# EXPERIMENTAL INVESTIGATION OF BOUNDARY LAYER TURBULENCE IN A WATER FLUME

Environmental Fluid Mechanics Laboratory, University of Colorado at Boulder

Daniel E. Dombroski

PI: John P. Crimaldi

# Some Background

- pollutants
- odor signals
- reproduction

*Environmental Fluid Mechanics:*

- Implications of Turbulence on Natural Systems
- Duality of Hydrodynamics and Chemical Signaling
- Methodology & Devolopment of Techniques

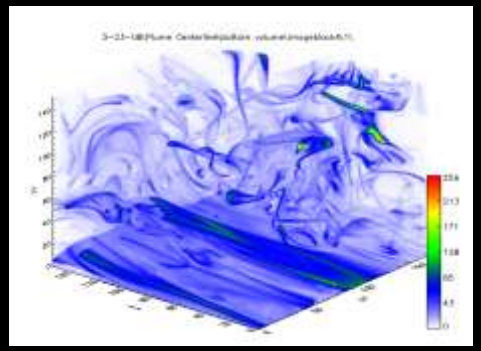
# Projects

- Accuracy of Acoustic Doppler Velocimetry (ADV) Measurements in Turbulent Boundary Layer Flows*

*Dombroski and Crimaldi, *Limnology & Oceanography: Methods*, 2007

- ***Biofouling Phenomena***:
  Growth of communities of organisms on submerged surfaces

