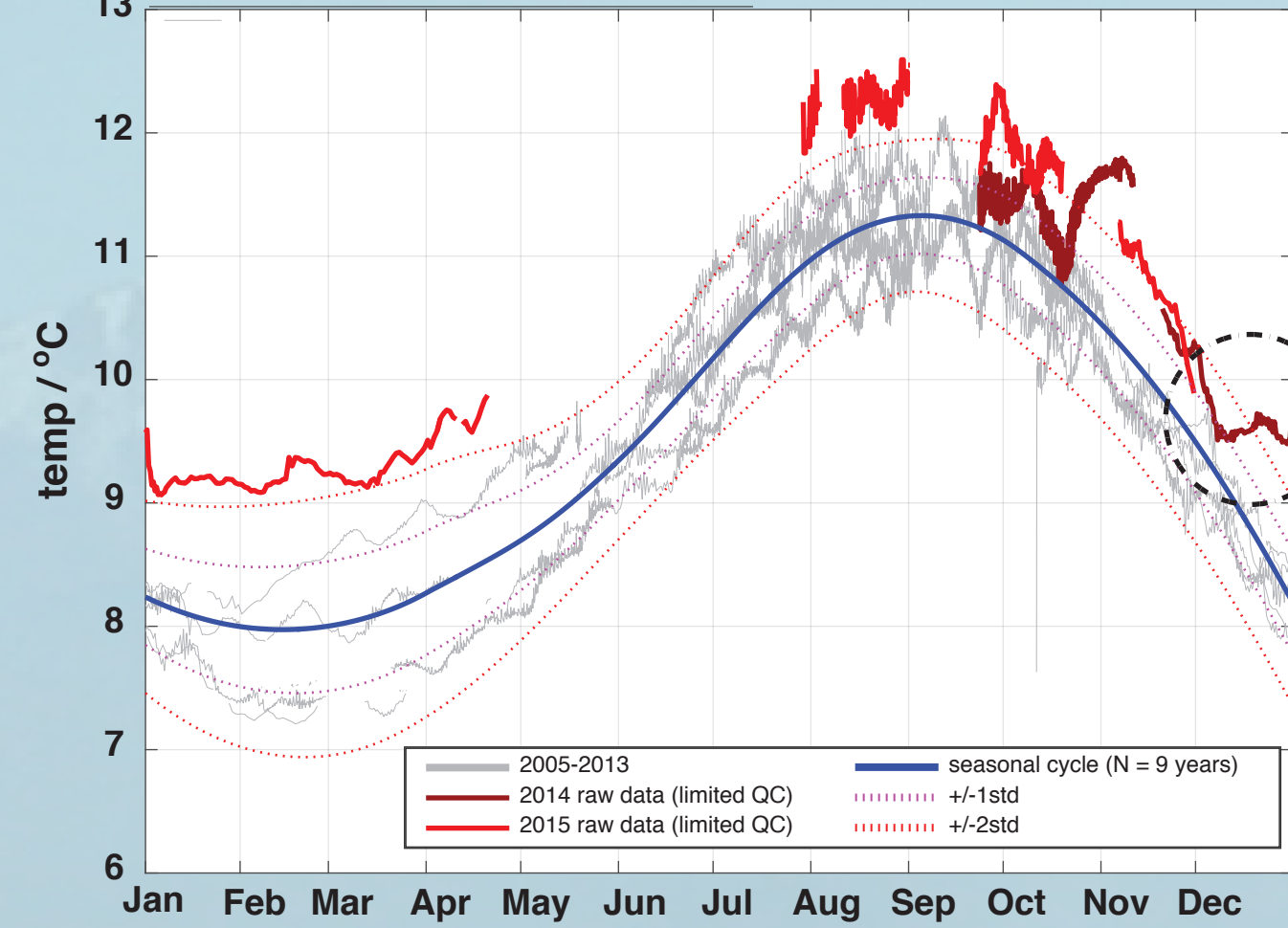
The Arrival of the Blob

### Temperature: Cha Ba (Washington Shelf) @ 85 m

The Blob first comes ashore on the Washington coast in October 2014 as upwelling relaxes. Deep water (84 m) on the shelf is >4 °C above normal. In 2015 there is also significant warming after the fall transition (upwelling stops), but not as extreme as in 2014.

