Analysis of nature gas bubble in NETL High Pressure Water Tunnel (HPWT) experiment and its application to natural seeps.

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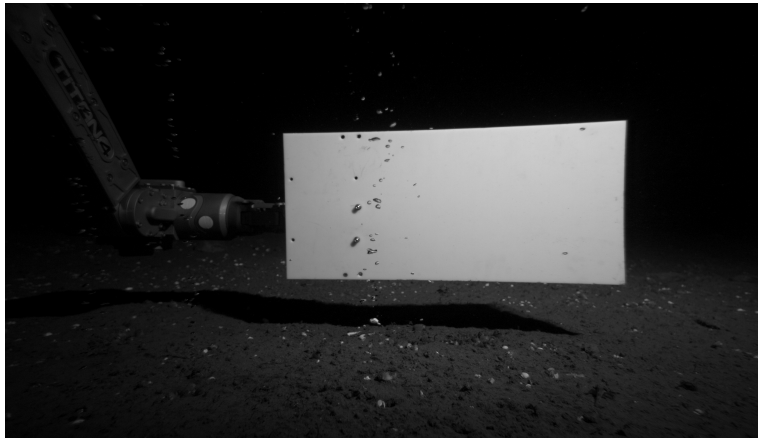
Problem Statements

Deepwater Horizon oil spill



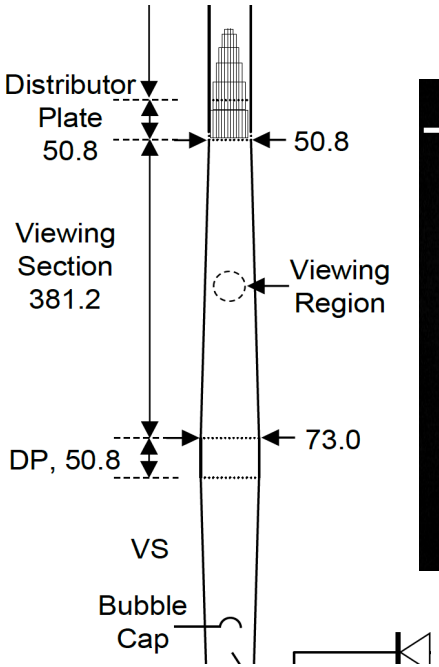
Natural Seeps, Hydrate Ridge, 780m depth

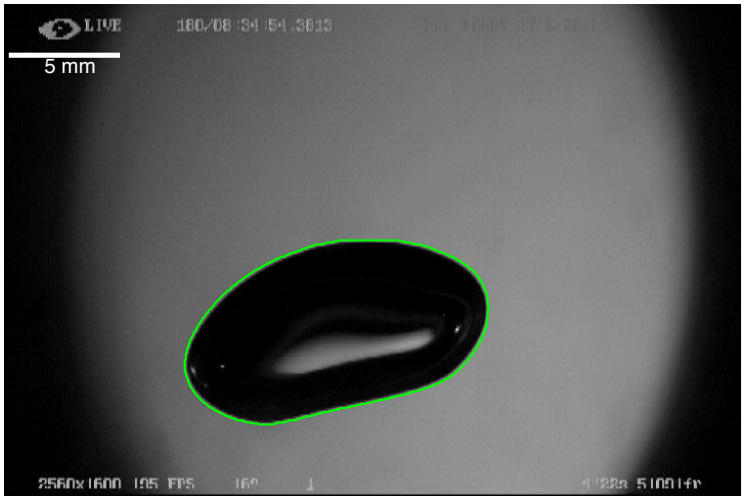
Limitation of Existing Natural Seep Models

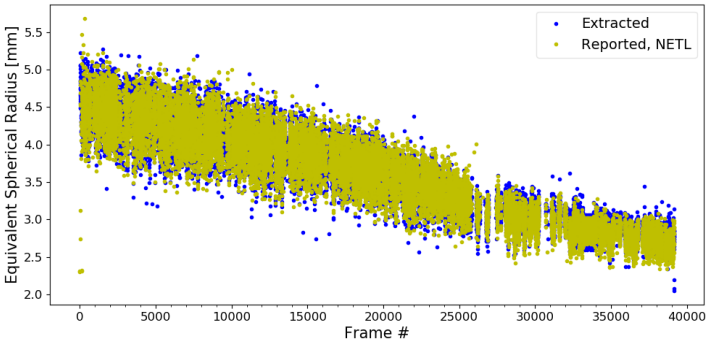
1. Uncertain what effect hydrate crystals and skins have on mass transfer rate
2. Uncertain what the primary mechanism of dissolution is, whether it is the gas or hydrate that is actually dissolving.