- 3D Visualization of Plume Dynamics



# Accuracy of Acoustic Doppler Velocimetry

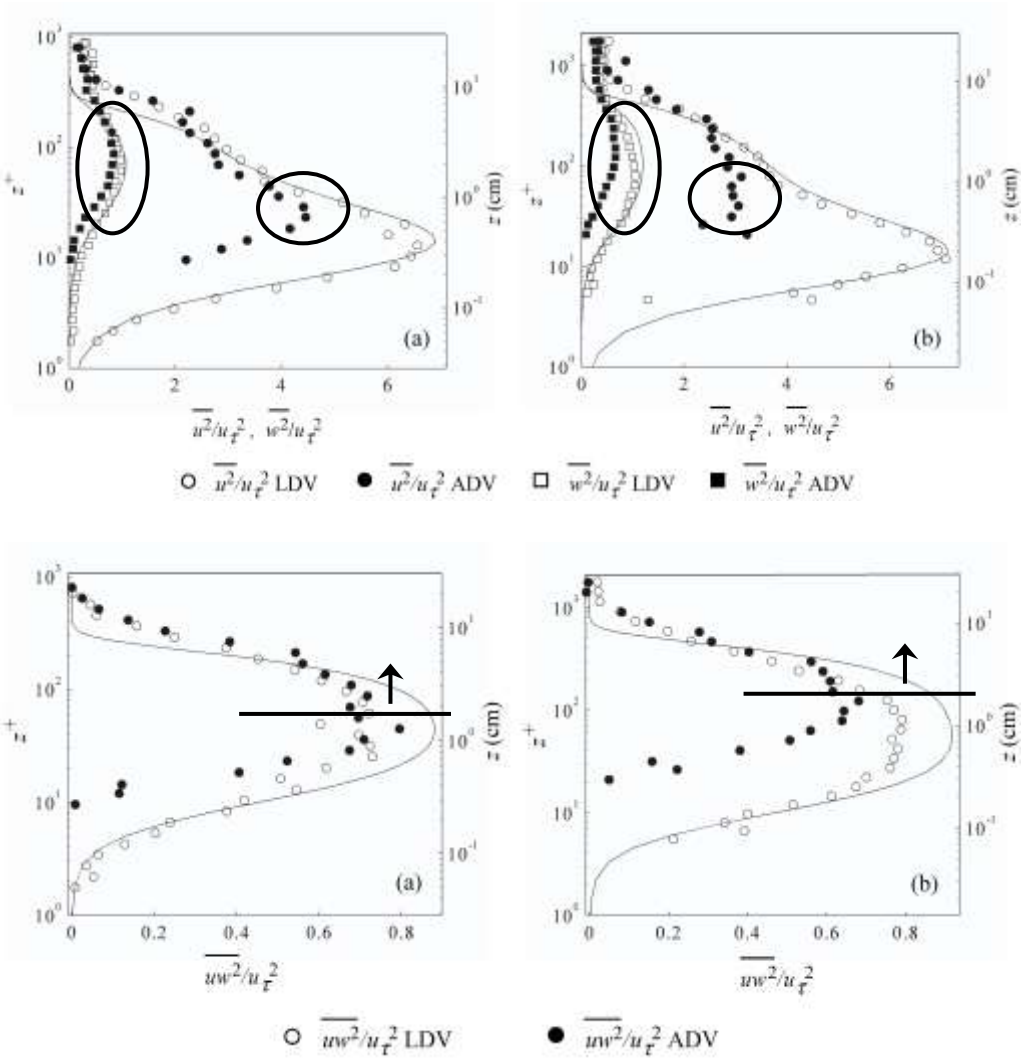
*Acoustic Doppler Velocimeter*

- Commonly Used Field Instrument
- ‘Economical’ ~ $10k
- Relatively Low Spatio-Temp Resolution

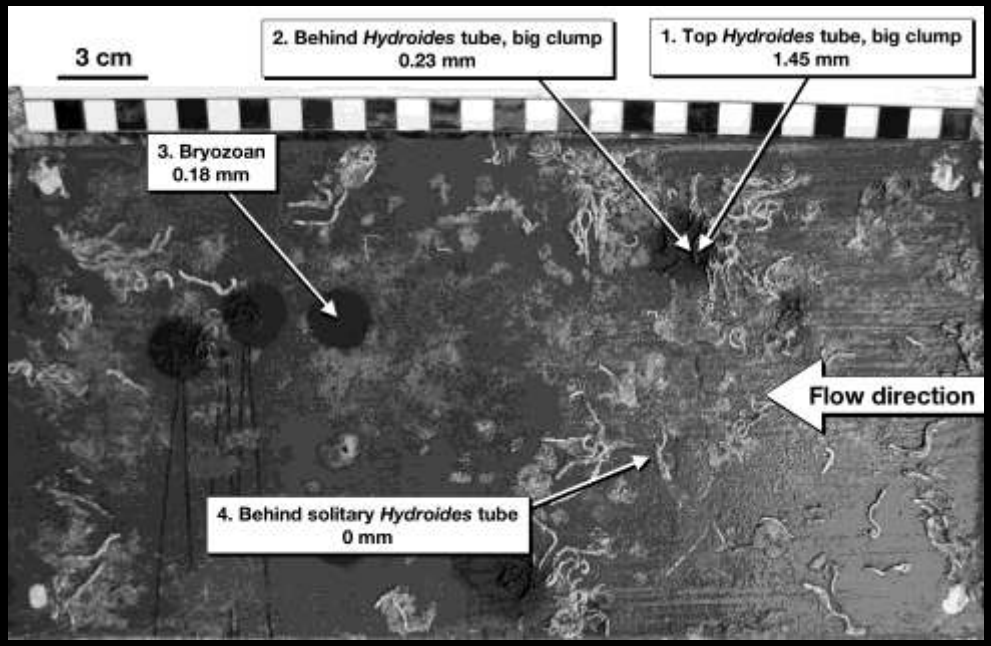
*Laser Doppler Velocimeter*

- Precision Laboratory Instrument
- ‘Pricey’ ~ $250k +
- High Spatio-Temp Resolution