Temperature: ORCA North Buoy @ 80 meters

The Blob first makes its appearance in Puget Sound (North Buoy) around December 2014, with some earlier smaller warm water events in October/Nov.

### Temperature: ORCA Hoodsport @ 80 meters

WOW!
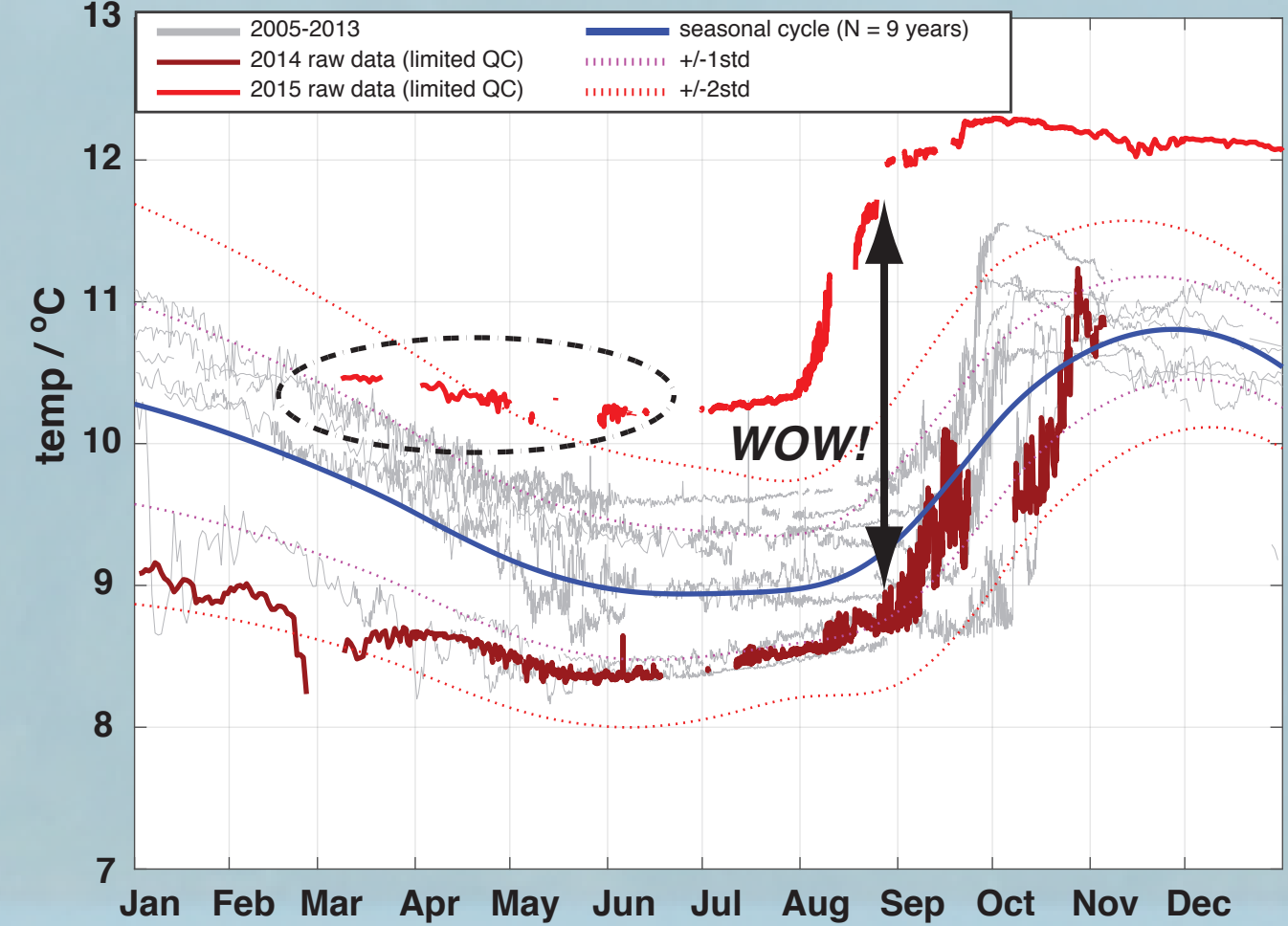
In the winter of 2015, deep water in Hood Canal does not cool as usual, with anomalies reaching 2 standard deviations above normal by May. Extreme temperature anomalies (>2.5 °C) occur as an anomalously-warm "fall" intrusion enters Hood Canal about a month earlier than previously observed.

