Trapping and Escape of Buoyant Plumes in Stratified Water

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Close Collaboration with **Roberto Camassa** and **Brian White**

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current grad: Claudia Falcon, Chung-Nan Tzou, Claudio Viotti, Duo Zhao
undergrads: Johnny Reis, Robert Overman, Bailey Watson, Casey Smith, David Nenon

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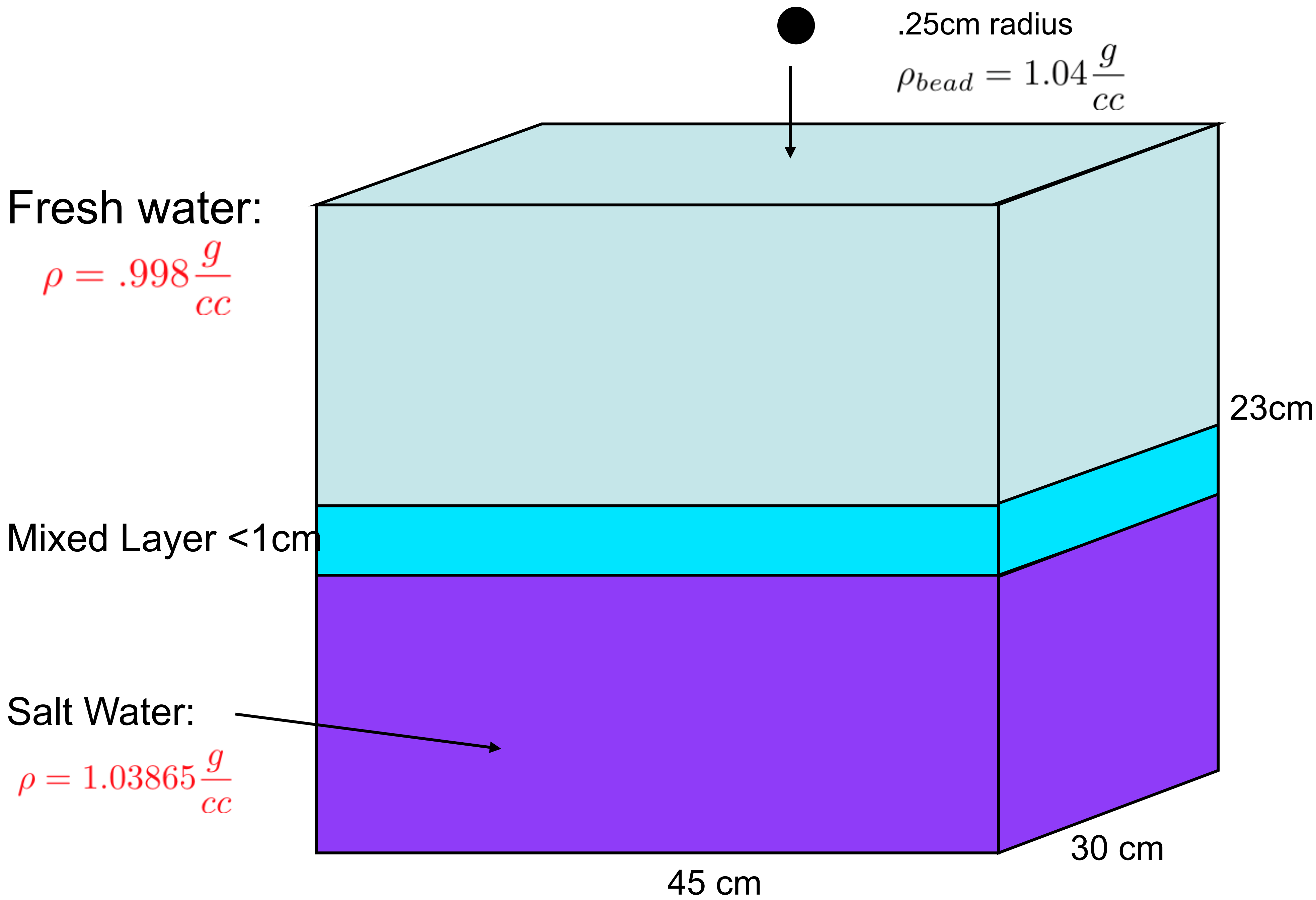
NSF CMG ARC-1025523
NSF DMS- 1009750

Experiment: Jets/Spheres in Stratified Fluids



Internal Splash

- 1.0396 g/cc
- Stratified
- Sphere heavier than fluid at all depths
- Fast Playback
- Re=300

Abaid,Adalsteinsson,Agyapong,McL Phys of Fluids 2004
Srdic-Mitrovic, Mohamed,Fernando, JFM 1999 (no bounce)

1.0385g/cc

For keynote with movies: See pink-lady.amath.unc.edu/~rmm/sost

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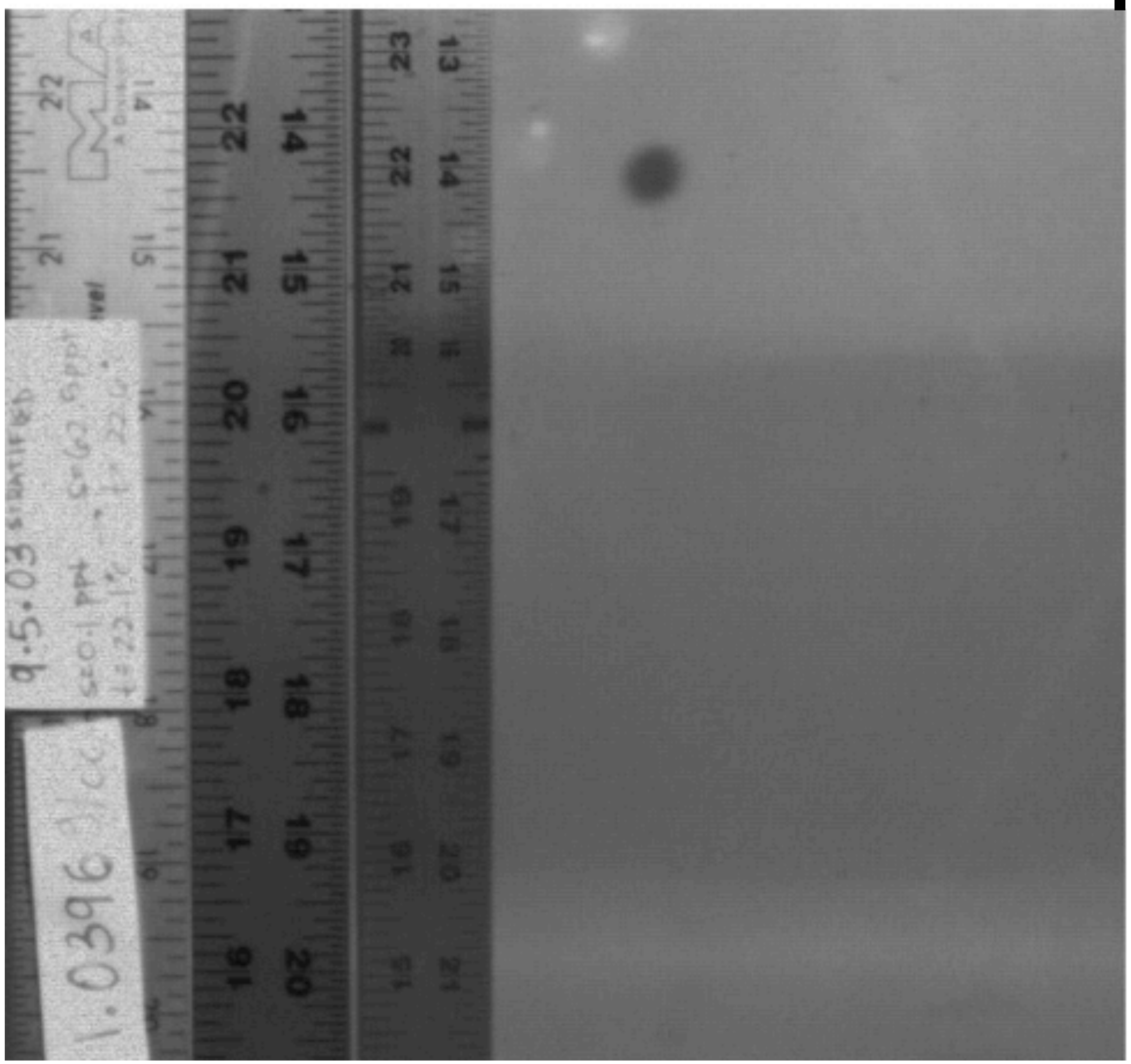