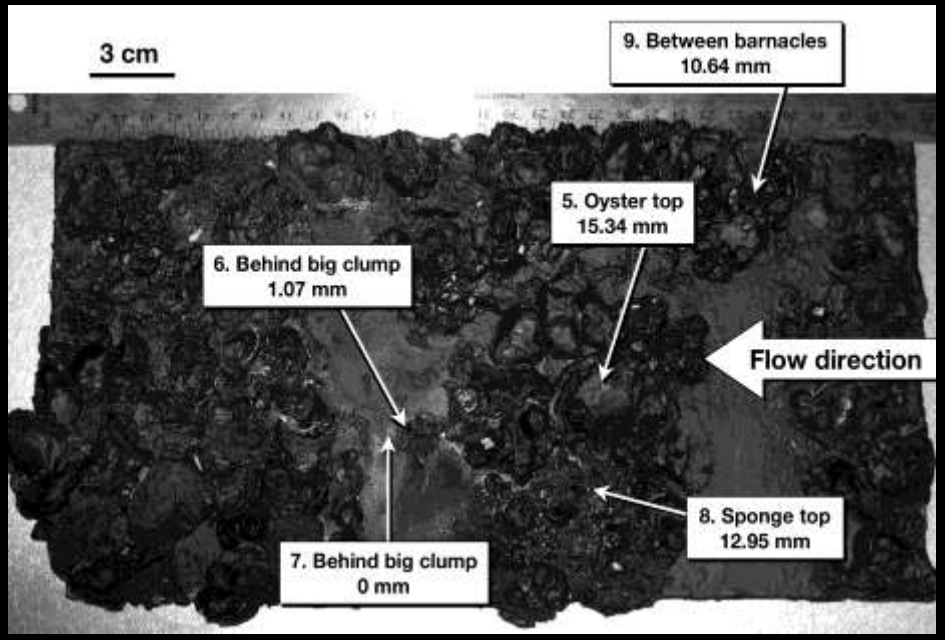
# ADV Significantly Underreports Turbulence Statistics



# Biofouling




# Early Stage Fouling Plate




# Late Stage Fouling Plate

# Algorithm

*Statistical analysis of stress lulls in instantaneous record*

Steps:

(1) Calculate stress record, $\tau = \rho u'w'$

(2) Divide record into stress 'lulls', $L_i$

(3) Calculate anchoring probability, $P_a$:

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

$$P_A(\tau_{crit}, t_a) = \frac{\sum_{i=1}^{M} \psi_i}{t_1 - t_0}$$

where $\psi_i = \begin{cases} L_i - t_a & \text{if } L_i \geq t_a \\ 0 & \text{if } L_i < t_a \end{cases}$

*Figure adapted from Crimaldi et al, 2002*

For discrete time intervals $\Delta t$, evaluate $\psi_i$ as:

$$\psi_i = \sum_{j=j_a}^{N_{max}} H_i(j)\Delta t$$

Where $j_a$ = # of time steps in $t_a$

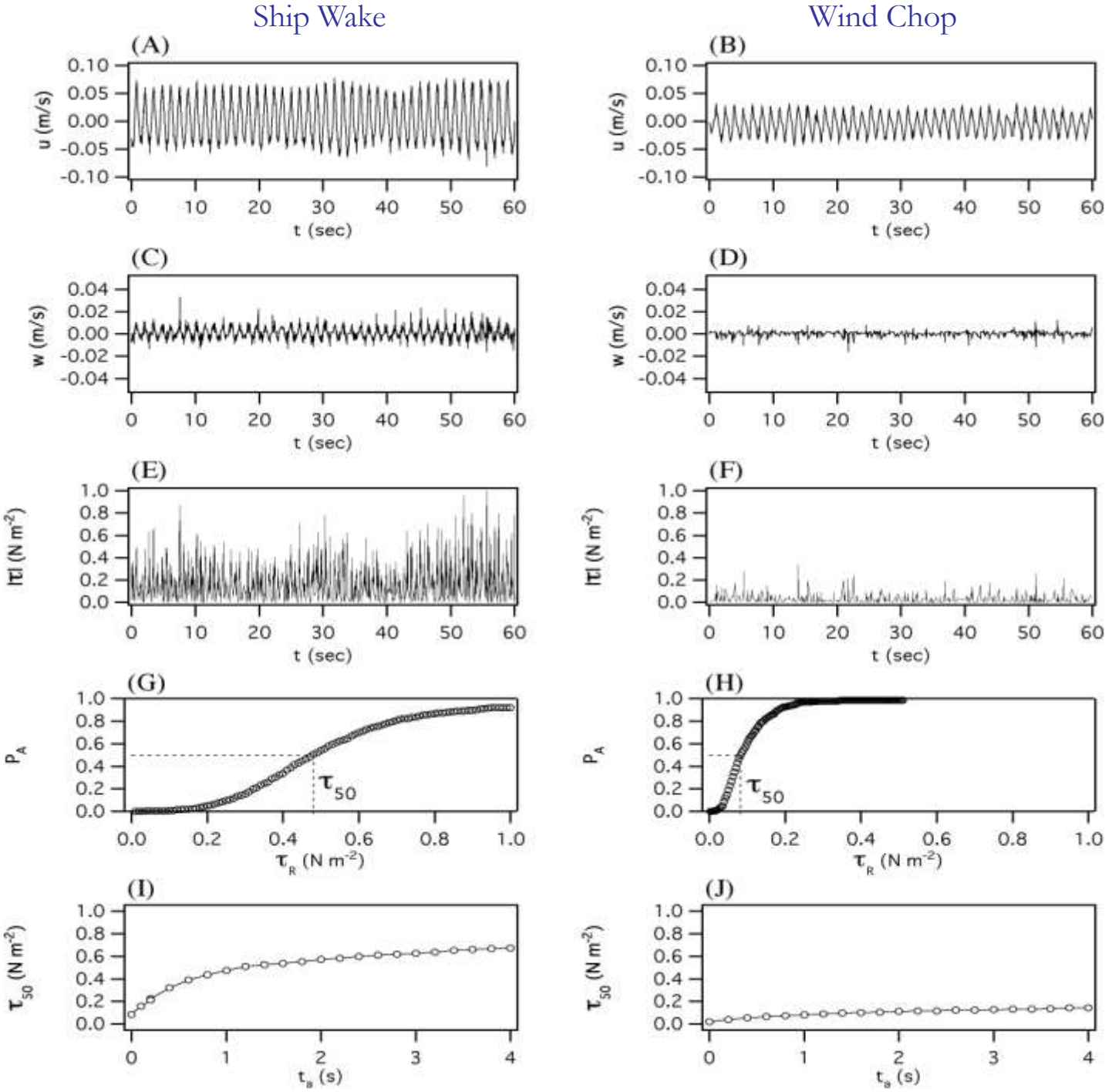
$Nmax$ = # of samples in *longest* stress lull

$H_i(j) = \begin{cases} 1 & \text{if } 1 \leq j < N_i \\ 0 & \text{if } j \geq N_i \end{cases}$ where $N_i$ = # of samples in $i^{th}$ stress lull

Combining, $$P_A(\tau_{crit}, t_a) = \frac{\Delta t}{t_1 - t_p} \sum_{j=j_a}^{N_{max}} \sum_{i=1}^{M} H_i(j)$$

