

Overview: working with LiveOcean model velocities and density differences to investigate a statistical relationship that can be used to leverage ORCA density profiles to estimate subtidal (7 day and longer periods) velocities. The velocity locations are along the thalweg in the primary basins between the ORCA mooring sites.

- Interpolate model values onto a z-grid from a density grid (it is ROMS)
- look at density differences in the water column below 70 m at Hansville and Hoodsport (Hood Canal proxy) and Hansville and Point Wells (Main Basin proxy).
- take the average over these depths for each location, then take the difference between them. Note: we should also try same depth range for places with different depths.
- Density differences and velocities running boxcar averaged over 7 days.
- look at the relationship between this and the thalweg velocity in the bottom 50 m (80-132 meters) of Hood Canal, and in the bottom 130 m of the Main Basin (40-172 m). The shallowest values of these depth ranges were chosen to maximize the correlation coefficient (R^2) of a cubic fit of density differences to the model depth-averaged velocity. The deep value is the model bottom depth. Although correlations decreased with greater distance from the bottom in Hood Canal above 80 m depth, they remained above 0.6 to about 55 m depth. In the Main Basin the correlations slowly *decreased* when averaging over a smaller depth range from the bottom.

Main Basin

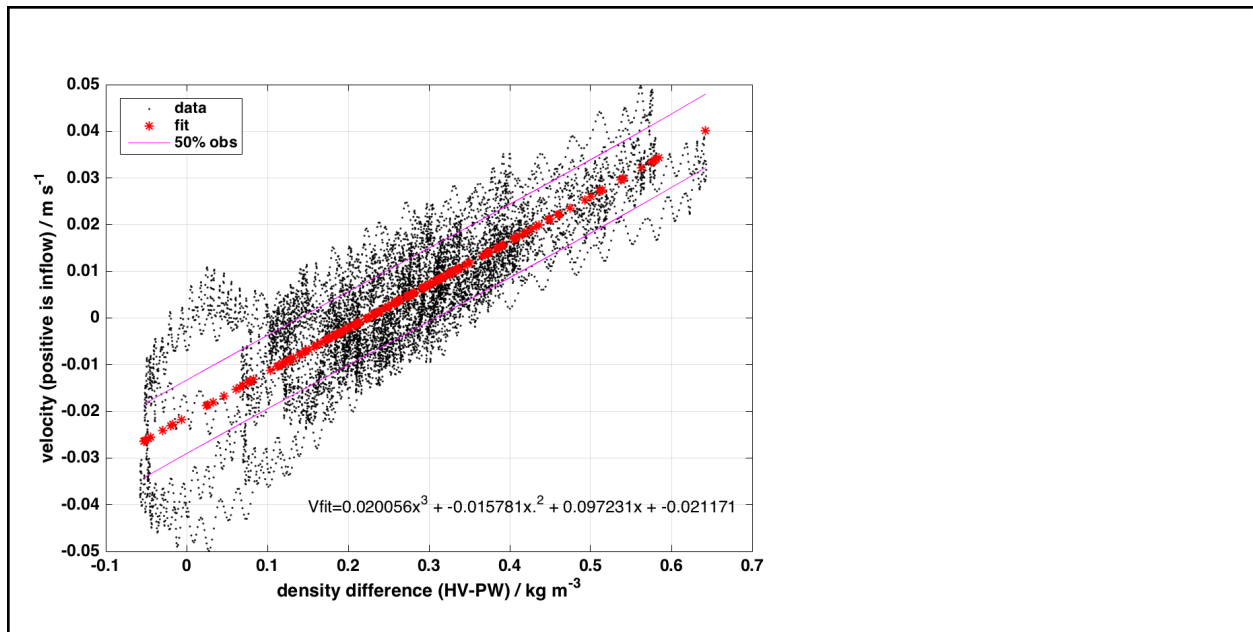


Figure 1: Scatterplot of LiveOcean model deep inflow (40-172 m) mid-channel in the central Main Basin (Y-axis) vs. *model* depth-averaged deep density differences between the ORCA Hansville and Point Wells locations (X-axis), with density lag-adjusted by 1 day. A cubic fit is shown in red. Quadratic and linear fits perform almost as well as the cubic fit.

The goodness of fit statistics for the Main Basin:

- sse: 0.5300
- rsquare: 0.7521
- Degrees of freedom: 8565 (but hourly values boxcar averaged over 7 days).
- Adj rsquare: 0.7520
- rmse: 0.0079