Salinity: ORCA NorthBuoy @ 80 meters
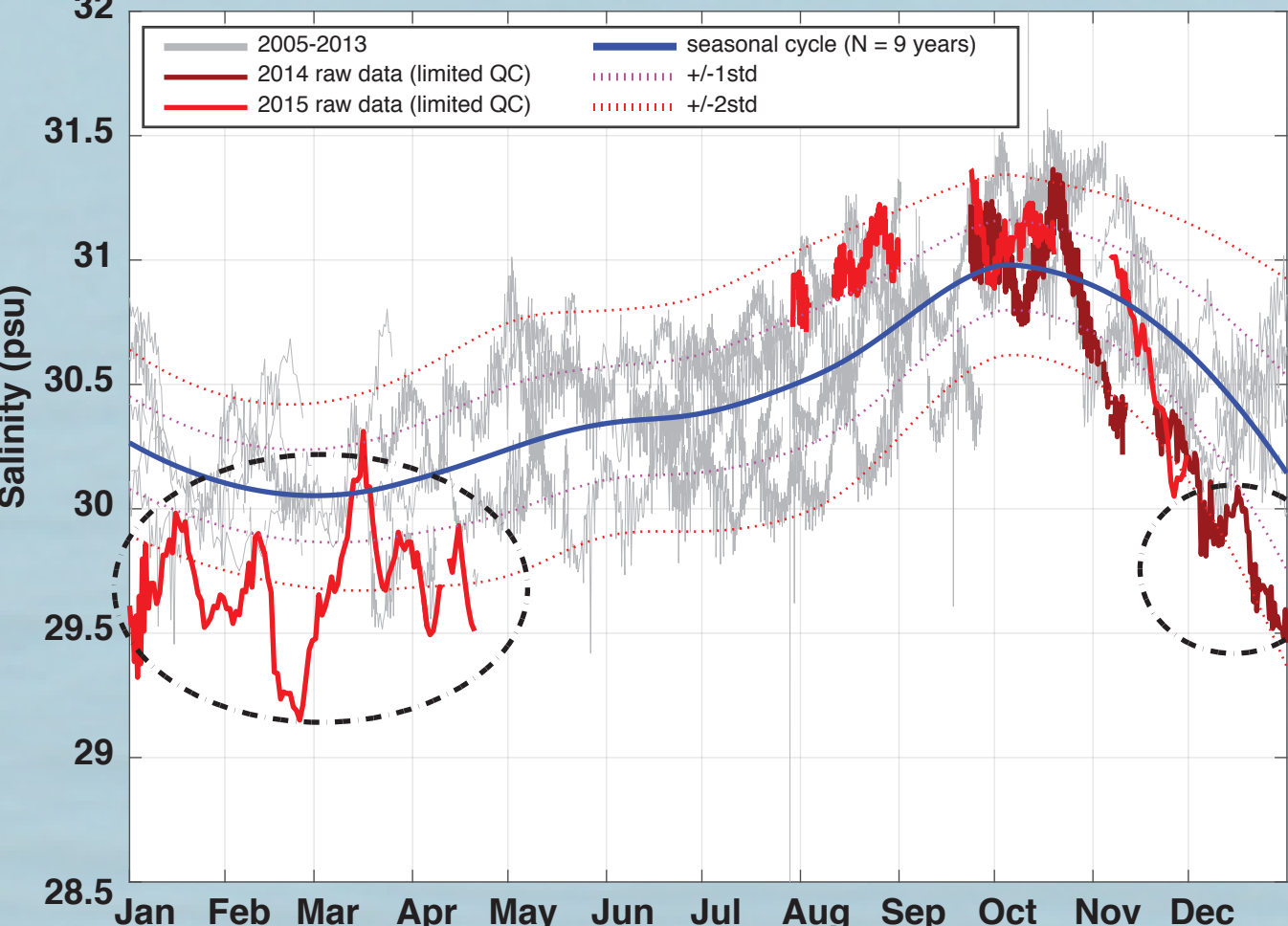
The Blob water is very FRESH, which combined with the warm temperatures causes it to have very low density. This low density has profound impacts on Puget Sound circulation. The salinity drop roughly accounts for 2/3 of the density drop, with temperature the remaining 1/3.