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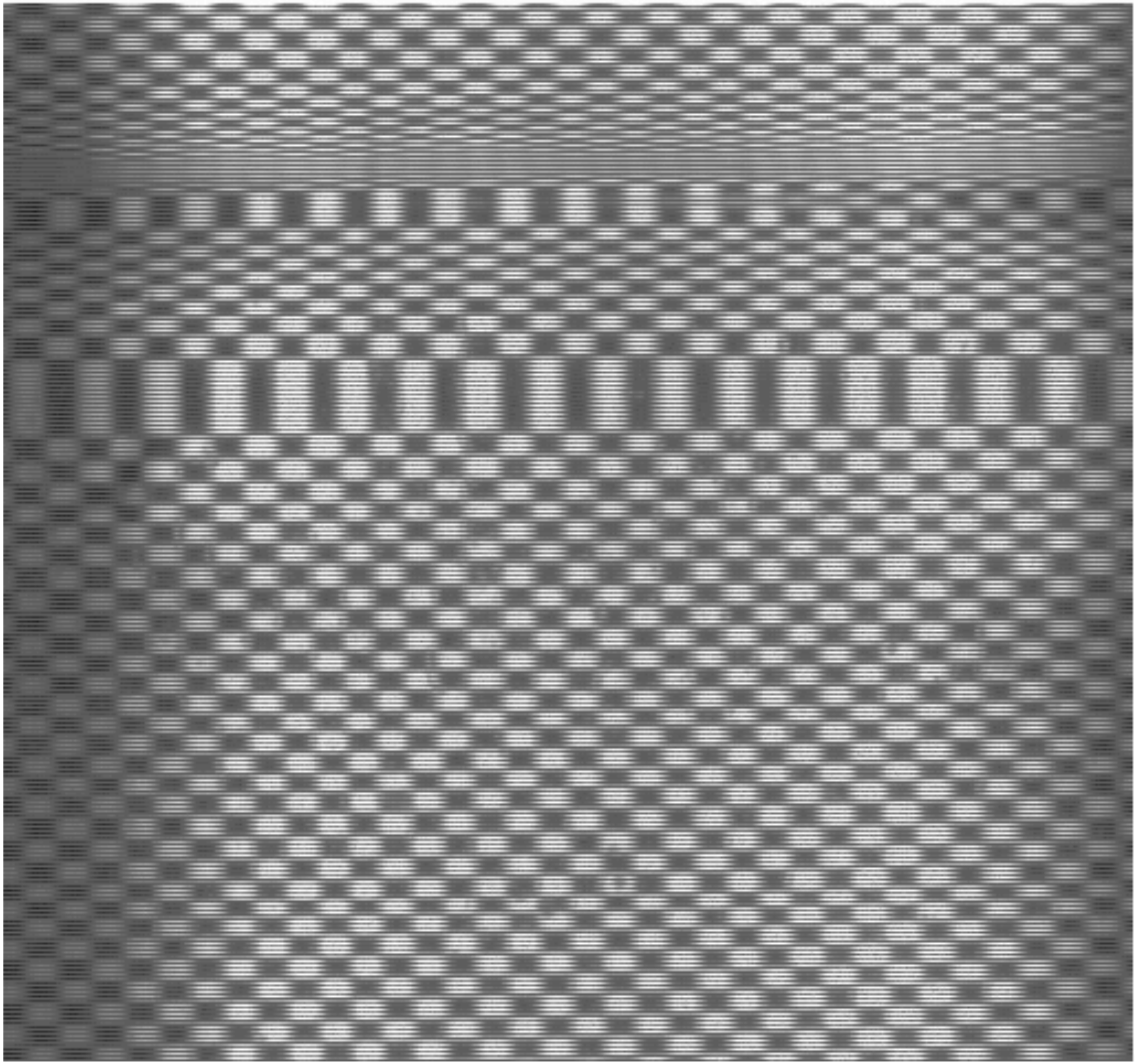