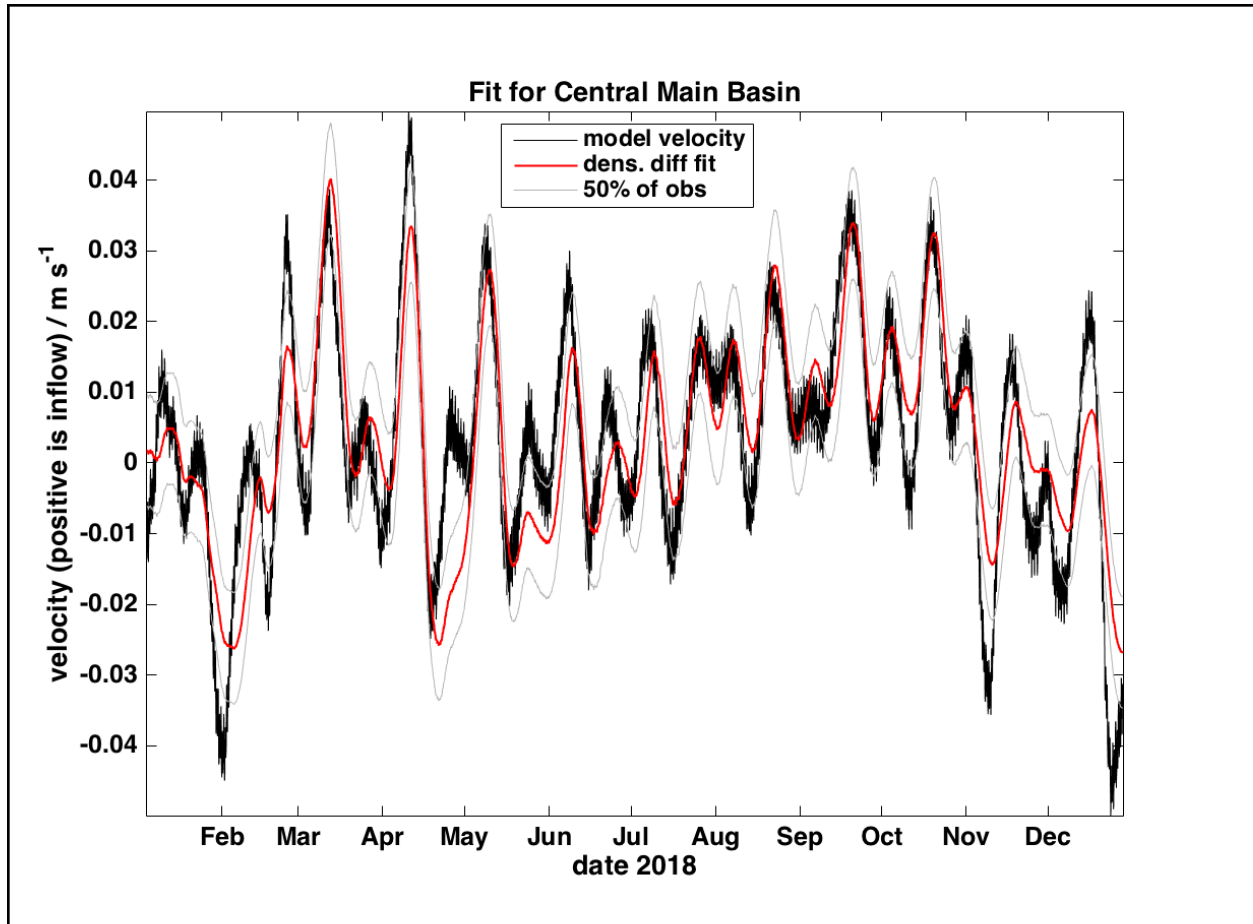


Figure 2: Time series plot of 7-day smoothed, deep inflow (40-172 m) mid-channel in the north central Main Basin LiveOcean model (black) and cubic fit from ORCA location model density differences (red). The fit was lag adjusted by 1 day where (oddly) changes in density differences *followed* velocity changes in the model time series.

Comparison of ORCA and LiveOcean model density differences for Main Basin.

Given the robustness of this relationship in the LiveOcean model, a comparison of model density differences to those observed at the ORCA moorings gives further confidence that 1) differences in ORCA mooring observations can be used to give rough along-channel velocity

estimates, and, 2) in the opposite sense, given that density (or pressure) gradients are the main driver of the deep subtidal along-channel flow in the basins, LiveOcean velocities can be expected to be somewhat accurate. This is a useful result given the present lack of direct velocity observations.

The coverage for ORCA observations is not great in 2018, although enough to show fair agreement between the model and observations, with differences as high as 0.2 kg m^{-3} in some cases, with the model differences being smaller than in the observations. The comparison between Hansville and Hoodsport (vs. Hansville and Point Wells) is much better (Fig. 6), suggesting that possibly the model Main Basin density values at the depths of interest are too high for some reason.