Dependent on criteria $T_{crit}$ & $t_a$

# $\tau_{50}$ Stress Calculation



# Flow Visualization

## *3D Planar Laser Induced Fluorescence*

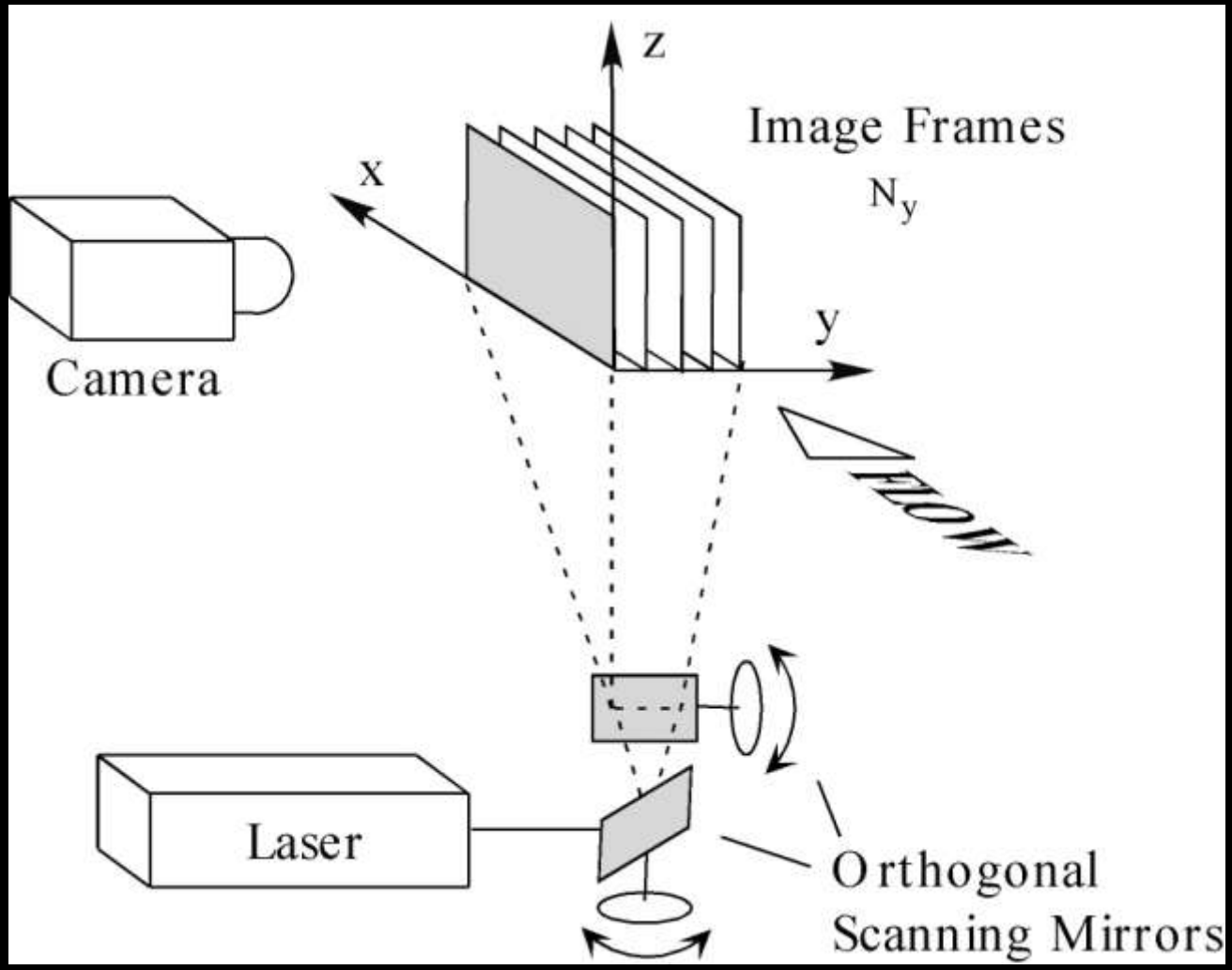
- Scalar:  Rhodamine 6G

  Passive - Moves with and diffuses relative to the flow without effecting the governing physics

  Conservative - Nonreactive

- Plume:  Bed-level, low momentum release
  - *Think* odor release at river bed

# 3D PLIF Schematic



# Flow Dynamics

# Coherence

# Relevant Scales

- Experimental Resolution
  - Image Plane (based on CCD chip) ~ *0.1 mm*
  - Transverse (based on laser beam) ~ *0.25 mm*
- Kolmogorov - smallest eddies

