On sampling biases arising from insufficient bottle flushing

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Collection of representative water samples using carousel bottles is important for accurately determining biological and chemical gradients. The development of more technologically advanced instrumentation and sampling apparatus causes sampling package size to increase and bottle "soak times" to decrease, increasing the probability that insufficient bottle flushing will produce biased results. Qualitative evidence from various expeditions suggest that insufficient flushing may be a problem. Here we report on multiple field experiments to better quantify the errors that can arise from insufficient bottle flushing. Our experiments suggest that soak times of more than 2 minutes are sometimes required to collect a representative sample.

Background

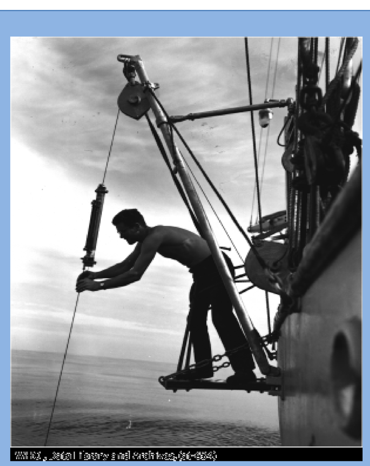

Figure 1. Only a few decades ago, water sampling consisted of attaching bottles in a series on a hydrowire. These bottle usually had relatively long "soaking times".

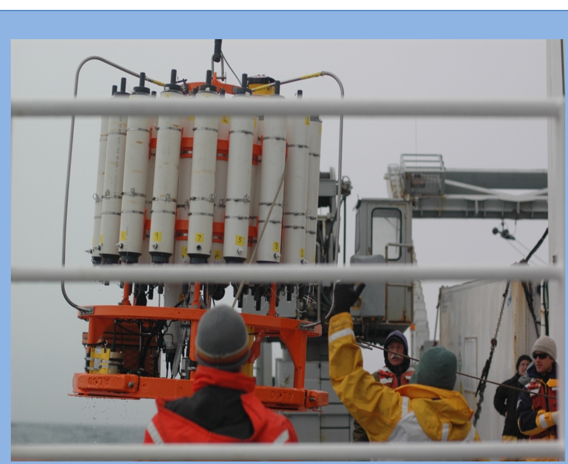

Figure 2. Today we see large CTD/rosette systems that add to the flushing problem, because of short soak times and because they entrain water as they are raised through the water column (courtesy of AWI).

Weiss Flushing Model

$$\ln \frac{C}{C_0} = -\frac{A}{V} * Z$$

Equation 1. C_0 and C are the initial and final concentrations, respectively of the tracer in the bottle. V is the volume of a sample bottle and A is the area of the bottle opening. Z is the distance the bottle travels. Based on this model, V/A defines the characteristic flushing length over which C_0 is reduced by 1/*e* (Weiss, 1971).

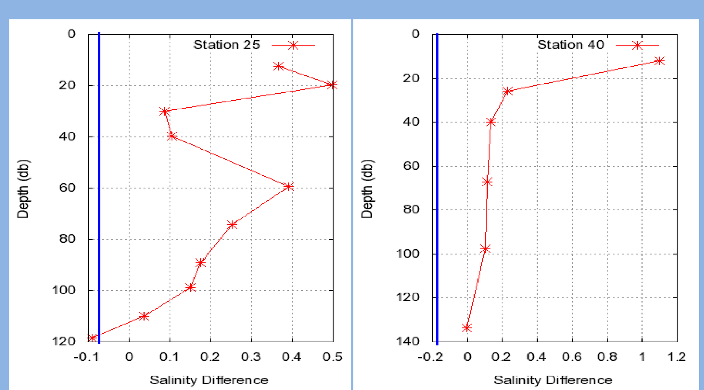

Figure 3. Bottle salinity minus CTD salinity. Two historical examples of profiles where sufficient flushing time was not allowed and the water sample salinity values were moderately to significantly deviant from the CTD salinity.