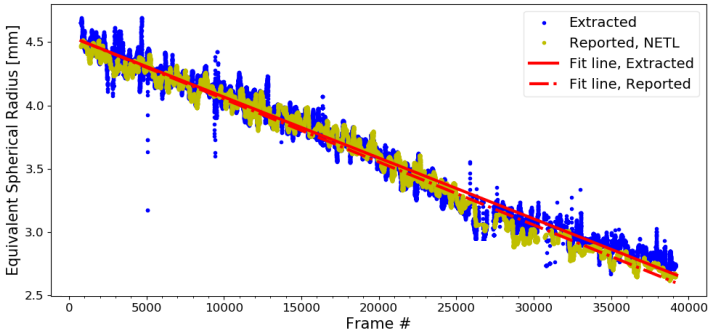
Submarine natural seeps present an **idealized system to study** the role of hydrates on bubble dynamics in situ in the deep ocean without the complication of a blowout plume.

NETL Experiment Result





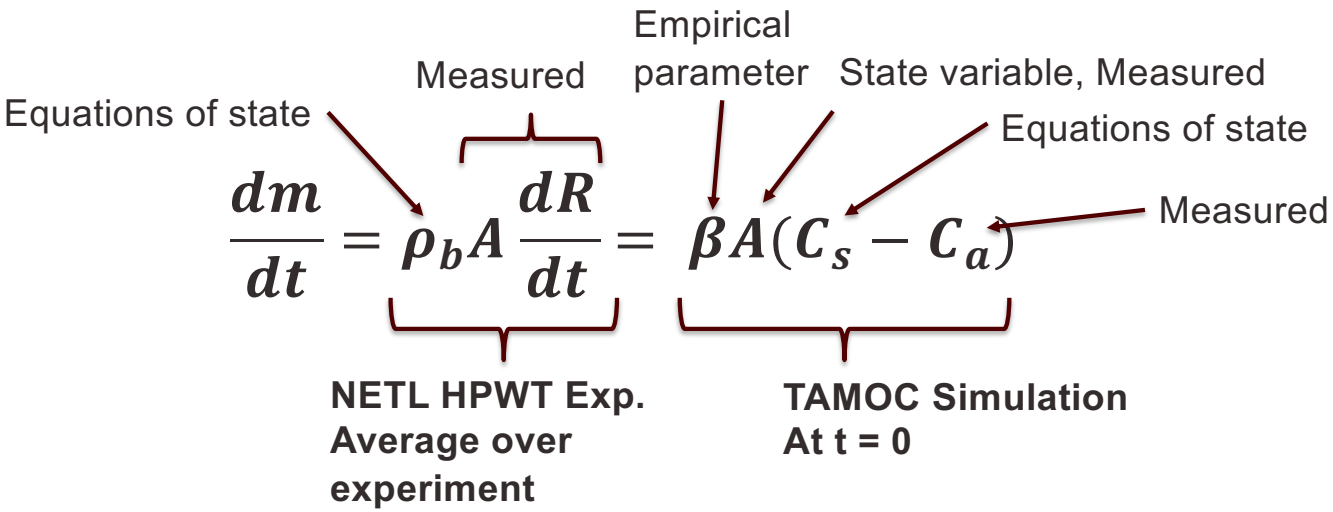




$R_e = \sqrt[3]{a^2 b}$, where a : major radius, b :minor radius

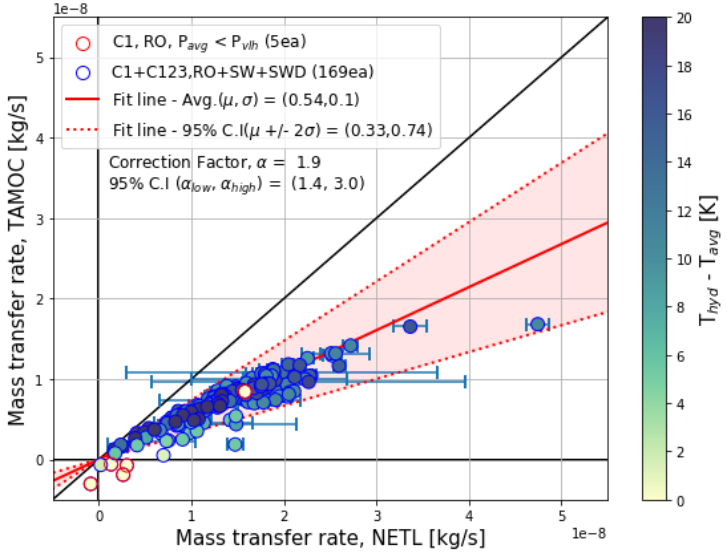
Resolution: 0.0224 mm/pixel

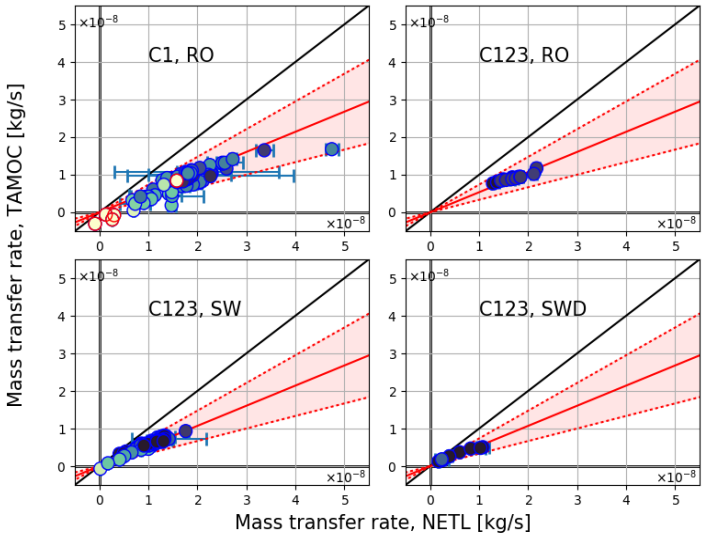
Model equations for surface-average dissolution of a bubble



- ρ_b: Bubble density
- β : Mass transfer coefficient
- A : Bubble surface area
- C_a: *A*mbient concentration in the water
- C_s: The concentration (or solubility) at the bubble/water interface

Determining Mass Transfer Coefficient (β) – Training dataset





$$\left.\frac{dm}{dt}\right|_{NETL} = \rho_b A \frac{dR_e}{dt}$$

$$\left.\frac{dm}{dt}\right|_{TAMOC} = \beta_{emp} \mathrm{A}(\mathrm{C_s} - \mathrm{C_a})$$