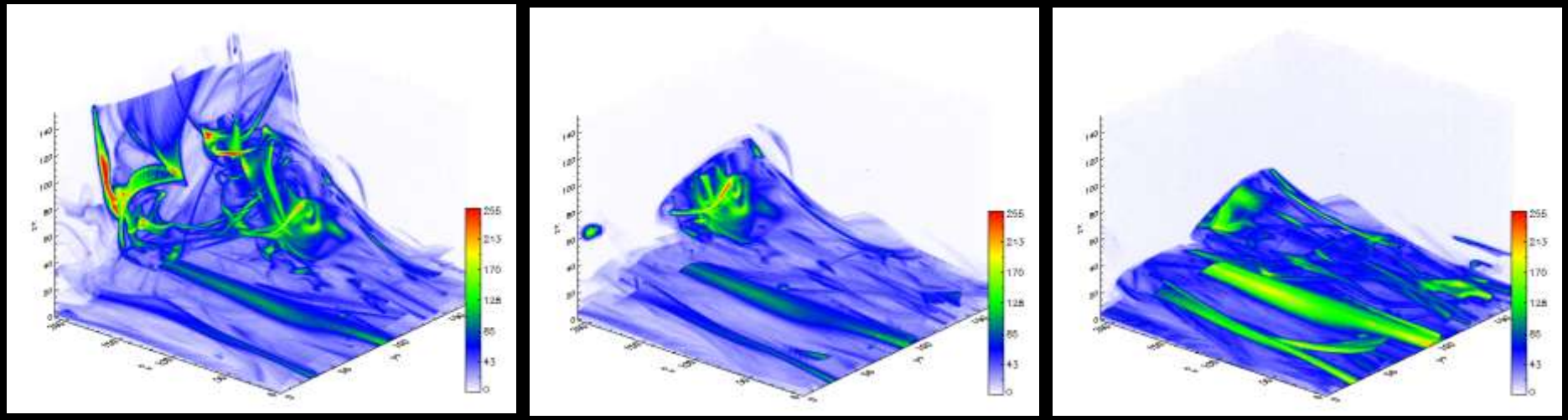
  *~ 1 mm*

  (Estimated from dissipative & viscous scaling)
- Batchelor - smallest chemical gradients

  *~ 0.01 mm*

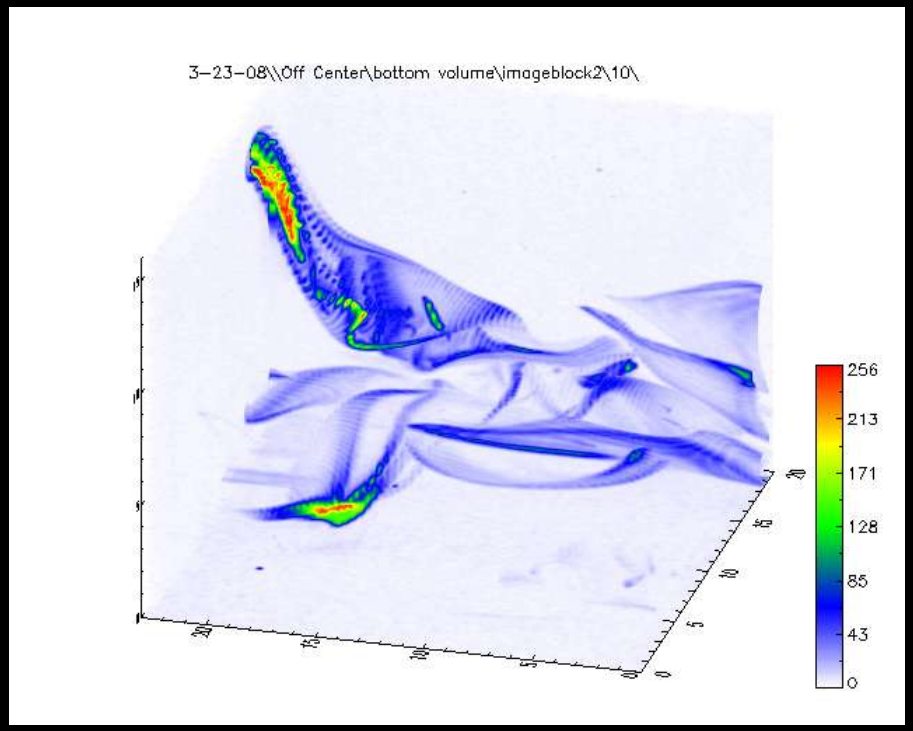
  (Estimated from Kolmogorov scale, Schmidt number)