Influence of Regional Weather

SeaTac Air Temperature

### SeaTac Integrated Hourly Surface Air Temperature Anomaly
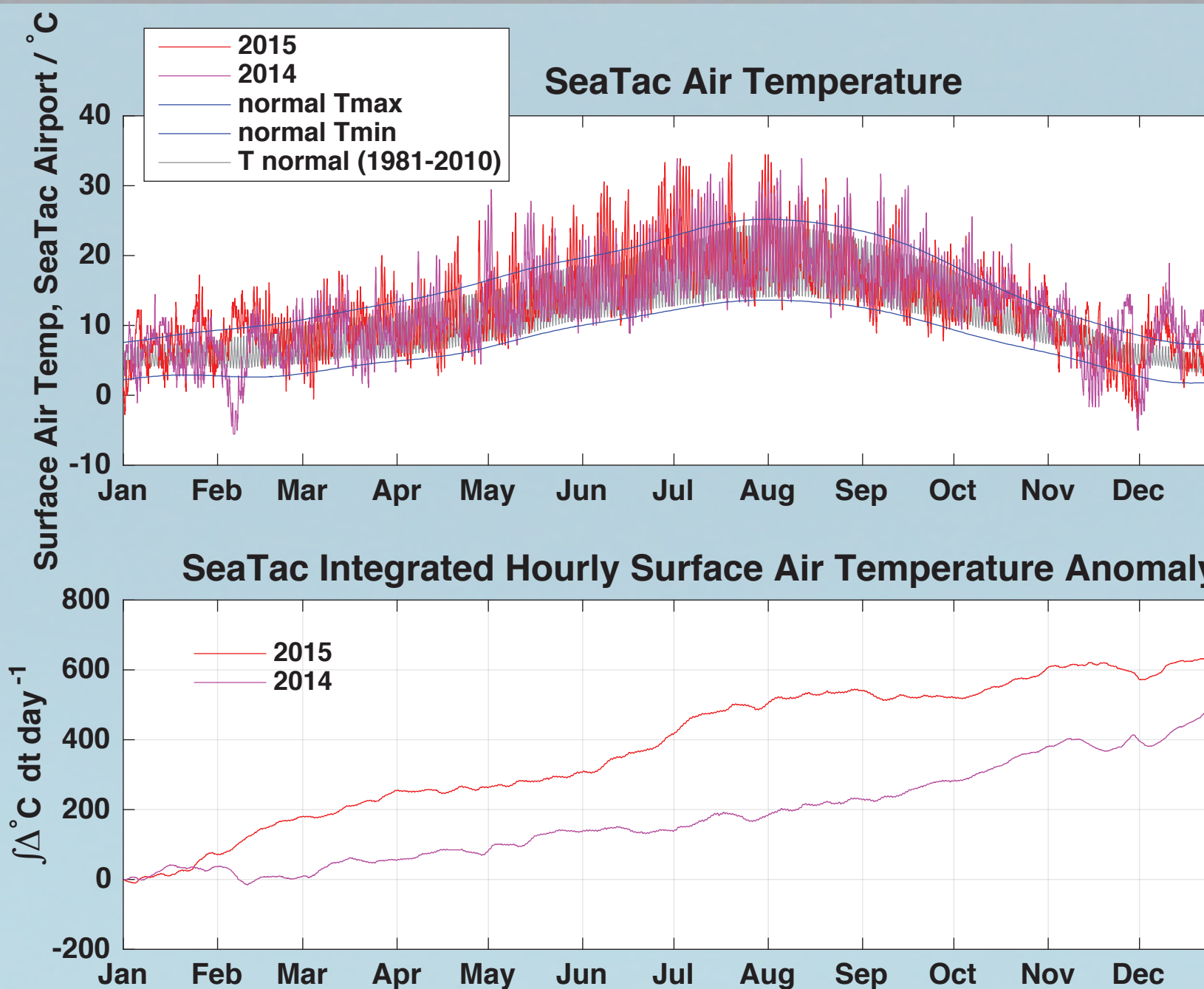
Regional air temperatures in 2014 and 2015 were well above normal. These anomalies appear to be communicated quickly to mid-depth waters in Puget Sound, such as at Carr Inlet which experienced significant warming before the arrival of the Blob in Dec. 2014.