Table 1. Calculations of flushing length (V/A) based on Weiss' model and his experimentally determined flushing lengths (λ) values.

Bottle Type	Volume (L)	V/A (m)	λ (m)
Nansen-normal valves	1.3	3.23	2.80
Nansen-restricted ports	1.3	4.96	4.37
Lexan Plastic Nansen	2.3	2.32	1.96
Niskin-1.7 L	1.7	0.42	0.49
Niskin-5 L	5.0	1.23	1.62
Niskin 30 L, 7.2 cm diam. port	30	7.37	12.7
Niskin 30 L, 12.7 cm diam. port	30	2.37	2.40

Experiments

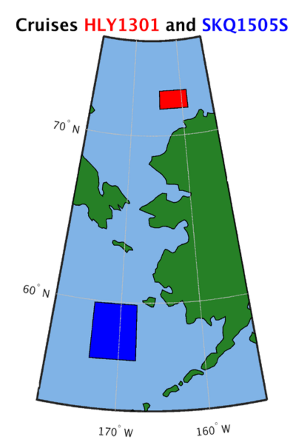

Figure 4. Map of the field locations

Figure 5. USCGC Healy

Figure 6. R/V Sikuliaq

We conducted bottle flushing experiments in the Bering and Chukchi Seas (Fig. 3) aboard the USCGC Healy (Fig. 4), red and the R/V Sikuliaq, blue (Fig. 5), respectively. Both areas were mostly ice covered and the seas were relatively calm. There were two general types of experiments: 1. tripping bottles in succession at the same depth for a period no greater than 280s (time series) and 2. tripping the bottles while the rosette continued to move (tripping on the fly). We also performed "Yo-Yo" experiments, but are only just beginning to examine these results.

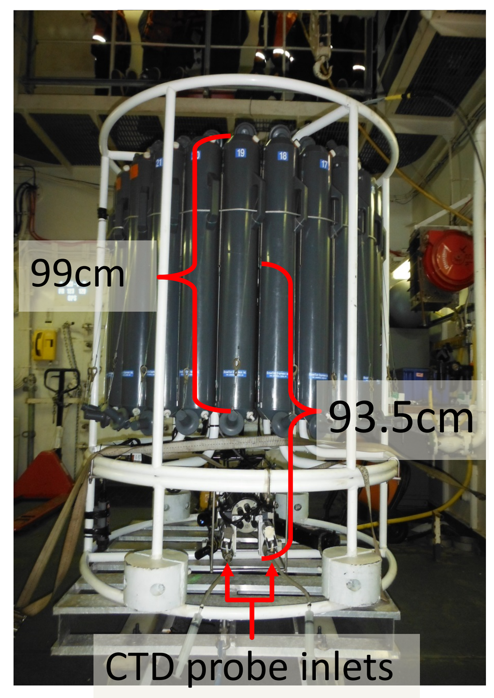

Figure 7. CTD/Rosette system aboard the USCGC Healy. It was equipped with 24 12L Niskin bottles and a large suite of sensors.

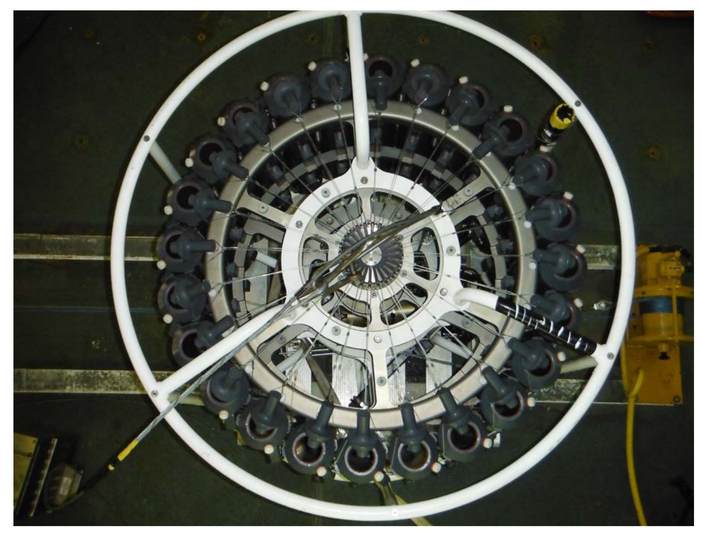

Figure 8. Top view of the rosette system aboard the USCGC Healy. Bottle caps display various degrees of obstruction.