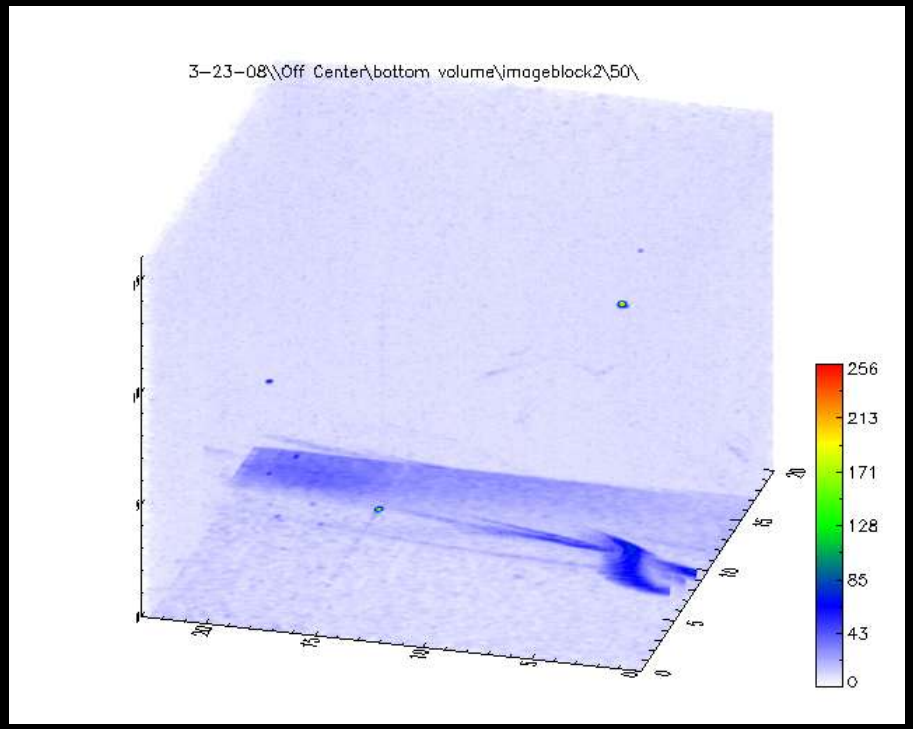
# “Burst – Sweep” Action



*time*

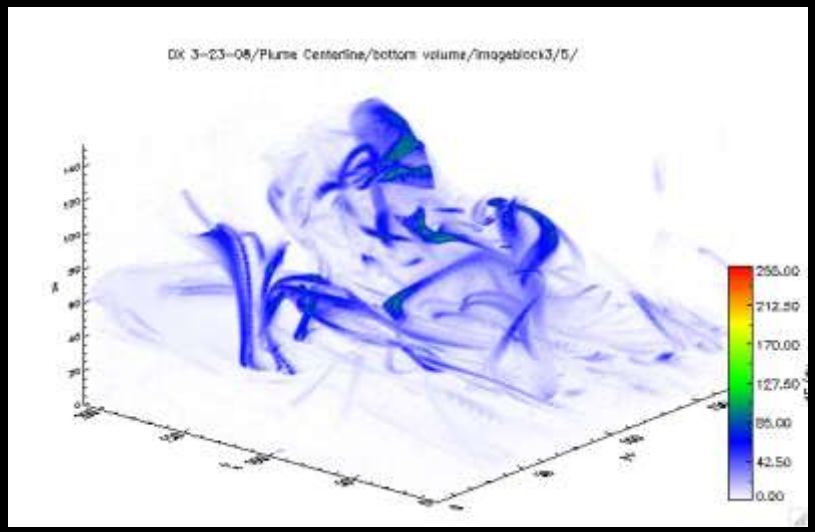
# Moving away from the plume centerline…