Temperature: ORCA Carr Inlet @ 35 meters

The 2015 Summer Intrusion and Fish Kill Event

Sigma-t: ORCA Hoodsport @ 80 meters

WOW!
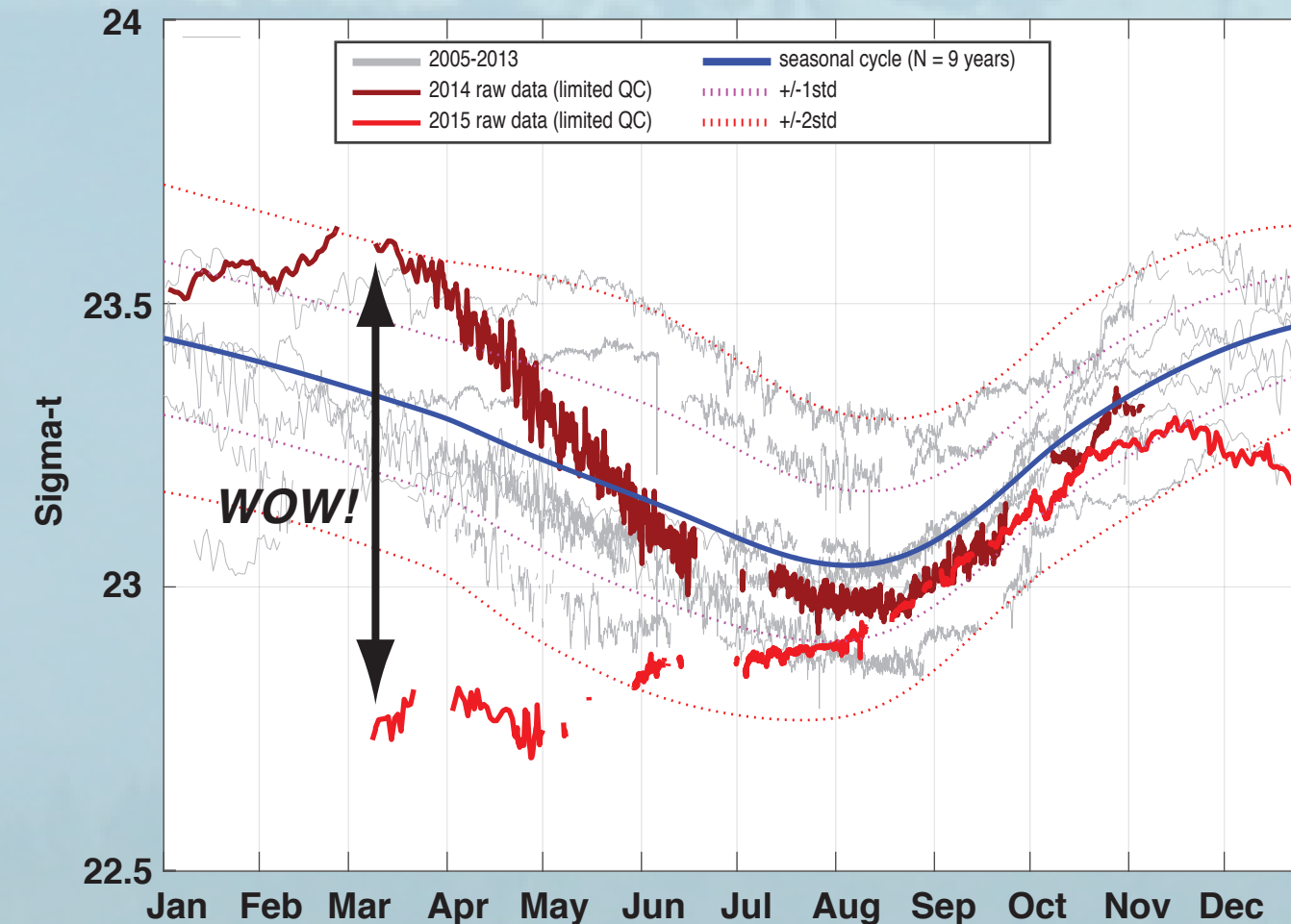
Density (sigma-t) of the deep water in the southern part of the main stem of Hood Canal showed a rapid drop between November 2014 and March 2015, during the period when the Blob arrived. Unlike in other years, density slowly increased over the spring and early summer of 2015, increasing more rapidly at the onset of the oceanic intrusion in August. The extremely low density of the Blob water likely preconditioned Hood Canal for a very early and strong oceanic intrusion in 2015.