Left: low speed untreated oil, right: high speed+dispersant

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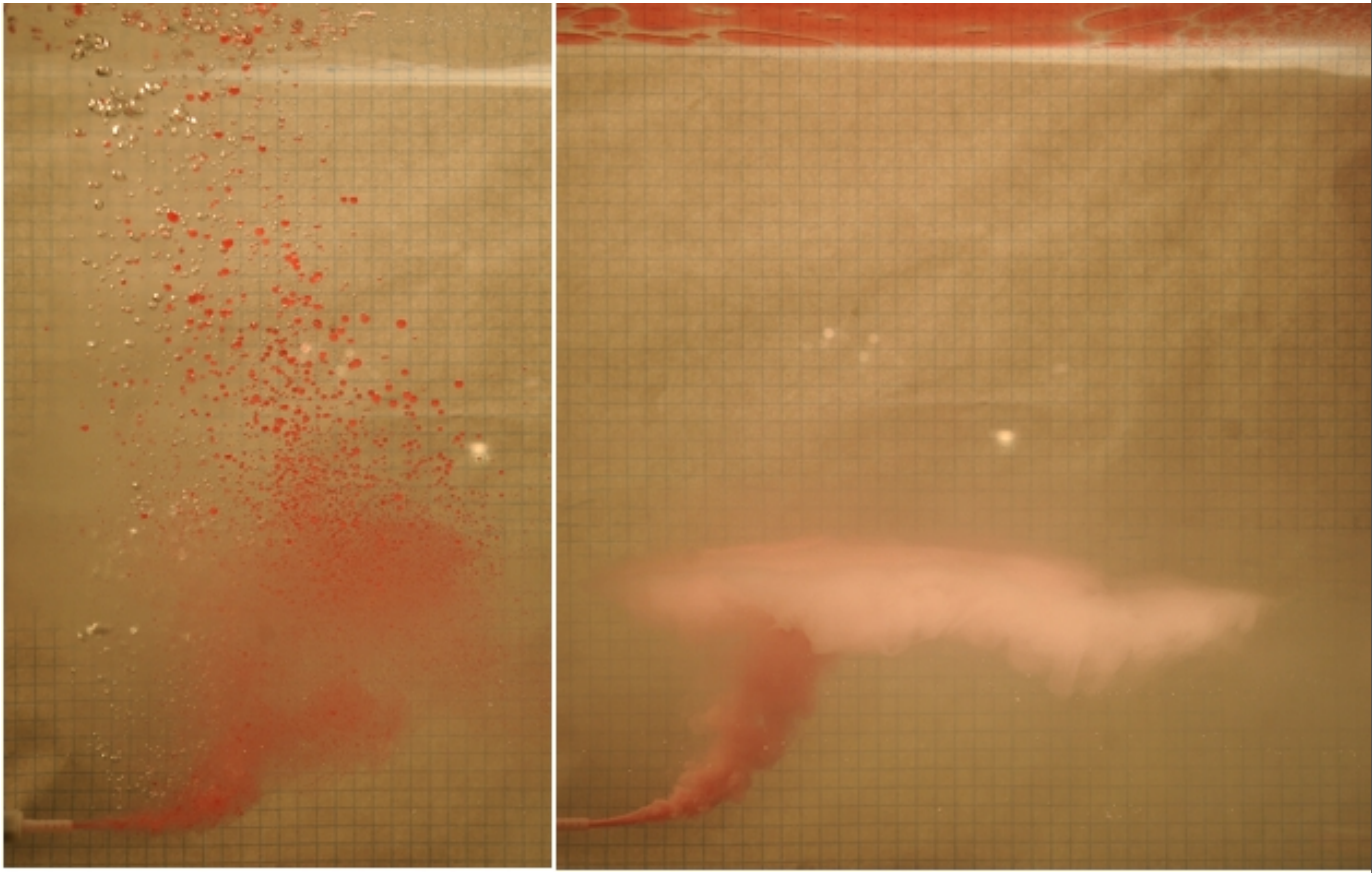
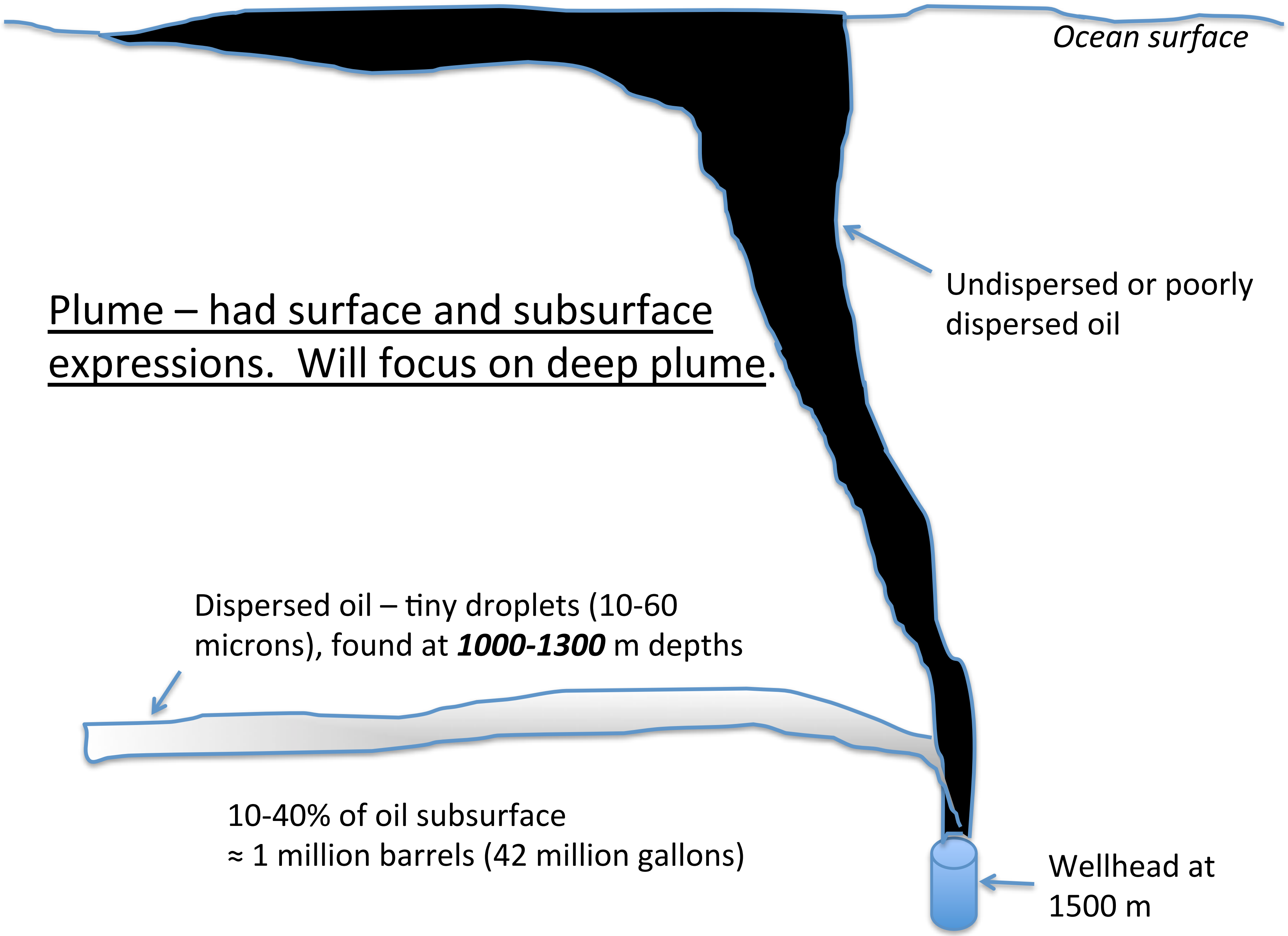
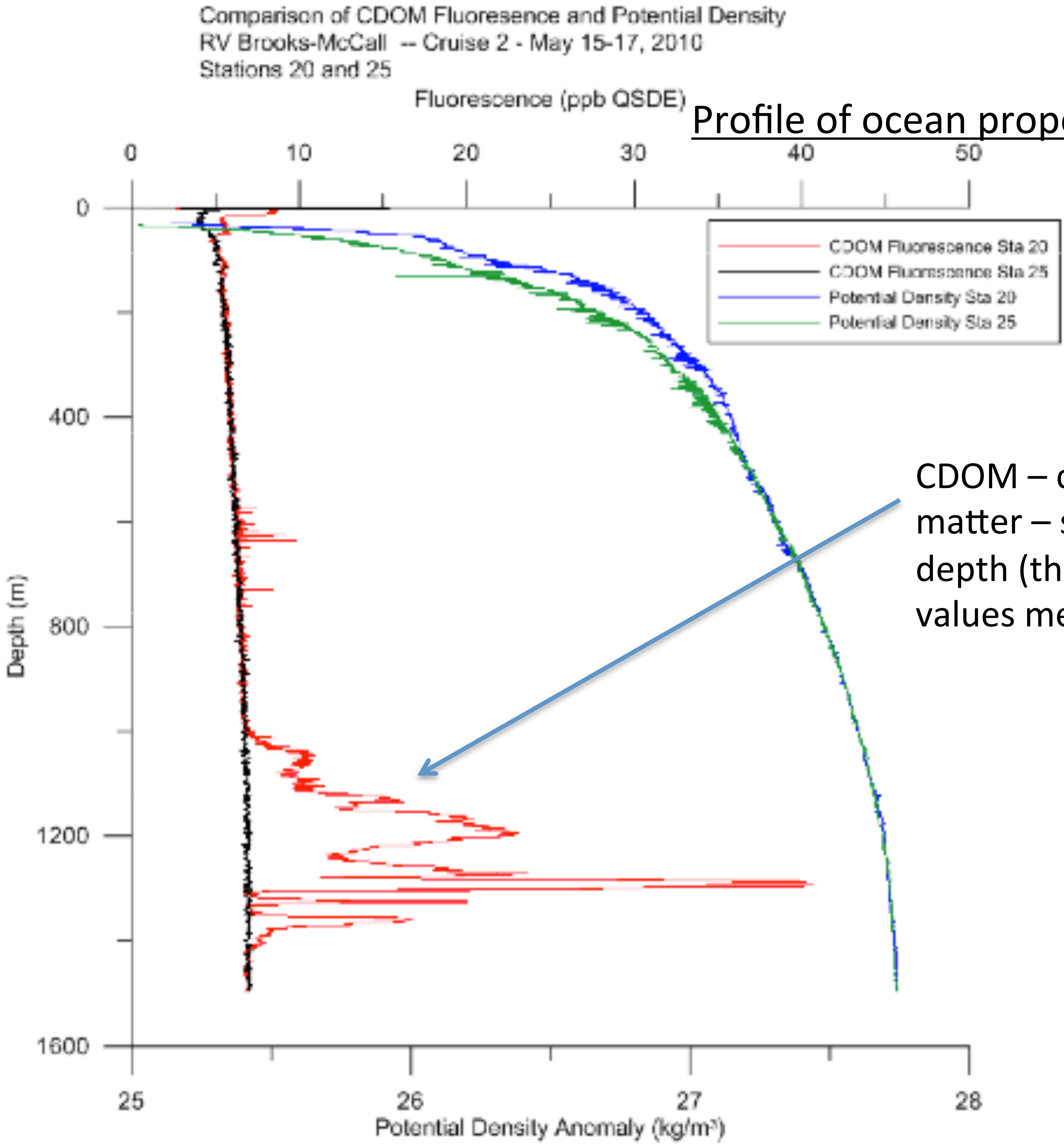


<u>Plume – had surface and subsurface expressions. Will focus on deep plume</u>.