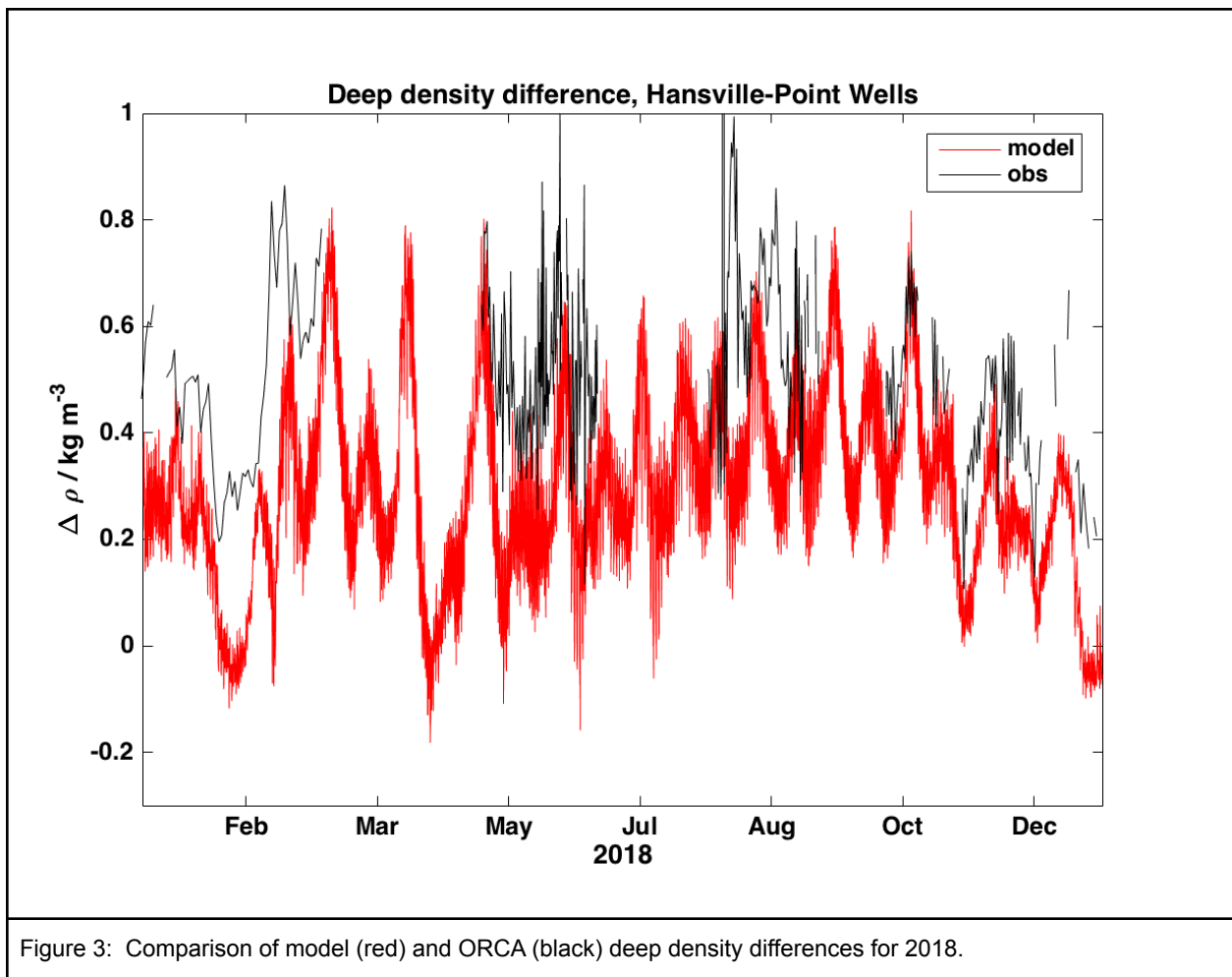
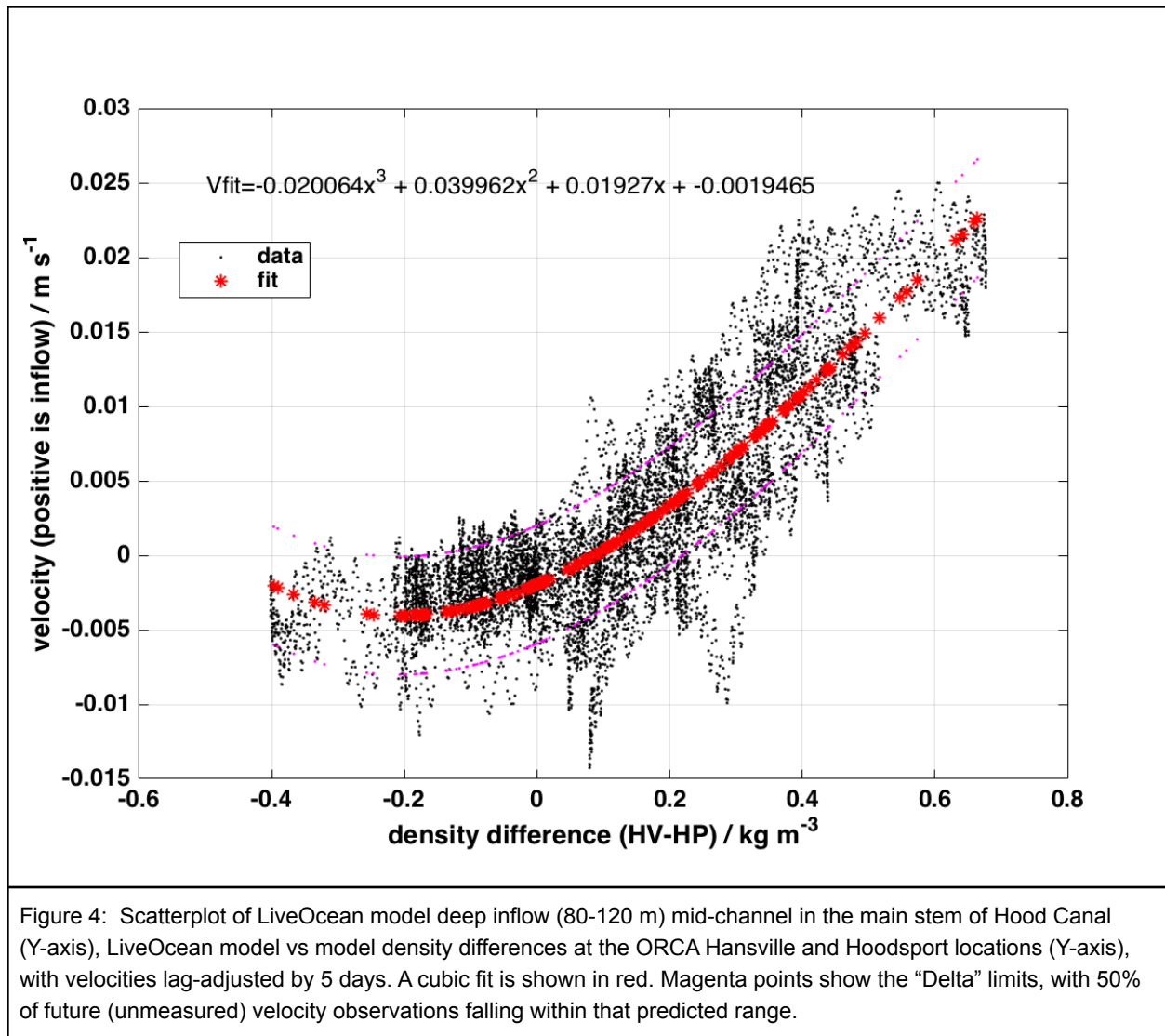


Figure 3: Comparison of model (red) and ORCA (black) deep density differences for 2018.