Dissolved Oxygen: ORCA Hoodsport @ 80 meters
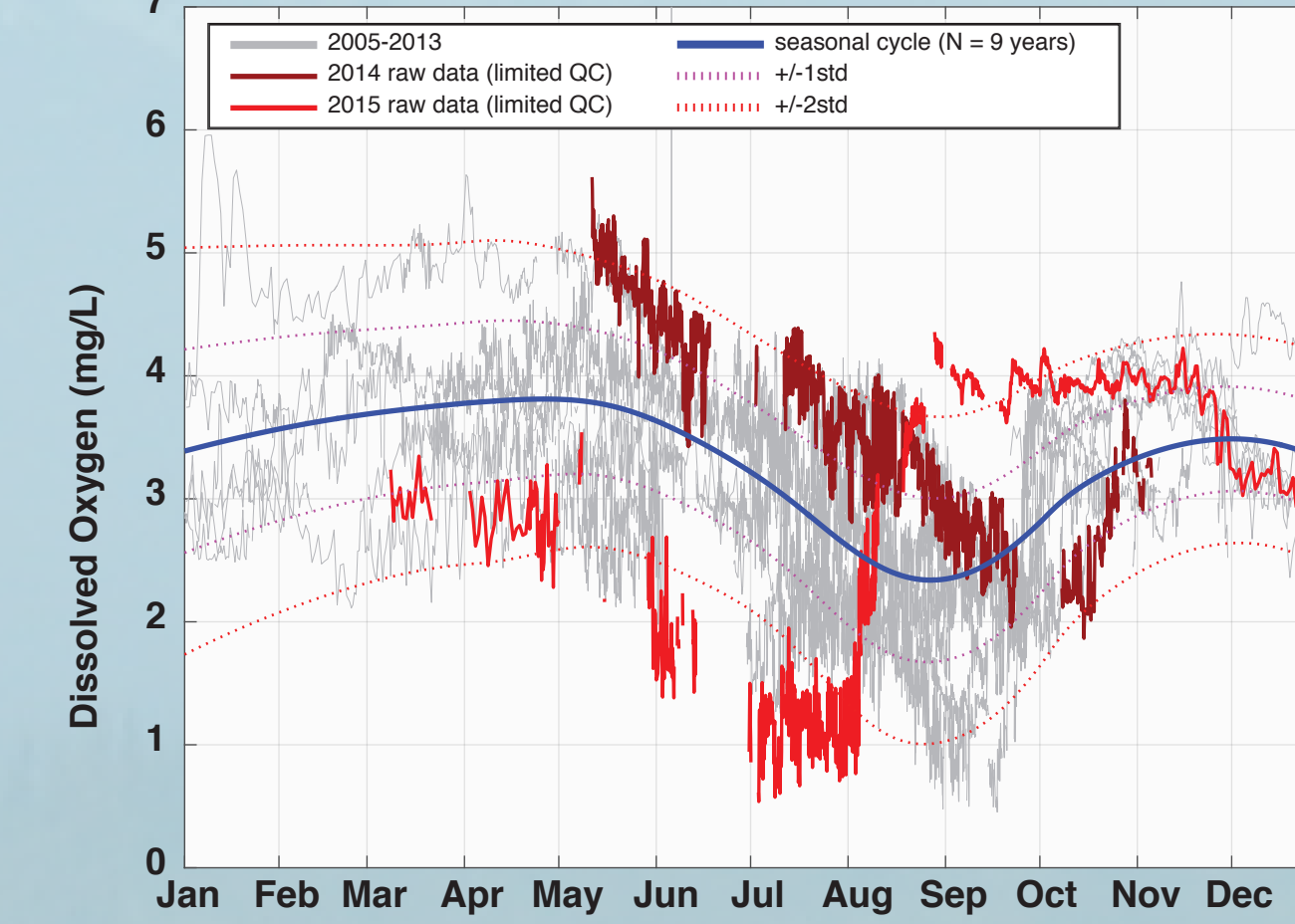
Following a late, weak fall intrusion in 2014, which appeared to incompletely flush the resident low-DO water in Hood Canal (see Twanoh plot a right), deep DO remained low in Hood Canal, reaching extreme lows in July and early August. The ~month early, robust oceanic intrusion which entered southern Hood Canal at the end of July rapidly increased the DO levels in the deep water from 2 standard deviations below to 2 standard deviations above climatology.