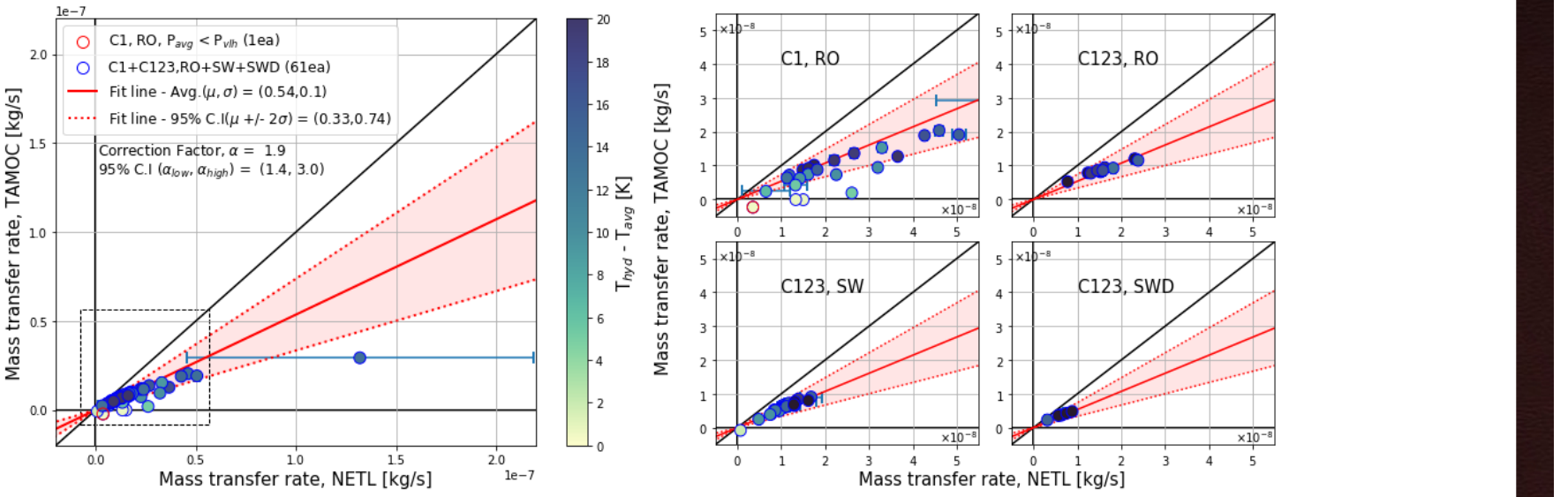
$$\beta_{emp} = -\frac{dm/dt}{\mathrm{A}(\mathrm{C_s} - \mathrm{C_a})}$$

$$\beta_{obs} = \alpha \beta_{emp}$$

$$\alpha = 1.9$$

$$\alpha_{95} = (1.4\ 3.0)$$

Determining Mass Transfer Coefficient (β) – Validation dataset



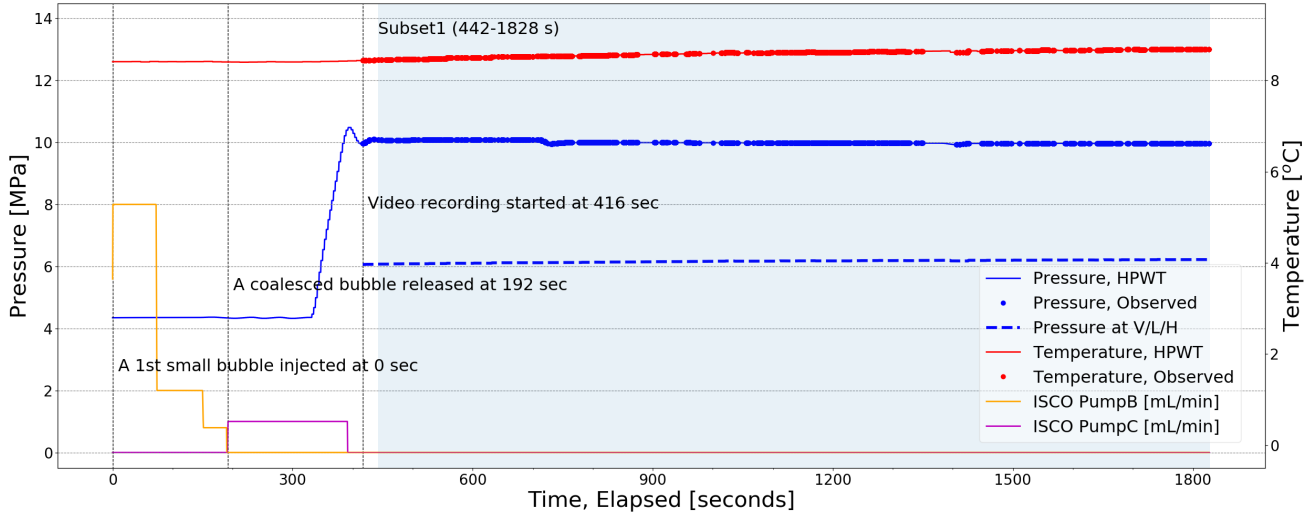
$$\%\ Error = \frac{1}{n}\sum_{i}^{n}\left|\frac{X_m^i - X_{cal}^i}{X_m^i}\right| * 100$$