Hood Canal

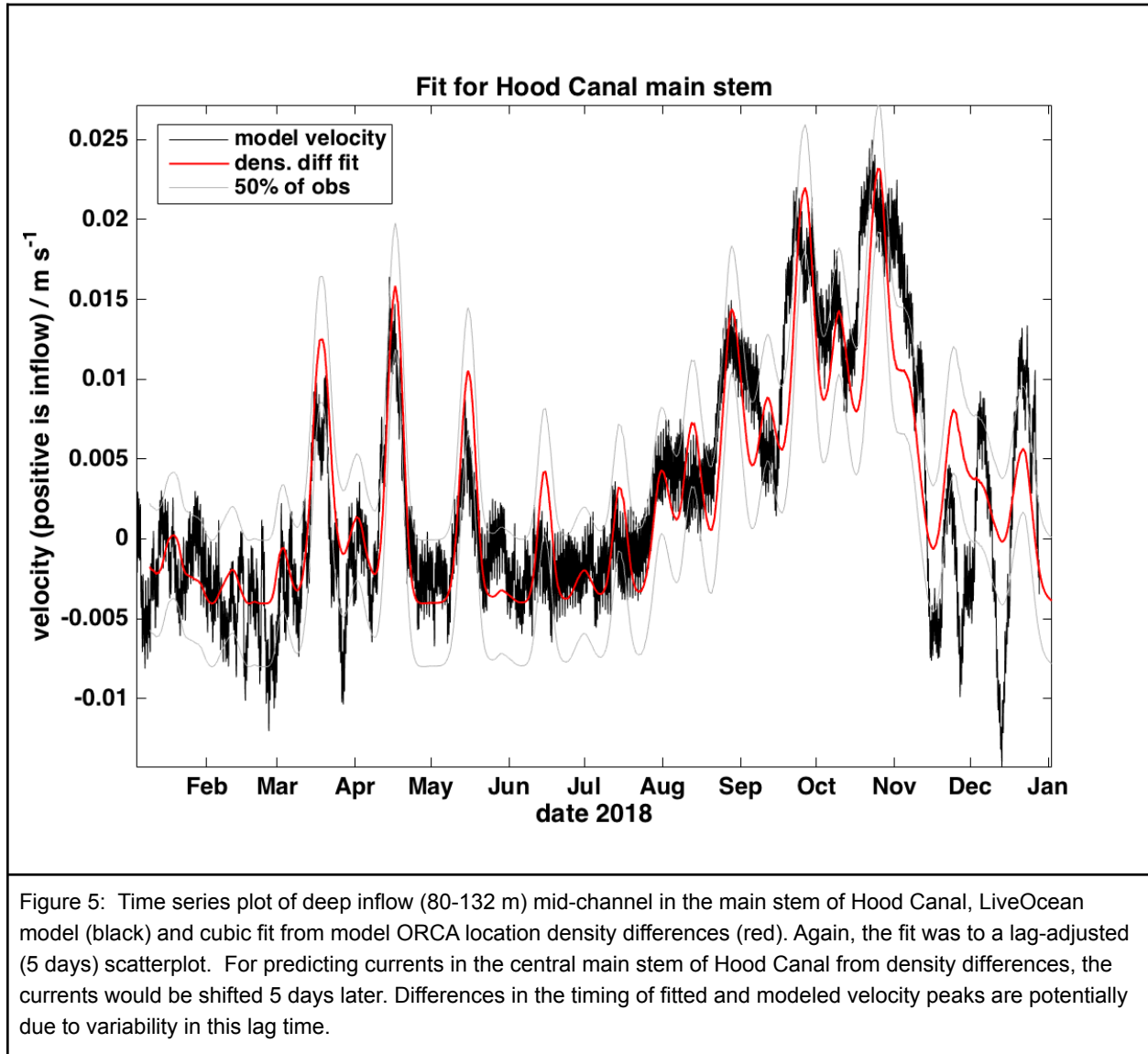
Unlike the Main Basin, the scatterplot shows a nonlinear relationship. Cubic fit works well. Quadratic fit gives inflow for times when Hansville density is *less* than HP density, which is unrealistic. This scatterplot is lag-corrected, with the flow response typically lagging the density difference by 5 days. This lag does change throughout the year in the 2018 model output, but it is almost always 5+- 2 days.



Goodness of fit statistics for the Hood Canal:

- sse: 0.1327
- rsquare: 0.7234
- Degrees of freedom: 8469 (but hourly values boxcar averaged over 7 days).
- Adj rsquare: 0.7233

- rmse: 0.0040



Note the fortnightly variability of density differences and velocities, largely driven by tidal mixing over Admiralty Inlet. This is a dominant feature in observations as well. Here are goodness of fit statistics.

Comparison of ORCA and LiveOcean model density differences for Hood Canal.

* compare very well for the 2018 Hoodsport and Hansville data that we have (Fig. 6).