Results

Time Series

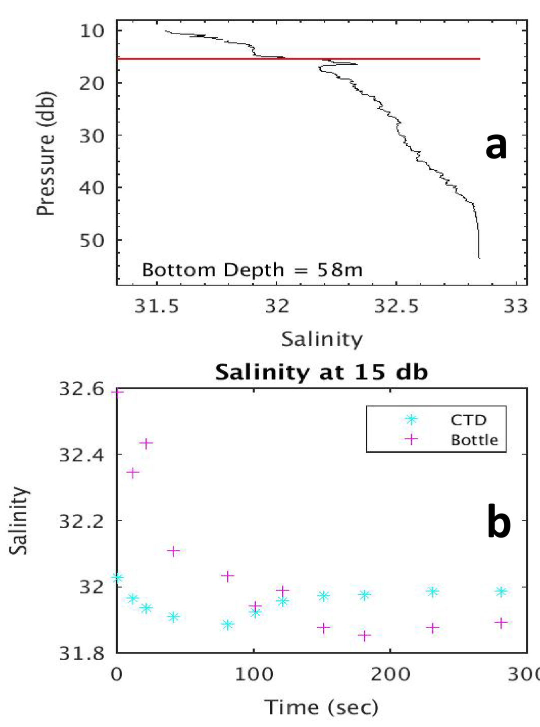

Figure 9. HLY1301 Station 00501 time series experiment. **a)** Upcast CTD salinity profile . The red horizontal line represents the bottle tripping depth. **b)** Salinity values from the bottles and the CTD at 15db over a period of 280s.

CTD Downcast and Upcast

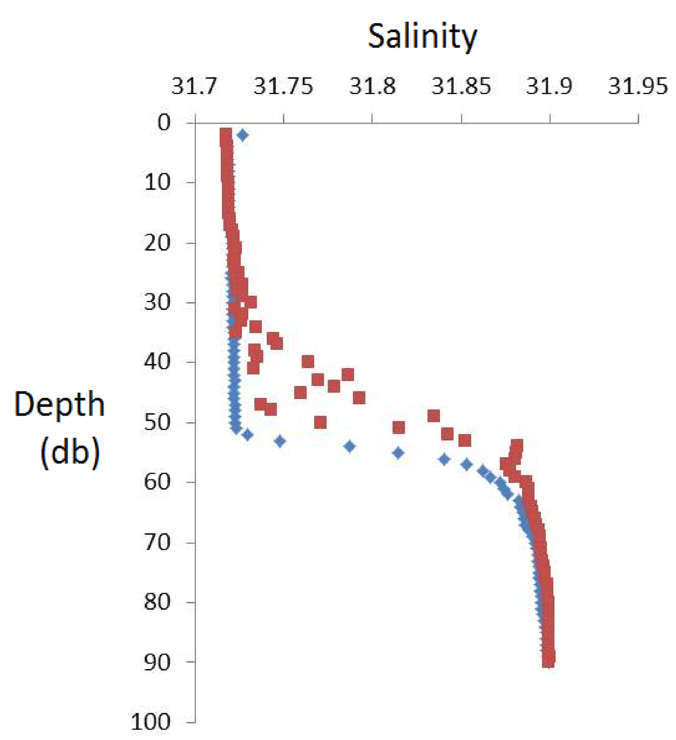

Figure 11. These CTD upcast (red) and downcast (blue) data made in a two layered system give a good idea of the potential importance of entrainment by CTD/rosette systems.