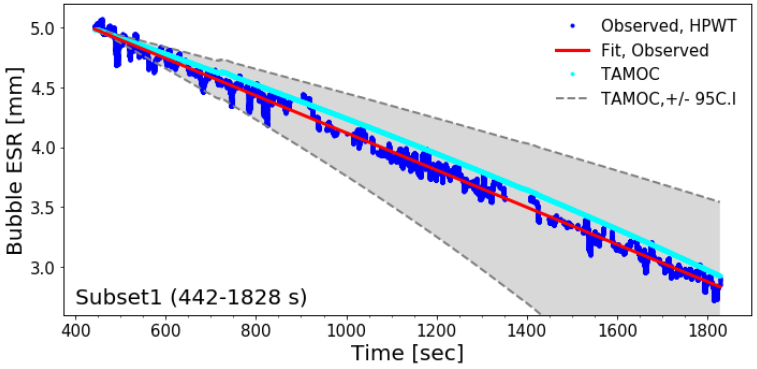
X_m : Observed mass transfer rate

X_{cal} : Mass transfer rate, computed using 1.9 β_{emp}

Case	% Error	Sample #
Training set	13.68	168
Validation set	15.03	58

CH4, RO water, No hydrate

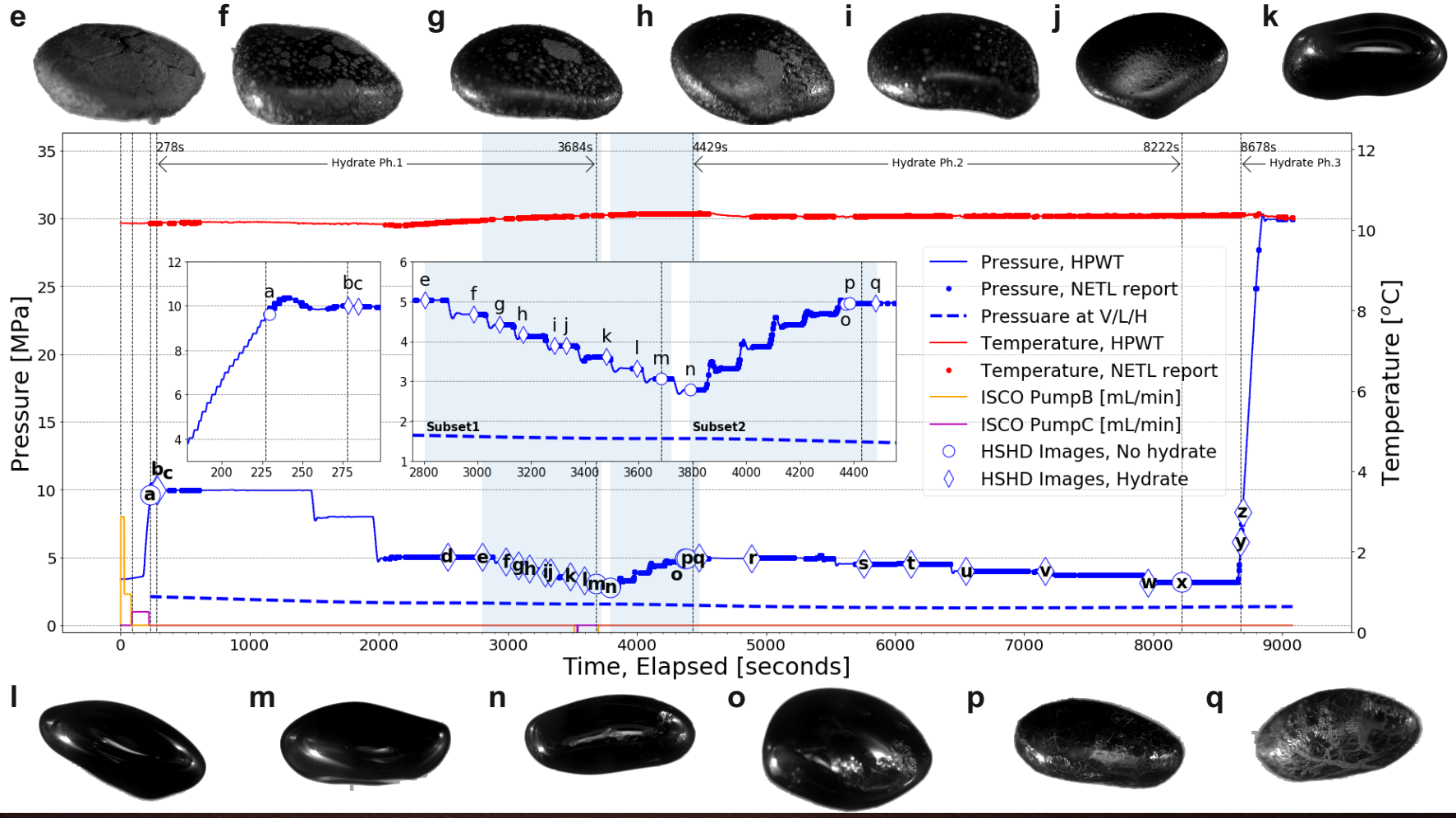