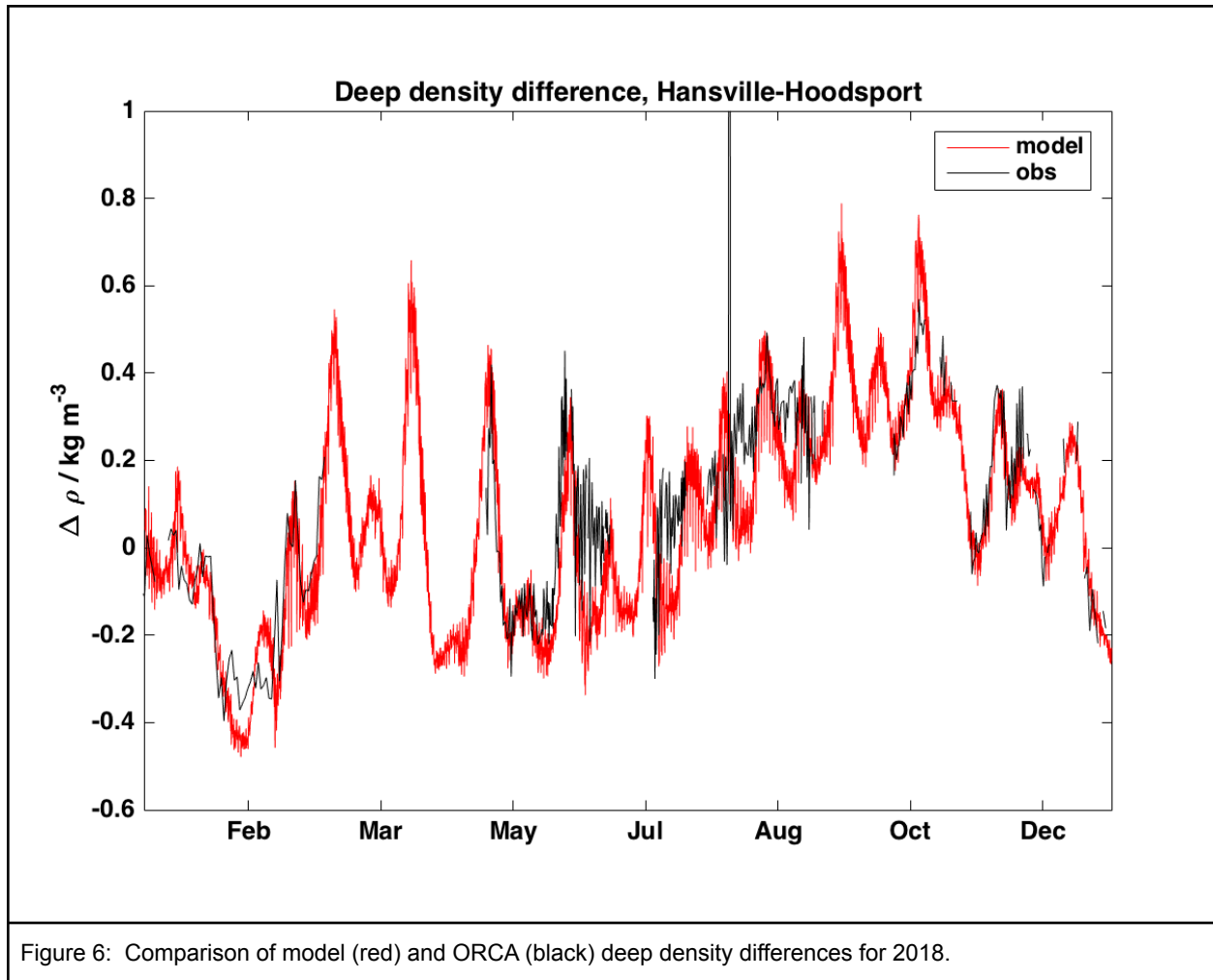


Figure 6: Comparison of model (red) and ORCA (black) deep density differences for 2018.

South Sound

Although there is a clear relationship between the lateral density difference between the Point Wells and Carr Inlet locations and deep inflow into South Sound (25 m to the bottom at 65 m), there is significantly more scatter than in the other two locations and a weaker relationship. This may be due in part to the greater distance between locations with an intervening sill (Tacoma Narrows) and the irregular geography of channel shape, etc. compared to Hood Canal. However, because the fit describes almost half of the variance of velocity in the model, we still believe it is a valuable metric, although not as robust as the other two locations.