Slide: from **Harvey Seim, Marine Sciences, UNC**

Profile of ocean properties collected with CTD



CDOM – colored dissolved organic matter – showed obvious ***anomaly*** at depth (this profile shows the largest values measured).

JAG, 2010

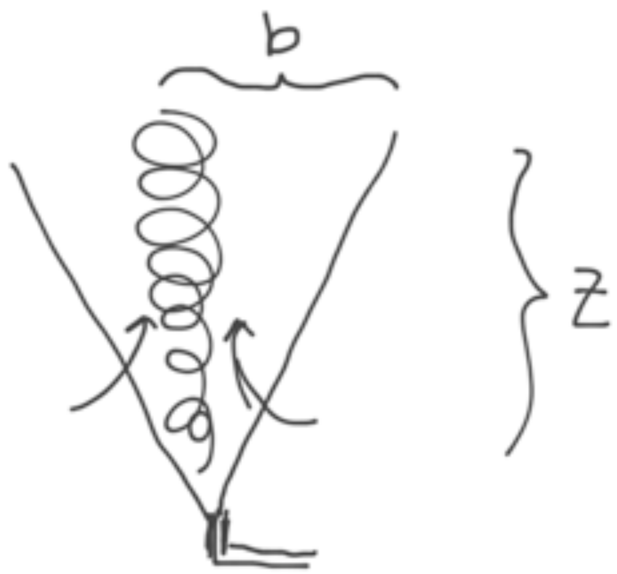
Slide: from **Harvey Seim, Marine Sciences, UNC**

Integral Models: Morton, Taylor, Turner, 1953

$$\frac{d(b^2 w)}{dz} = 2\alpha b w,$$

$$\frac{d(b^2 w^2)}{dz} = 2g\lambda^2 b^2 \theta,$$

$$\frac{d(b^2 w \theta)}{dz} = -\frac{1+\lambda^2}{\lambda^2}\frac{d\epsilon}{dz} b^2 w$$

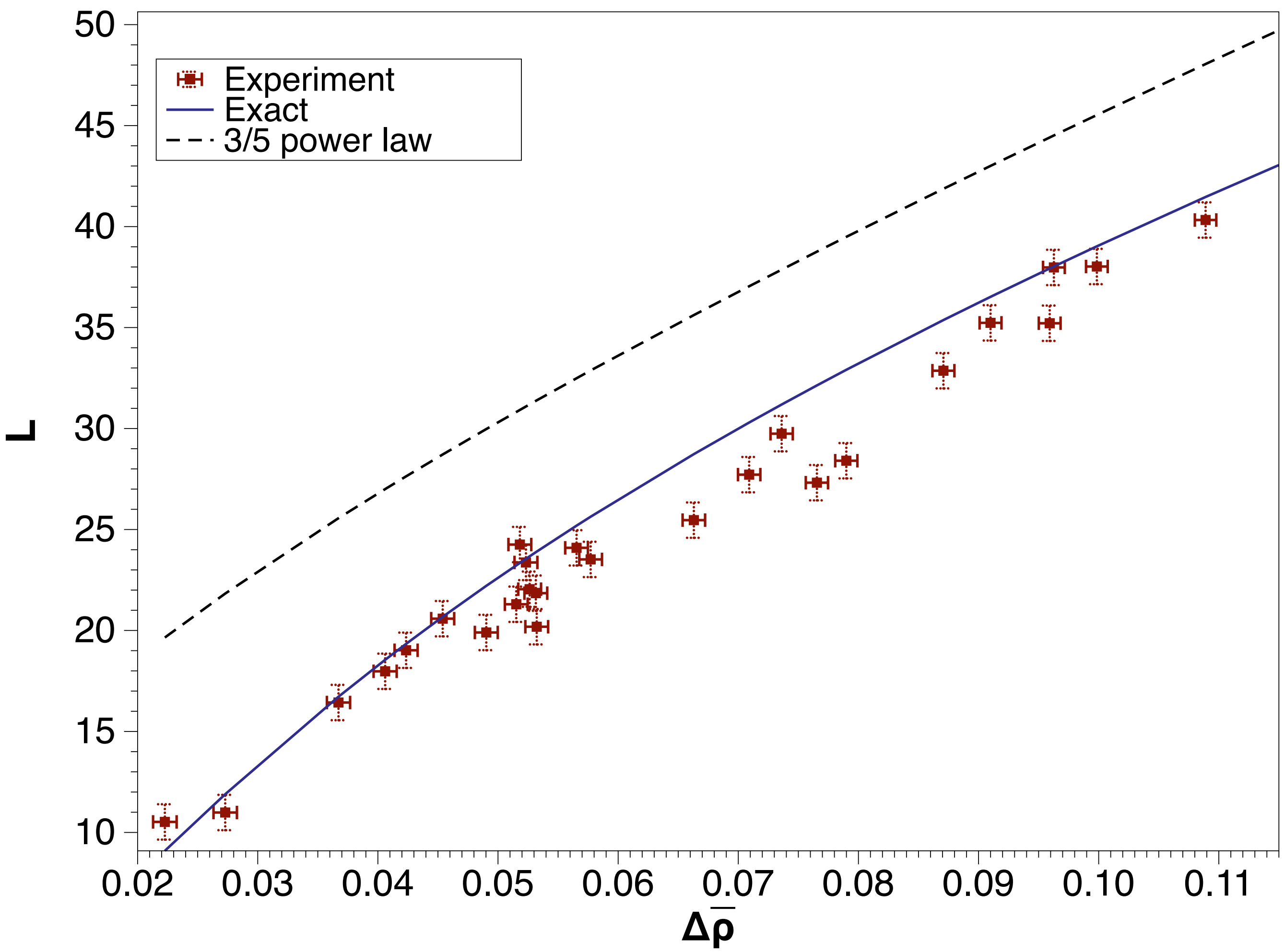


ϵ -- ambient stratification

b, w, θ -- jet radius, center speed, density

λ,α --entrainment, mixing coefficients

Miscible Limit: Critical Escape Height For Buoyant Jets



$$L = L_0 \int_1^A \frac{ds}{\sqrt{s^{5/4} + \epsilon - 1}}$$

$$\epsilon = \frac{5(1+\lambda^2)(\Delta\bar{\rho})r_0 g}{16\sqrt{2}\alpha w_0^2} \qquad A = (1 + \epsilon(\frac{\theta_0^2}{\theta_f^2} - 1))^{4/5}$$