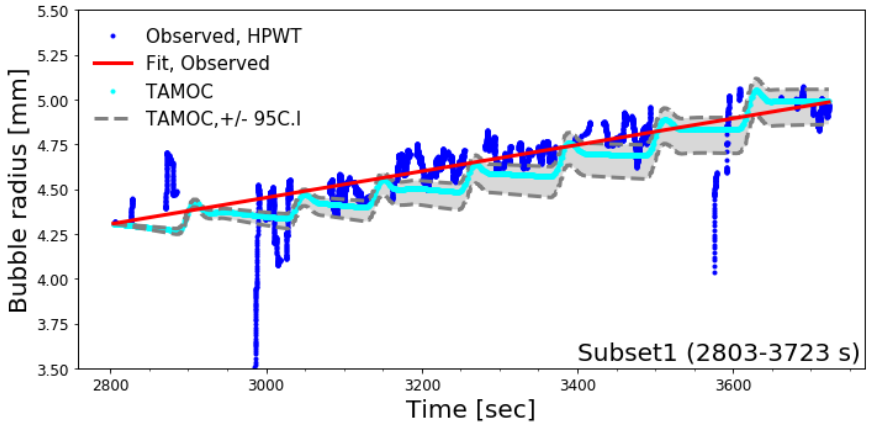
Y	*A*	*B*	*% Error*
dR/dt	TAMOC	Observed	4.66
R_e	TAMOC	Observed	0.51

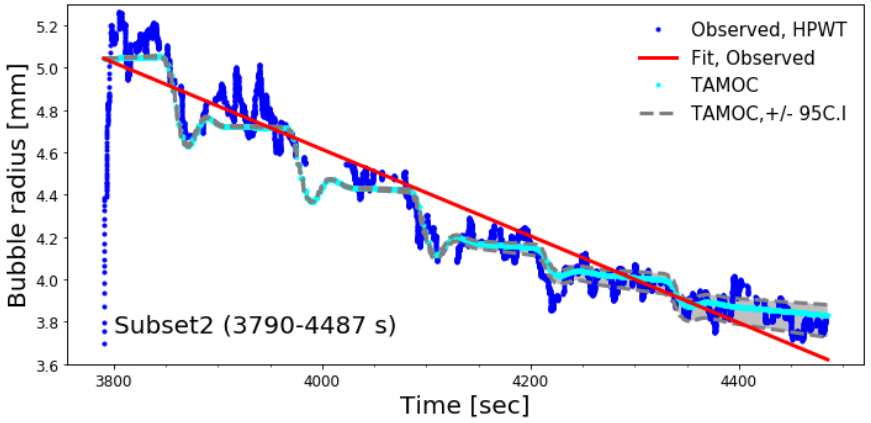
$$\%\ \boldsymbol{Error} = \left|\frac{\boldsymbol{Y_A - Y_B}}{\boldsymbol{Y_B}}\right| * \mathbf{100}$$