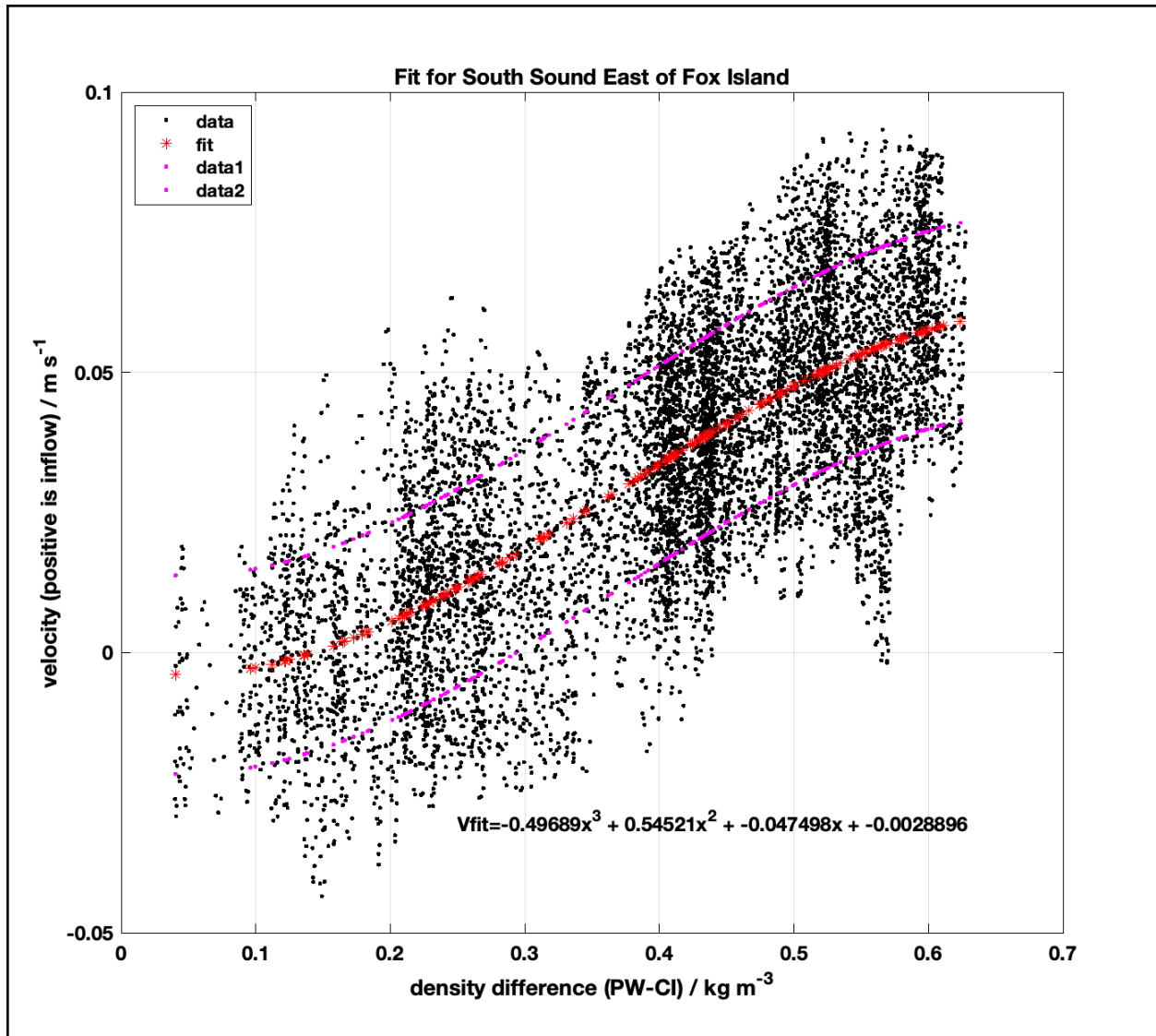


Figure 7: Scatterplot of LiveOcean model inflow (25-65 m) mid-channel east of Fox Island in South Sound (Y-axis), LiveOcean model vs model density differences at the ORCA Point Wells and Carr Inlet locations (Y-axis) with a lag of 2.2 days *of velocity leading density*. A cubic fit is shown in red. Magenta points show the “Delta” limits, with 50% of future (unmeasured) velocity observations falling within that predicted range.

Goodness of fit statistics for the Carr Inlet:

- sse: 2.6559
- rsquare: 0.5329
- Degrees of freedom: 8535 (but hourly values boxcar averaged over 7 days).
- Adj rsquare: 0.5327
- rmse: 0.0176