Dissolved Oxygen: ORCA Twanoh @ 25 meters
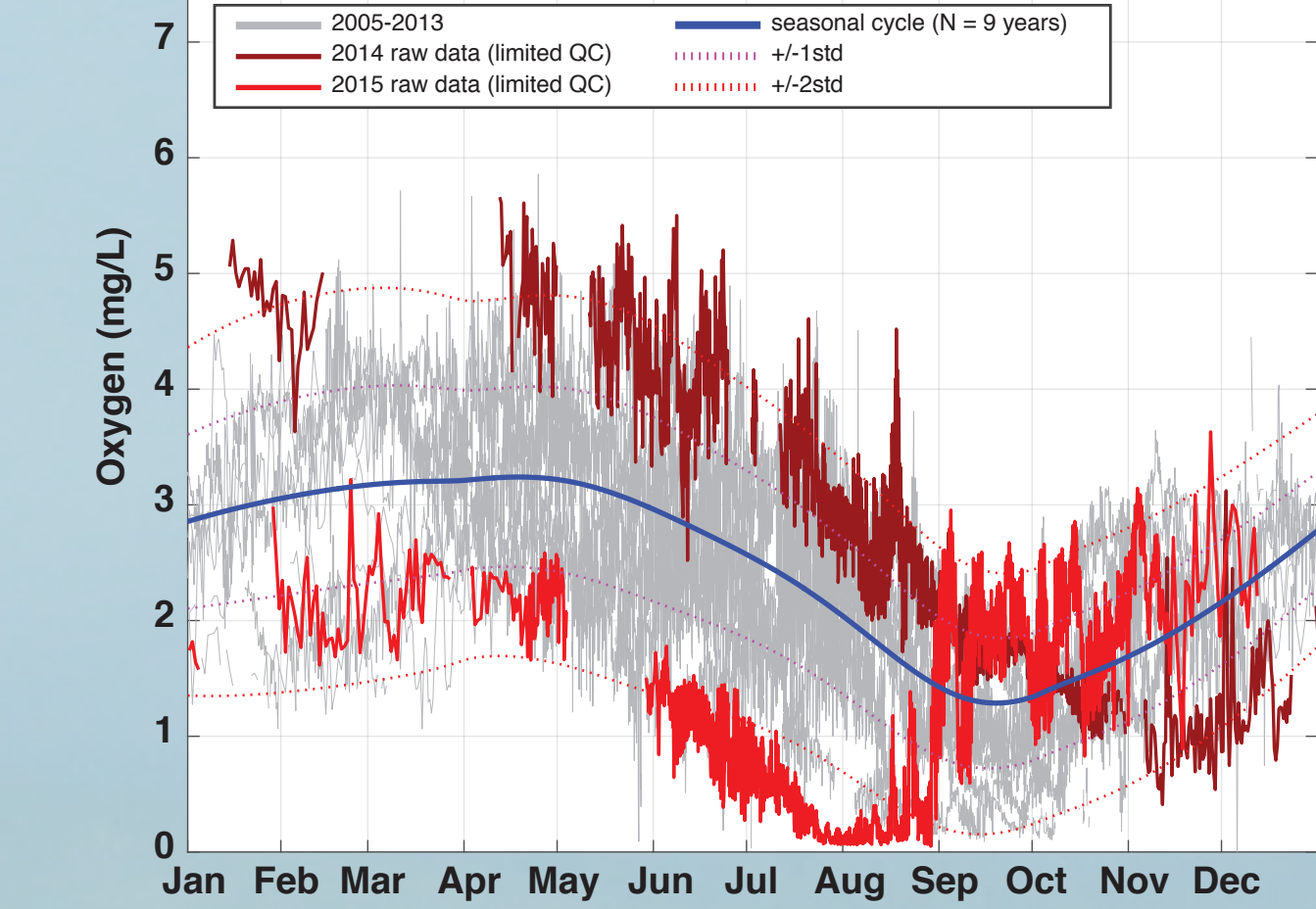
In 2014 at Twanoh ORCA (lower Hood Canal) DO levels started well above normal like in much of Hood Canal, but weak fall flushing allowed DO to continue to drop well into late fall. Like the deep water at Hoodsport, DO levels remained low throughout winter and spring, with respiration using up all DO in the near-bottom water by the end of July. The early, rapid flushing in August 2015 is a sharp contrast with the previous year.