Dissolution rate with variable system pressure



Dissolution rate with variable system pressure

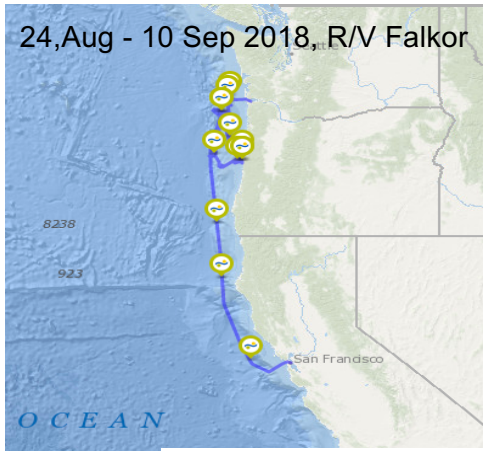


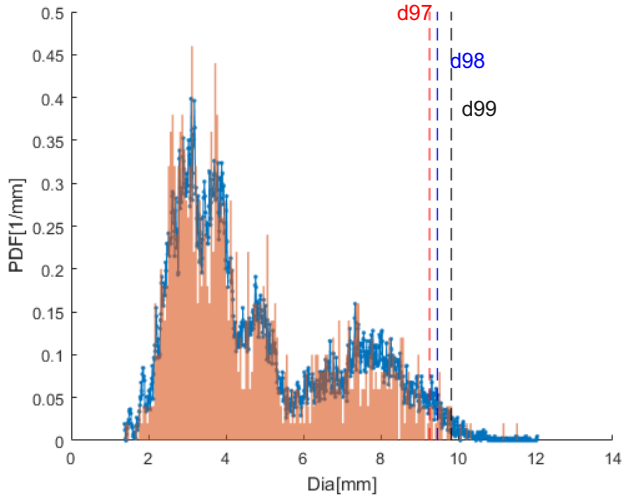


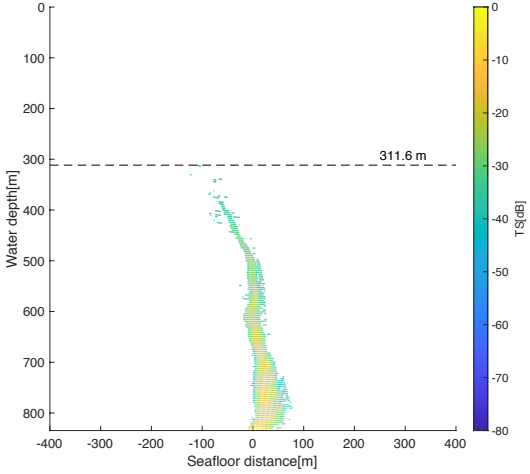
	Y	*A*	*B*	*% Error*
Subset 1	R_e	TAMOC	Observed	0.63
Subset 2	R_e	TAMOC	Observed	0.35

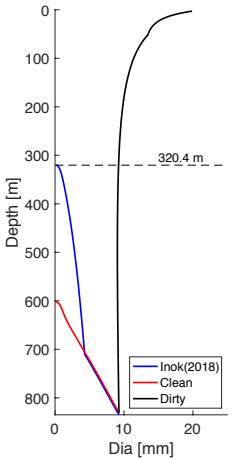
$$\%\ Error = \left|\frac{Y_A - Y_B}{Y_B}\right| * 100$$

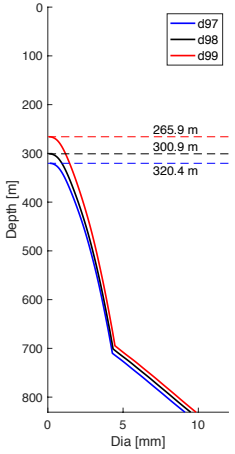
Application To the Field Data











Summary

- The entire database of NETL HPWT data was used to calibrate and validate our model, TAMOC for dissolution of methane and mixture (C1C2C3) bubbles at various ambient conditions (P, T, X, Salinity) with and without a hydrate skin on bubble surface.
- Dirty bubble mass transfer rates show the best agreement with the experiment data and the rates observed in the water tunnel were about 1.9 times larger than theoretical values.
- For Non hydrate case, the model tracks the bubble size correctly with $1.9\ \beta_{emp}$.
- For hydrate case, when the system pressure is changing, dirty bubble mass transfer rates with the solubility of methane gas agree with the experiment results.

Acknowledgement

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Reference

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