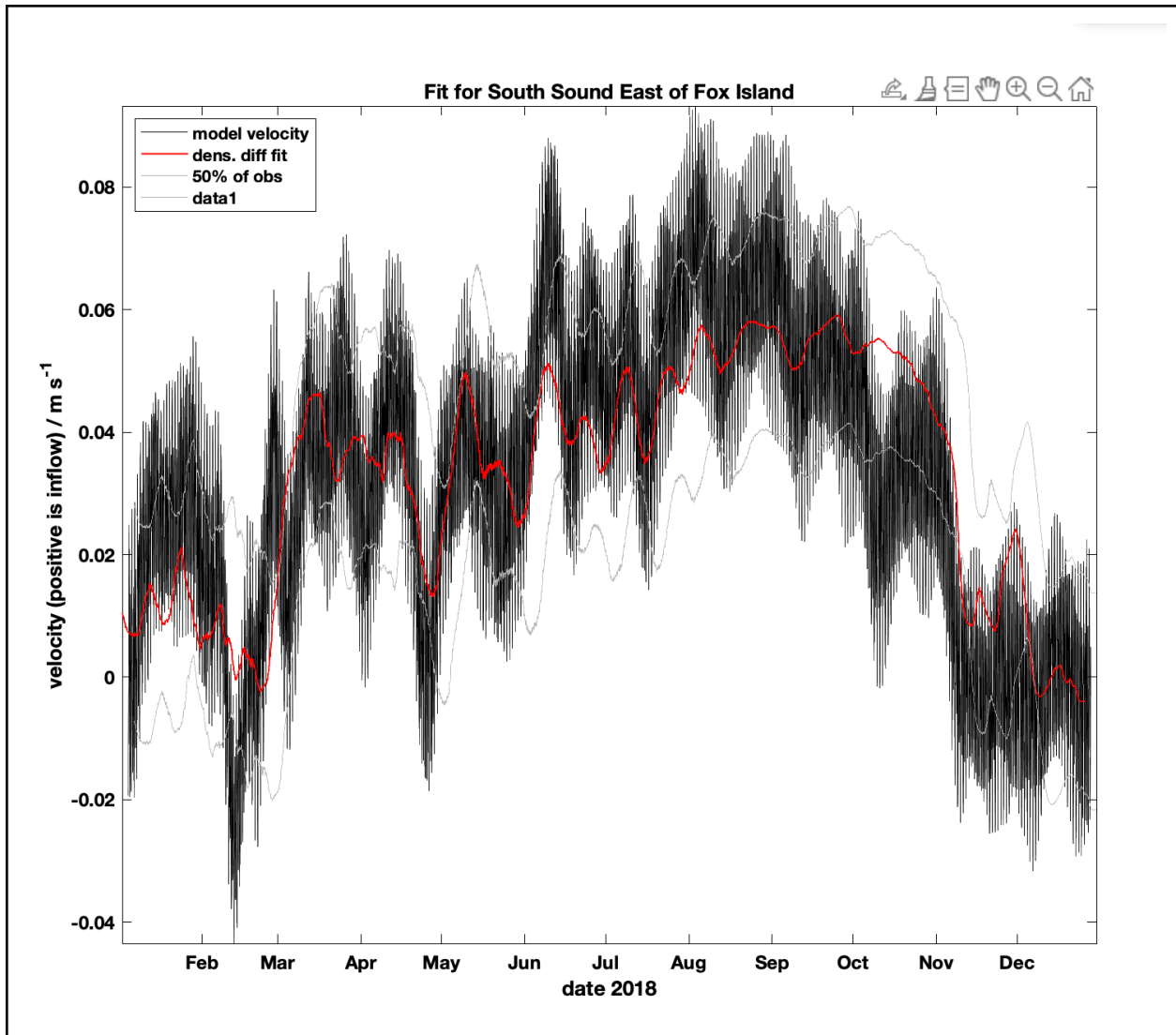


Figure 8: Time series of inflow (25-65 m) mid-channel east of Fox Island in South Sound. LiveOcean model (black) and cubic fit from model ORCA location density differences (red). This fit was carried out with a lag of 2.2 days of *velocity* leading *density*, which achieved the highest r-square values. This may be due to density values increasing at locations in the Main Basin closer to Carr Inlet (e.g. north of Tacoma Narrows in East Sound) prior to changes in the central Main Basin.

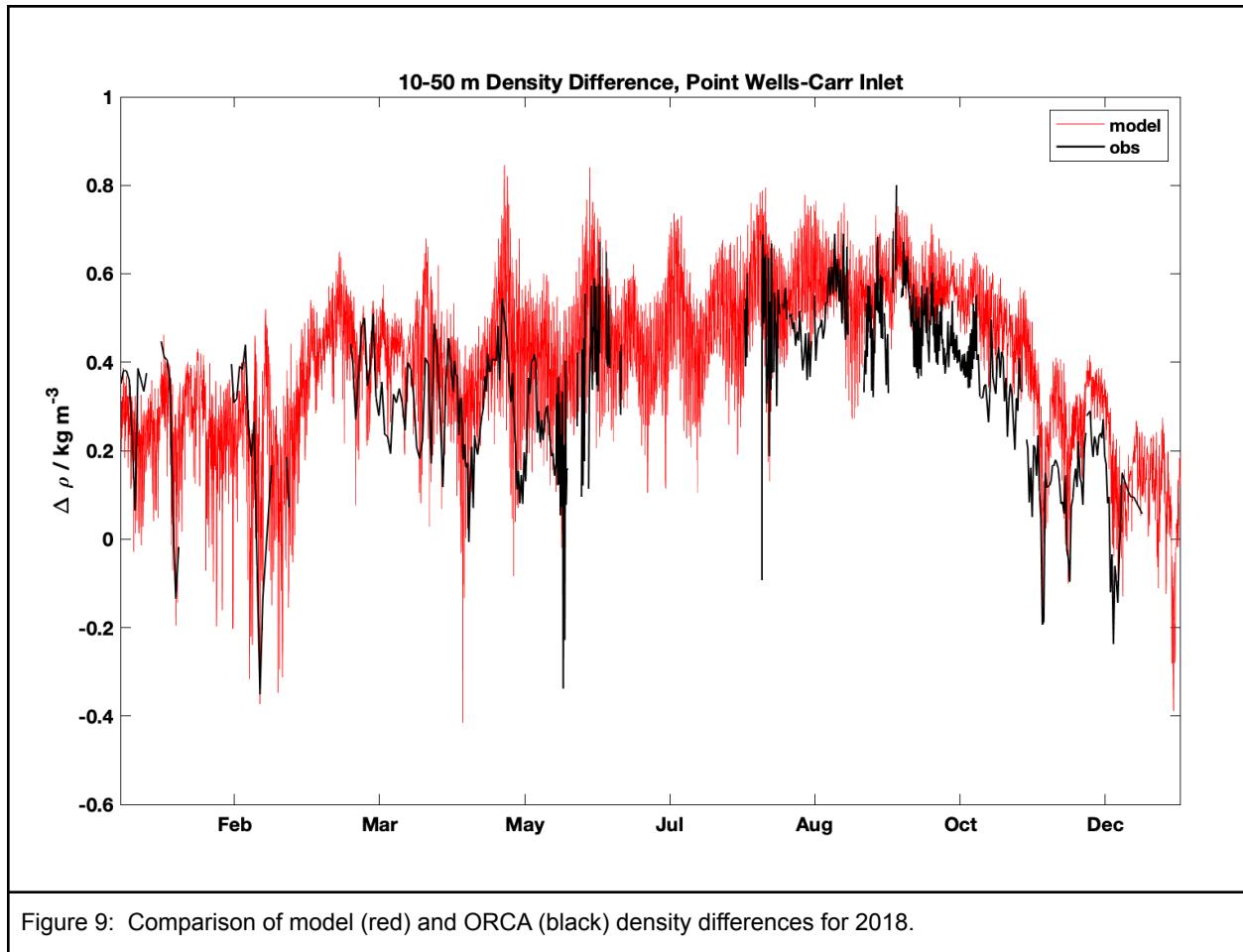


Figure 9: Comparison of model (red) and ORCA (black) density differences for 2018.

Older COOPs comparisons:

1) Limited coverage of ORCA buoy densities for ~3-month summer ADCP records in 2015 and 2016.