Trip on the Fly

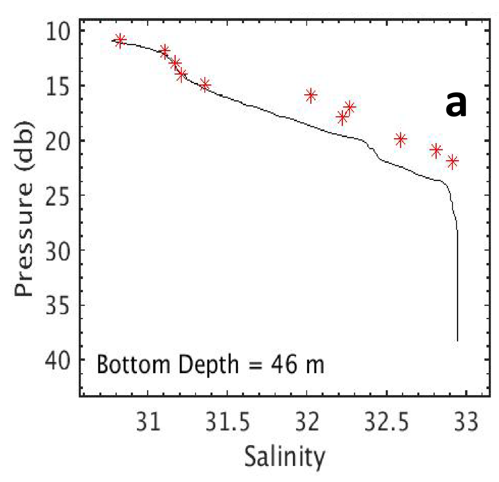

Figure 10. HLY1301 Station 02201 tripping on the fly. Entrainment falsely enhances the agreement between these upcast CTD and bottle salinity values, see Fig 11. CTD salinity profile represented by the black line and the red asterisks represent the bottle values.

Discussion

Weiss showed that bottle flushing can be an issue for individually deployed bottles (not part of a carousel).

Our results show that the employment of large CTD/rosette systems can exacerbate the flushing problem investigated by Weiss in four ways:

1. **The bottles employed often have large volumes and relatively small openings resulting in relatively large flushing lengths (V/A).**
2. **The bottles are often cocked in a haphazard way (see Fig. 8) resulting in even longer flushing lengths.**
3. **The bottles are often tripped with minimal soak times as soon as the CTD/rosette reaches the desired depth.**
4. **Entrainment of water by the CTD/rosette package lengthens the required soak times.**

Although our results for the "tripping on the fly" experiments sometimes show relatively good agreement between the CTD and bottle salinity values, we believe that such agreement may often be false because of entrainment. For this reason, we are currently re-examining these data by comparing the upcast bottle salinities with the downcast CTD profiles.

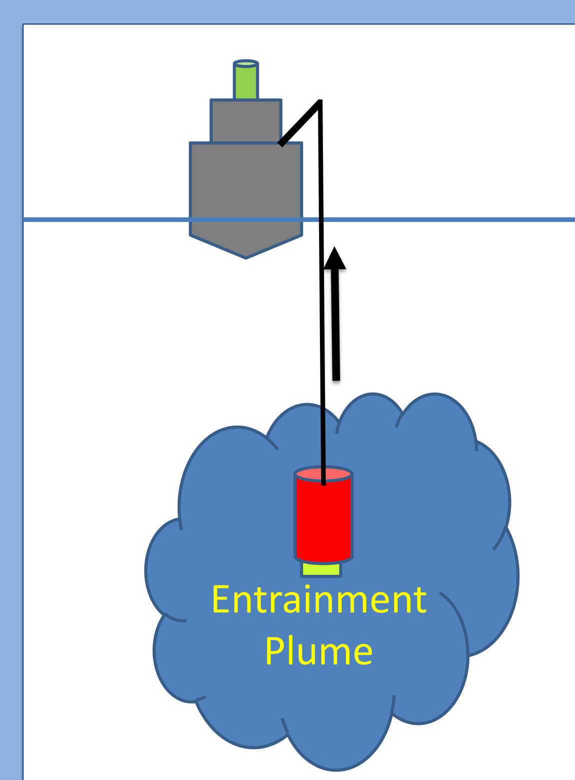

Figure 12. Cartoon showing water entrainment around the CTD/rosette system as it is raised through the water column.

Reference

R.F. Weiss. 1971. Flushing characteristics of oceanographic sampling bottles. Deep-Sea Research, Vol. 18. pp. 653 – 656.

Acknowledgements

We wish to express our profound thanks to all the people that helped with this research, to include Tom Weingartner, Victoria Coles, Lee Cooper, and the crew members and marine technicians aboard the USCGC Healy and R/V Sikuliaq.