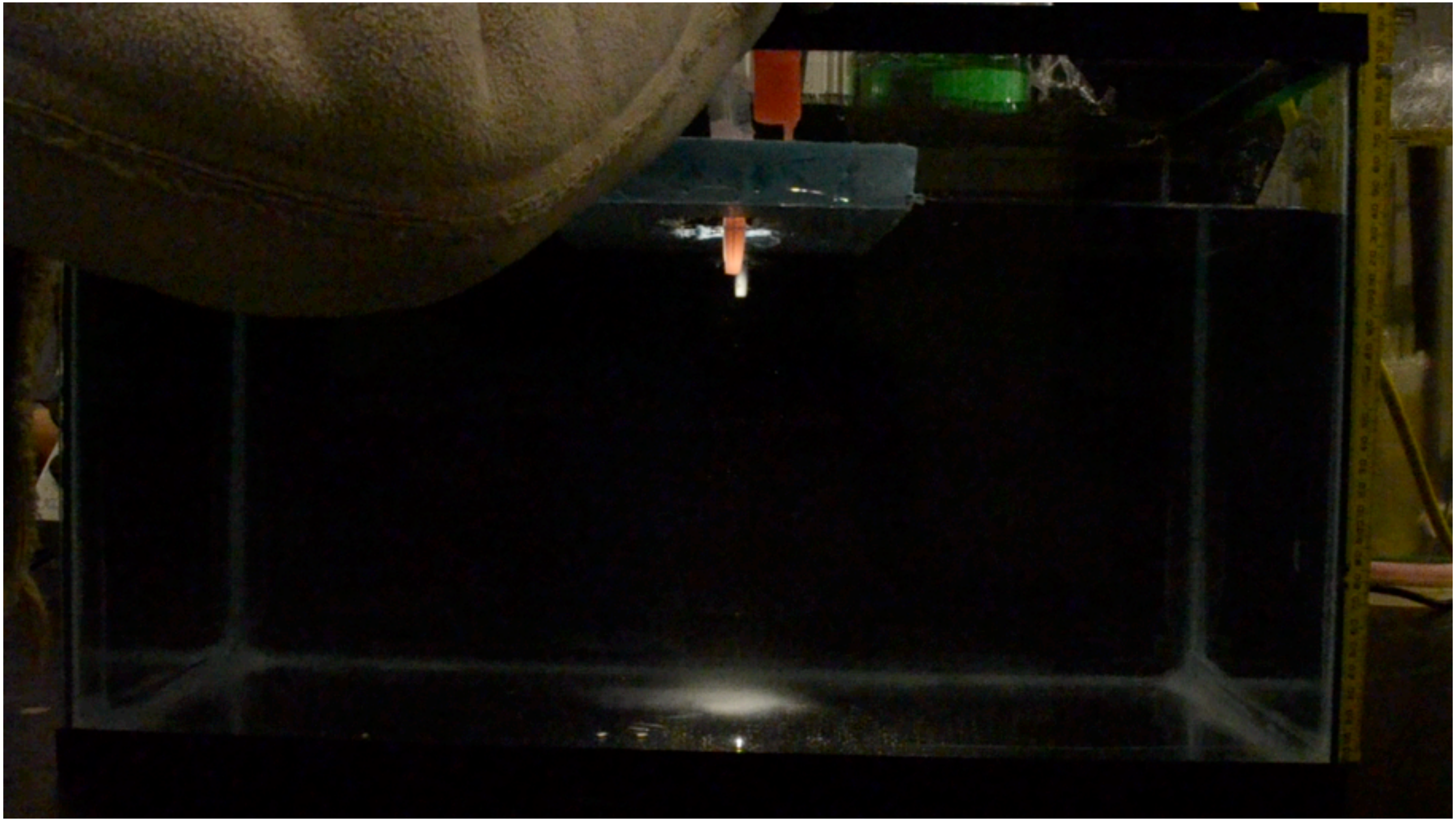
$$\theta_0 = \frac{(1+\lambda^2)}{\lambda^2}\Delta\bar{\rho} \qquad \theta_f = \frac{\rho_b - \rho_t}{\rho_b} \qquad \Delta\bar{\rho} = \frac{\rho_b - \rho_j}{\rho_b}$$

$$L_0 = (\frac{5r_0 w_0^2}{16\sqrt{2}g(1+\lambda^2)\alpha(\Delta\bar{\rho})})^{1/2}$$

Adalsteinnson. Camassa, Falcon, Lin, McLaughlin, Mertens, Nenon, Smith, Walsh, Watson, White, to appear: "Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise, AGU Monograph Series