>Hansville-Point Wells (2015) for mid-PS Basin stations (PUG1503, PUG1511). Coverage poor, unable to obtain statistical relationship.

>Hansville-Point Wells (2016) for Possession Sound station (PUG1605). Coverage fair, decent statistical relationship. Why DID it fail during the ~1 week timeframe??

>Hansville-Hoodspout (2016) for Hood Canal (PUG1602), Coverage fair, fair statistical relationship.

>Point Wells-Carr (2016) for South Sound (PUG1532), Coverage poor, unable to determine statistical relationship.

2) Alternate approach:

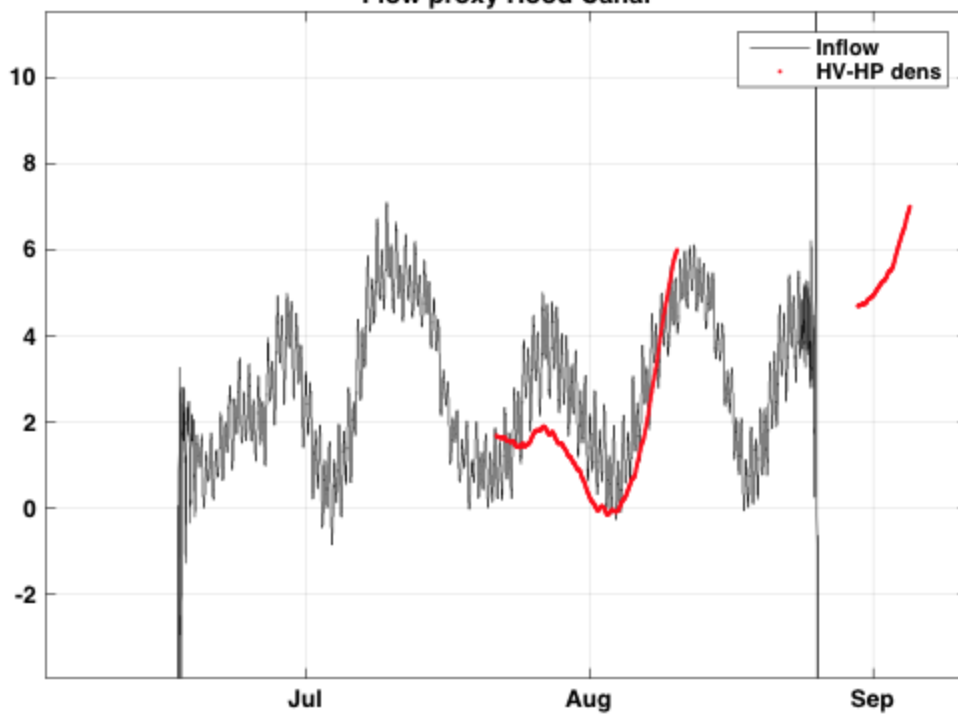
a) look at relationships in LiveOcean model -- e.g. density differences and ~7-day flow tendency.

b) if the above holds, then USE the present ORCA mooring data BASED on those relationships? Possibly can constrain some of them with observations.

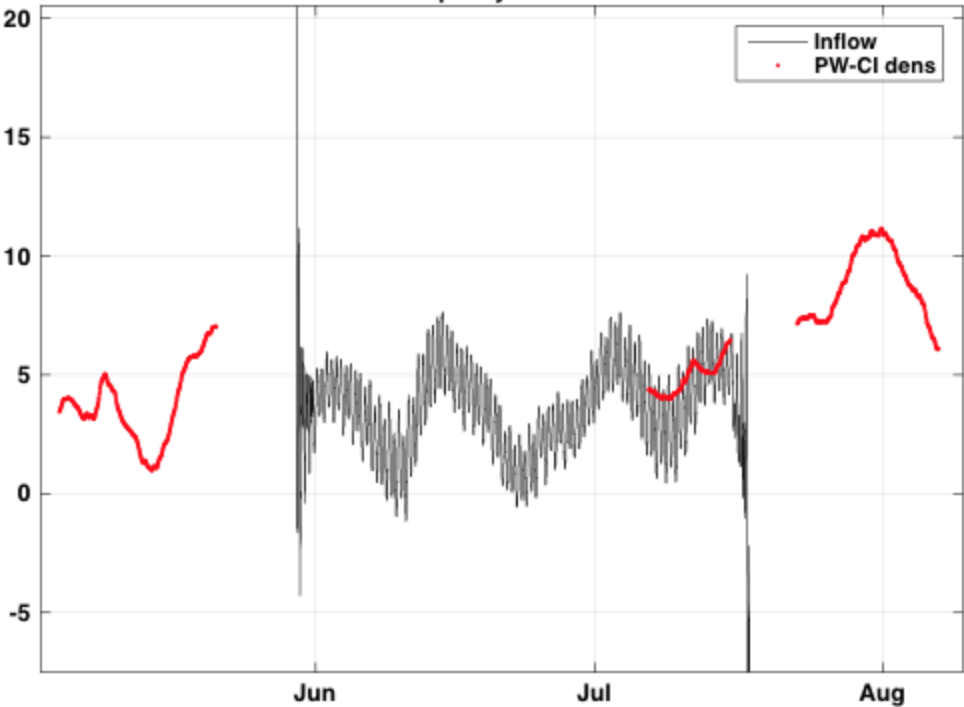
c) for Hood Canal, try to avoid seiche motions by looking *north* of sill?

***NOTE, the model started in 2017, so *after* COOPS stations were finished ...**

Flow proxy Hood Canal



Flow proxy Carr Inlet



Flow proxy Possession Sound