Dissolved Oxygen at Hoodsport, July-August 2015

> 2 mg/l
< 2 mg/l
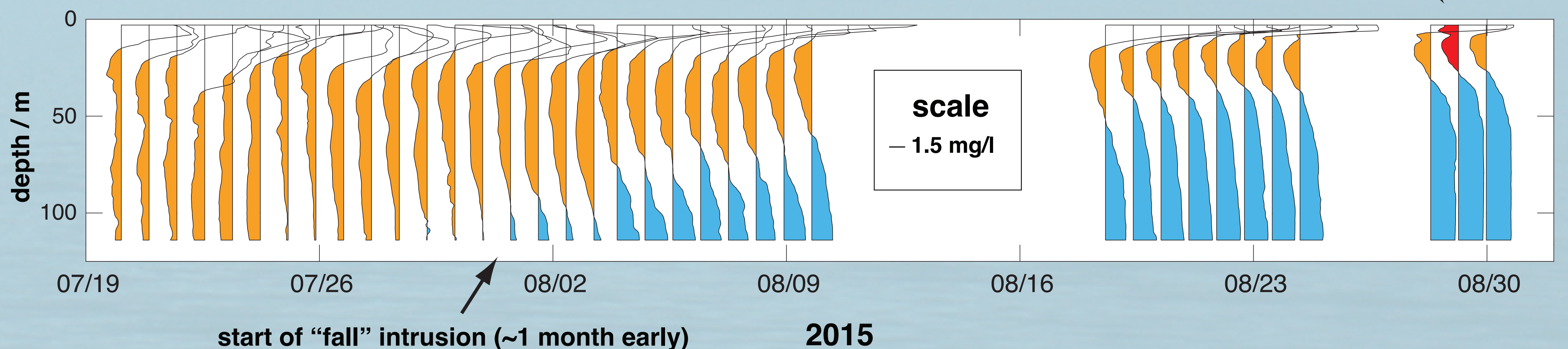
low DO outcrops to surface (fish kill)

scale
— 1.5 mg/l

start of "fall" intrusion (~1 month early)

2015

Time series of dissolved oxygen concentration at the Hoodsport ORCA mooring, plotting a subset of profiles. Note the roughly month-early start of late-summer/fall intrusion and gradual shoaling of low-DO water. This sequence of events led to a fish kill around August 28th, when the low-DO water outcropped at the surface. DO levels above 2 mg/l in the near-surface layer are not shaded for clarity.