Asymptotics-- Camassa, McL, Tzou, Zhao, in prep

Current Events: Ocean Carbon Pump



Plume Destabilization

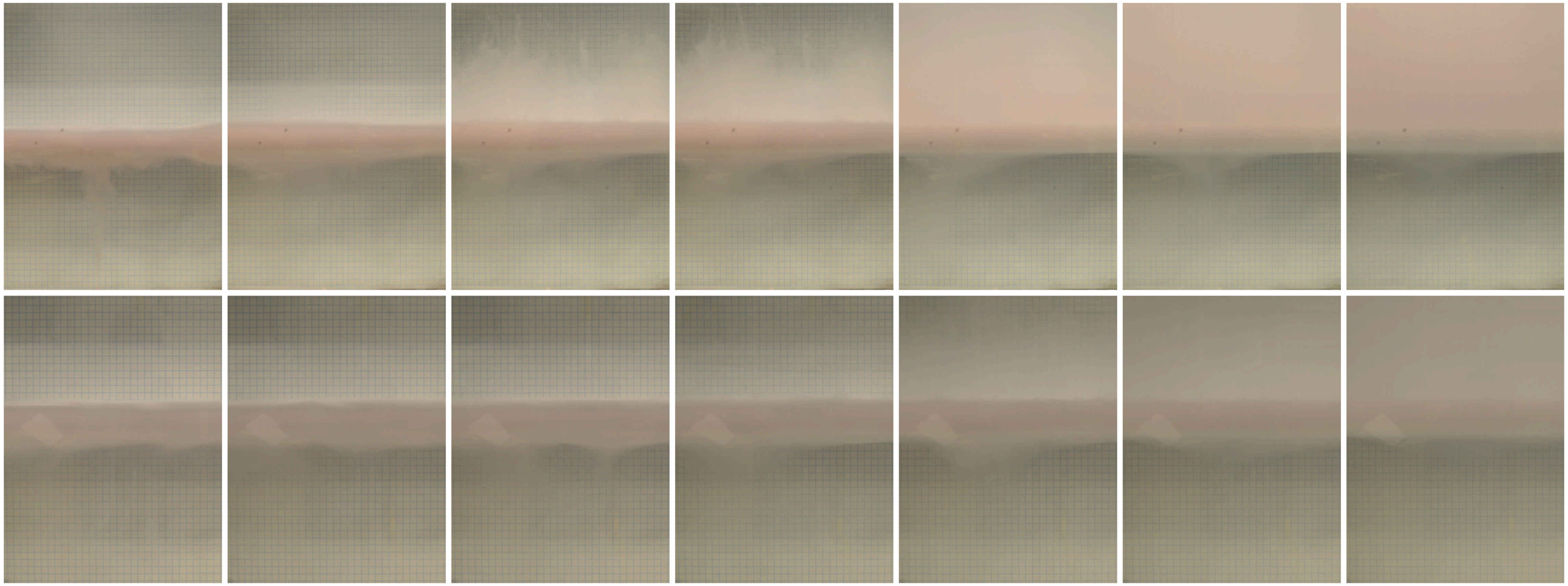
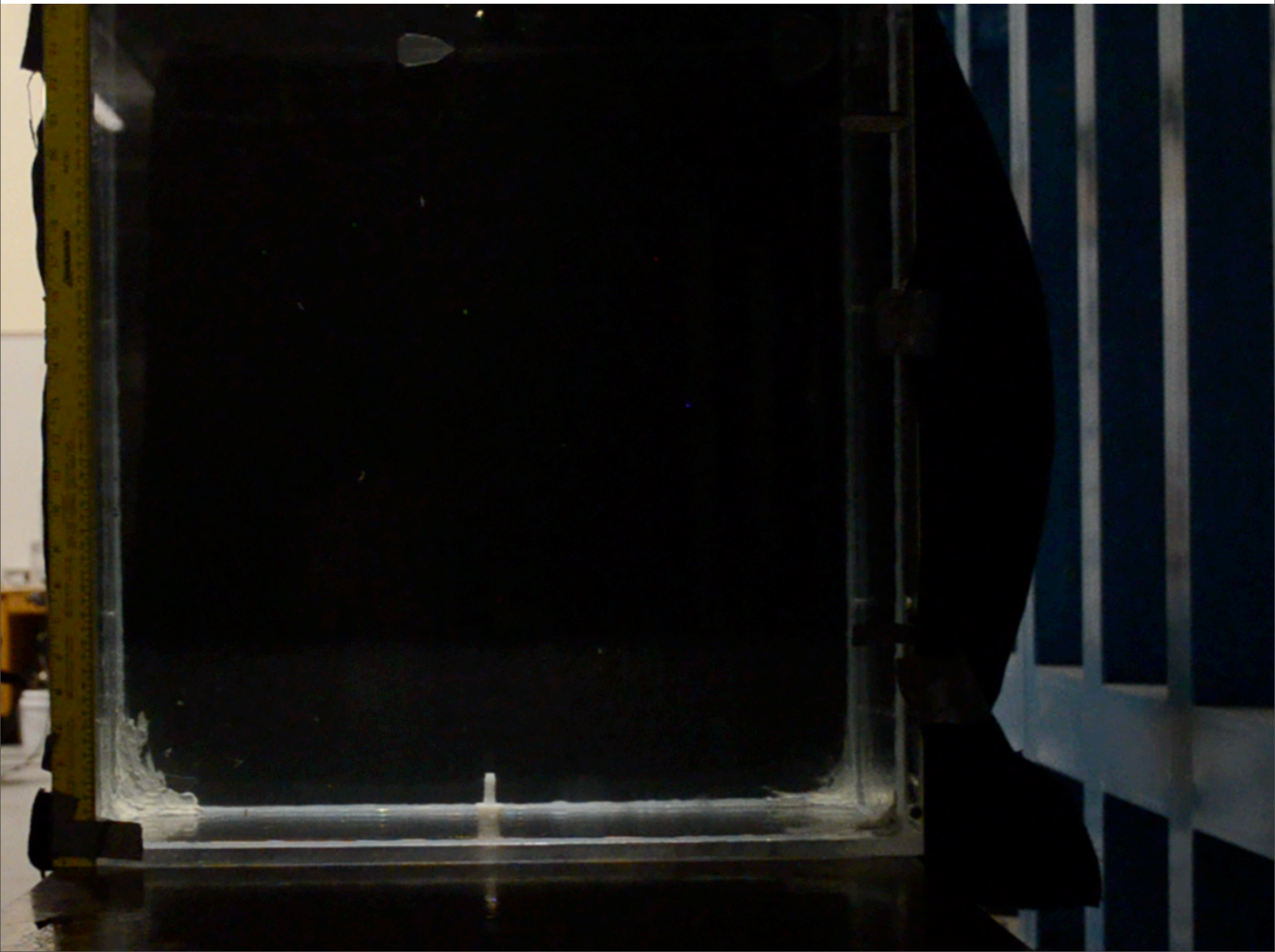
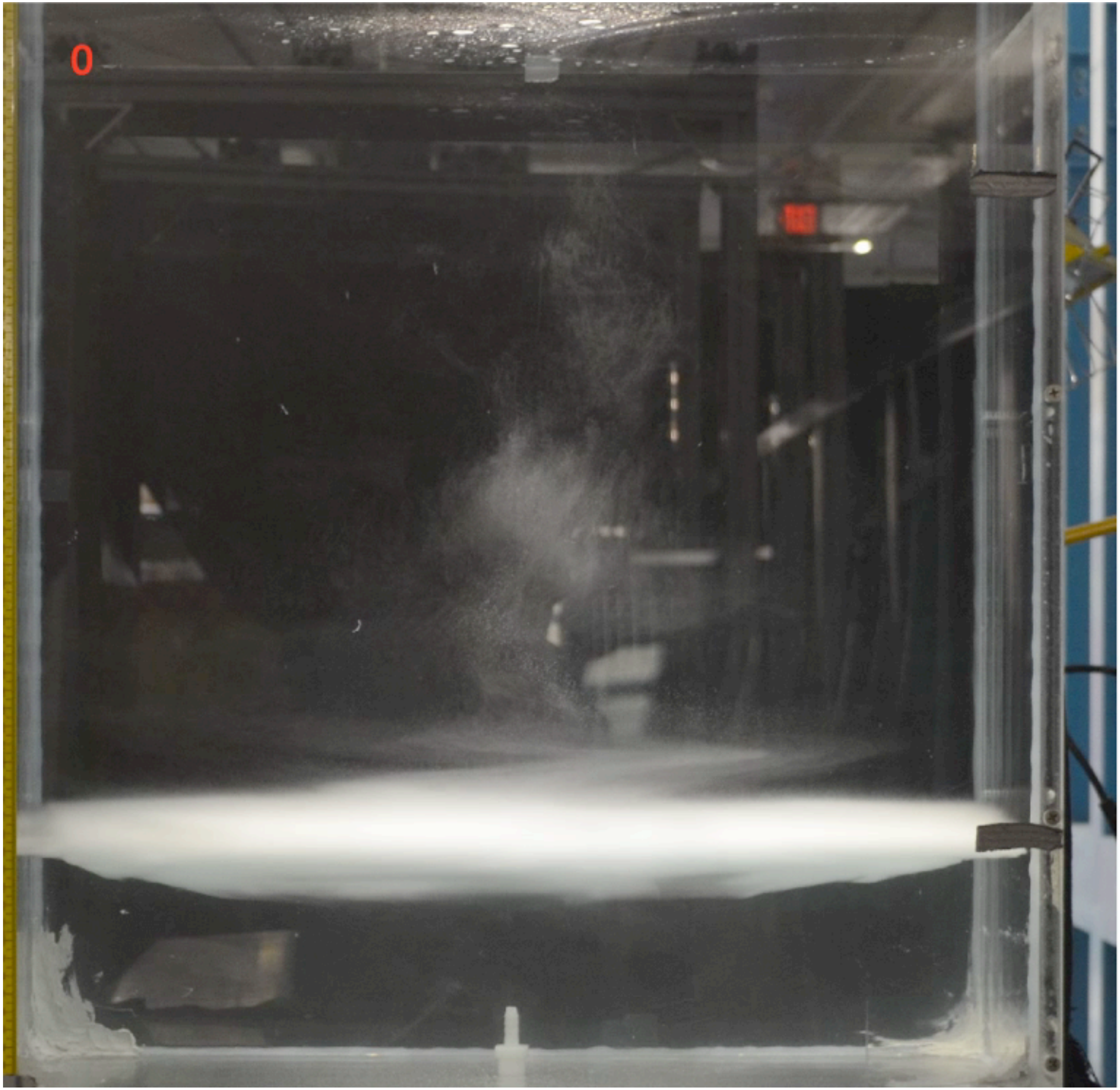


Figure 3. Time series showing timescale of plume instability. **Top**: OSW 4:3:2, t = 30, 450, 870, 900, 1800, 3600, 7200 sec. **Bottom**: OSW 4:3:17, t = 30, 450, 900, 1800, 3600, 7200, 14400 sec. Notice the onset of instability in the top row, first evident at t = 870 sec.

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Top: 48 cm travel, Bottom 15cm
Left to right: increasing flow rate

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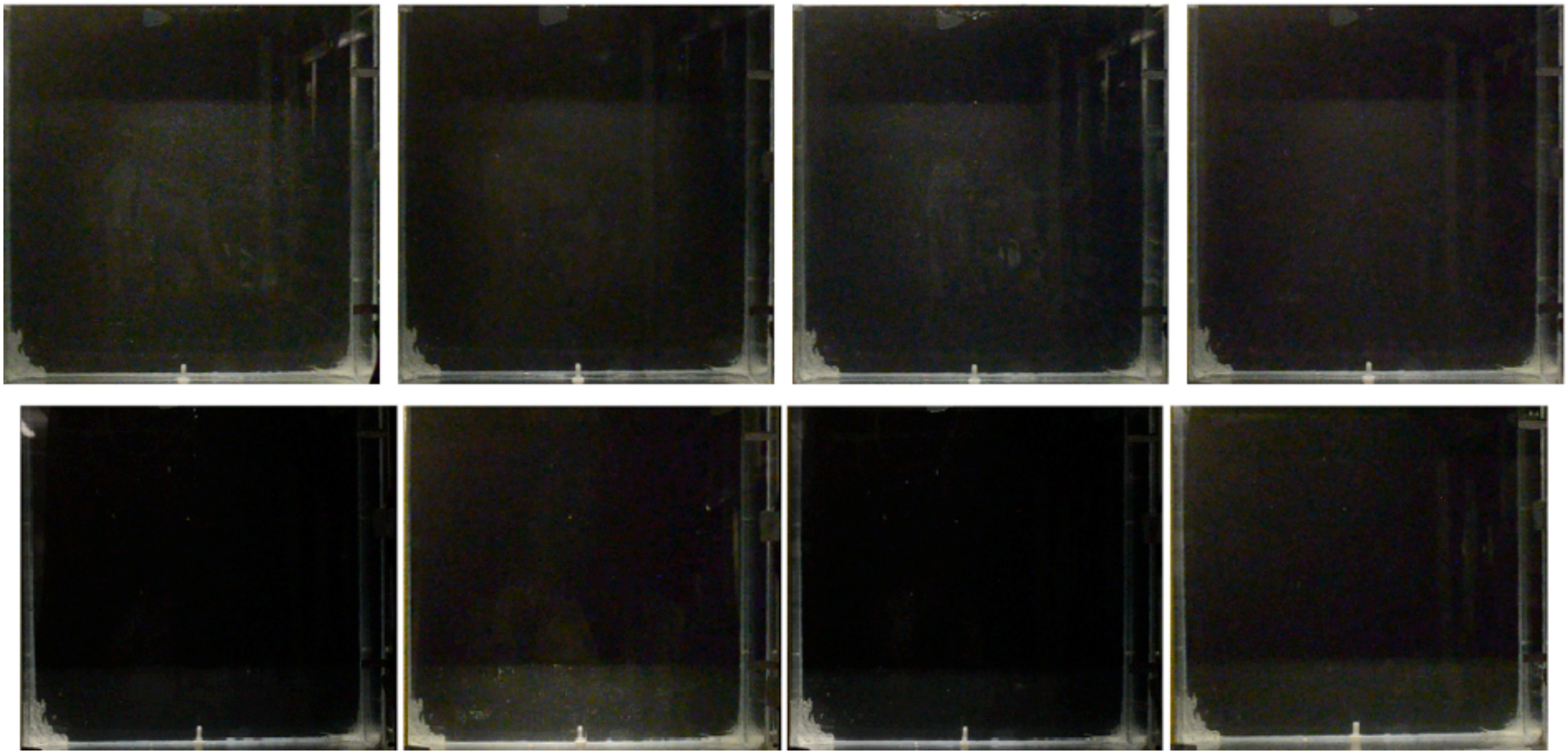

Stratified Vortex Rings

Camassa, McL, **Keith Mertens**, D. Nenon, C. Smith, C. Viotti, in prep

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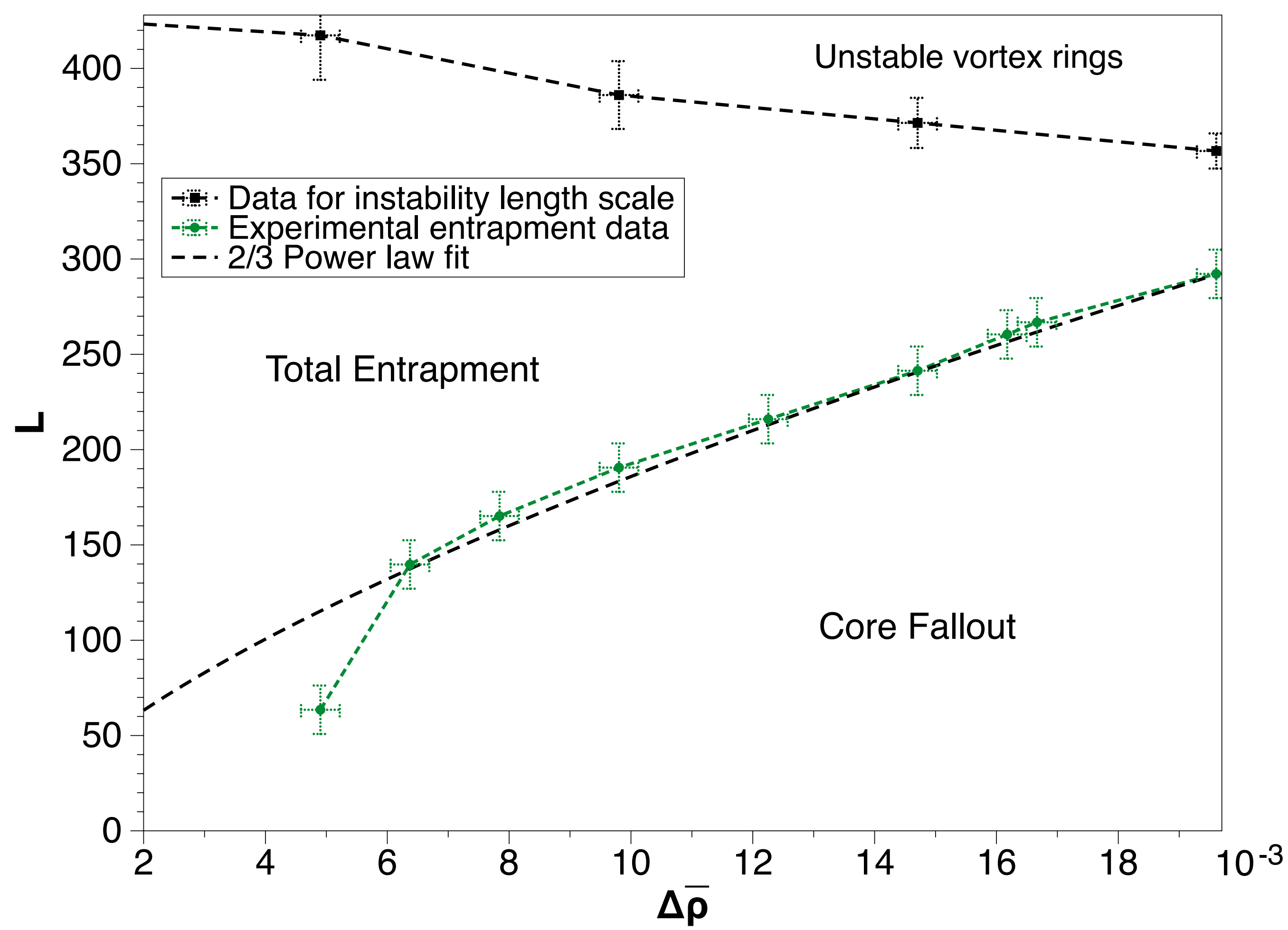
DNS: Varden (A. Almgren LBL Code) modified by Claudio Viotti

mesh:256x256x1024,
parallel on 256 processors
run time: 6 hours
periodic x-y, slip wall velocity lids
no flux bc for scalar



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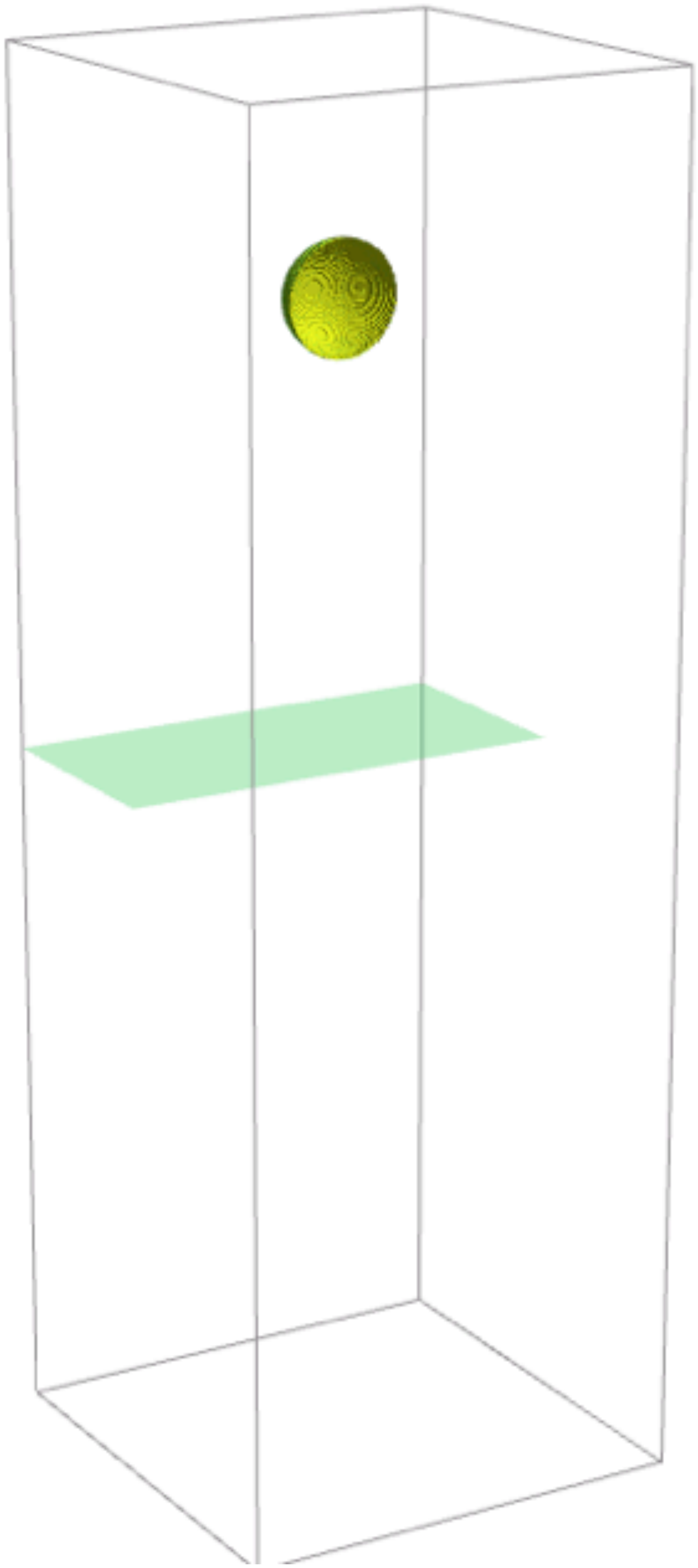

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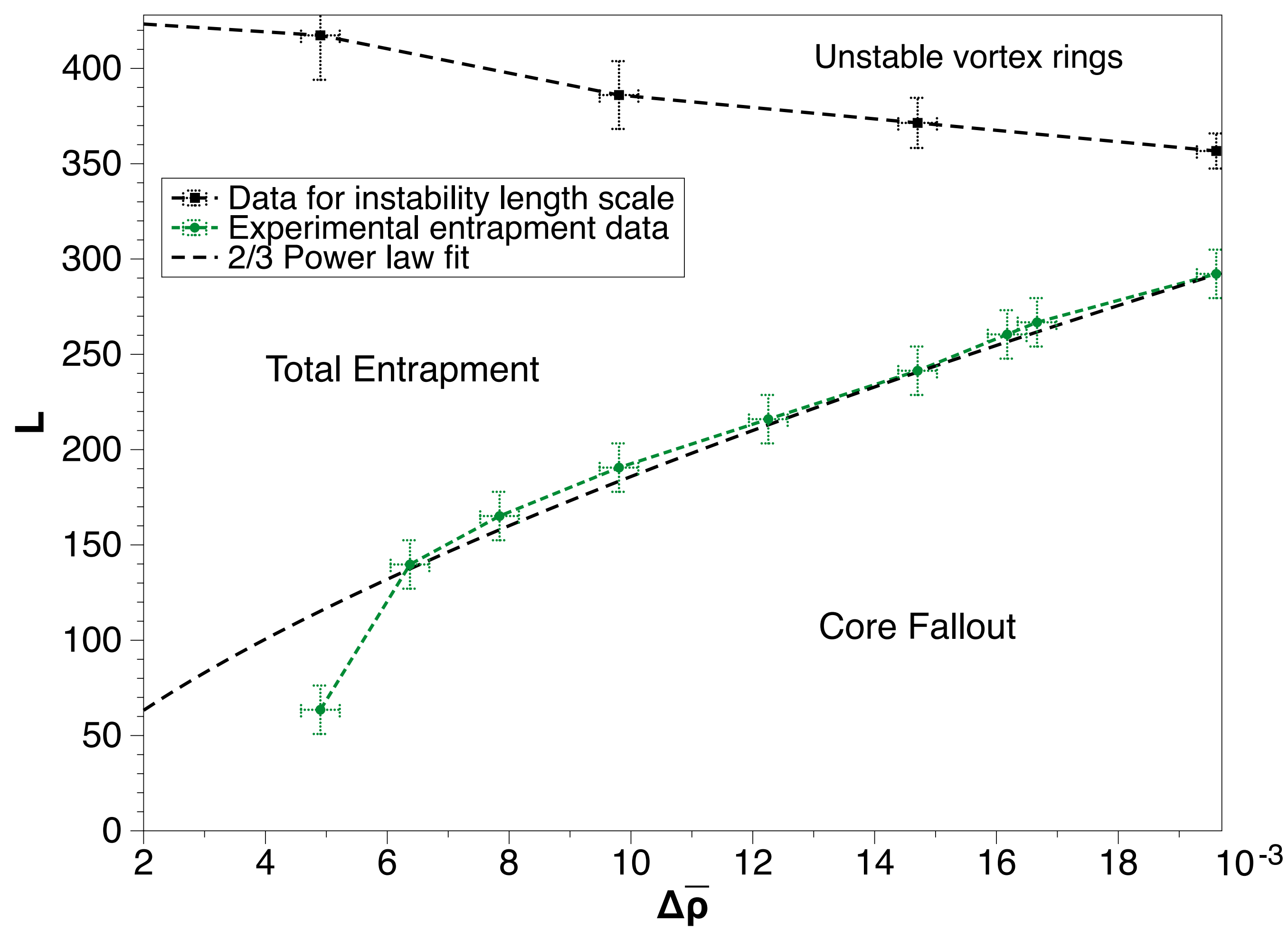

Conclusions and Future:

Buoyant plume formation in stratification

Trapping timescales vary with mixture

Plume destabilization may occur

Internal waves-- larger scale experiments

Inflow full DNS CFD marginally resolvable

UNC Joint Fluids Lab, Chapman Hall Level B, rm B02

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Why Did Huge Oil Plumes Form After the Gulf Spill

Dispersants broke oil into micro-droplets suspended by equally dense water.

Oil jets pre-mixed with soap are fired into layered fluid, mimicking the spreading of a Gulf oil plume.

Photograph by Steve Harenberg, Rich McLaughlin, Johnny Reis, William Schlieper, Will Owens, Brian White, UNC Joint Fluids Laboratory and UNC Center for Interdisciplinary Applied Mathematics Roberto Camassa/The University of North Carolina