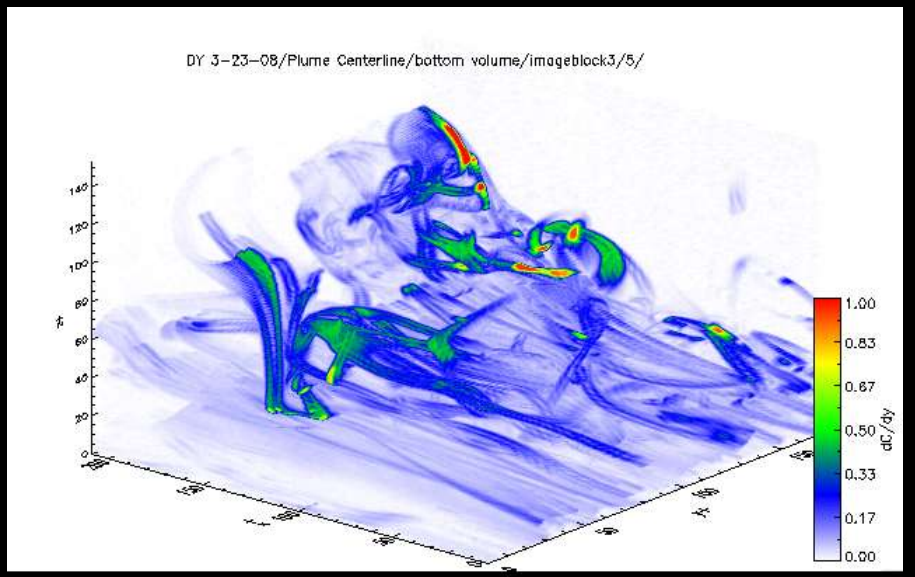


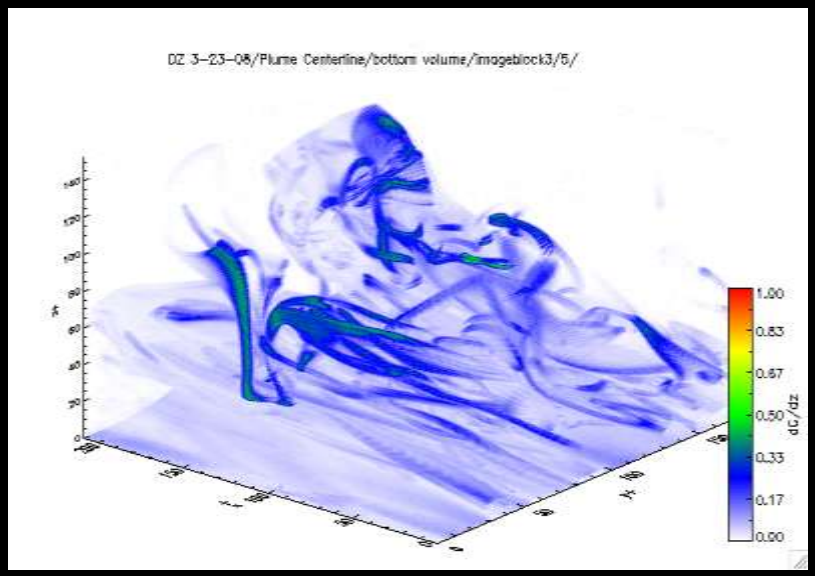



# Scalar Gradients

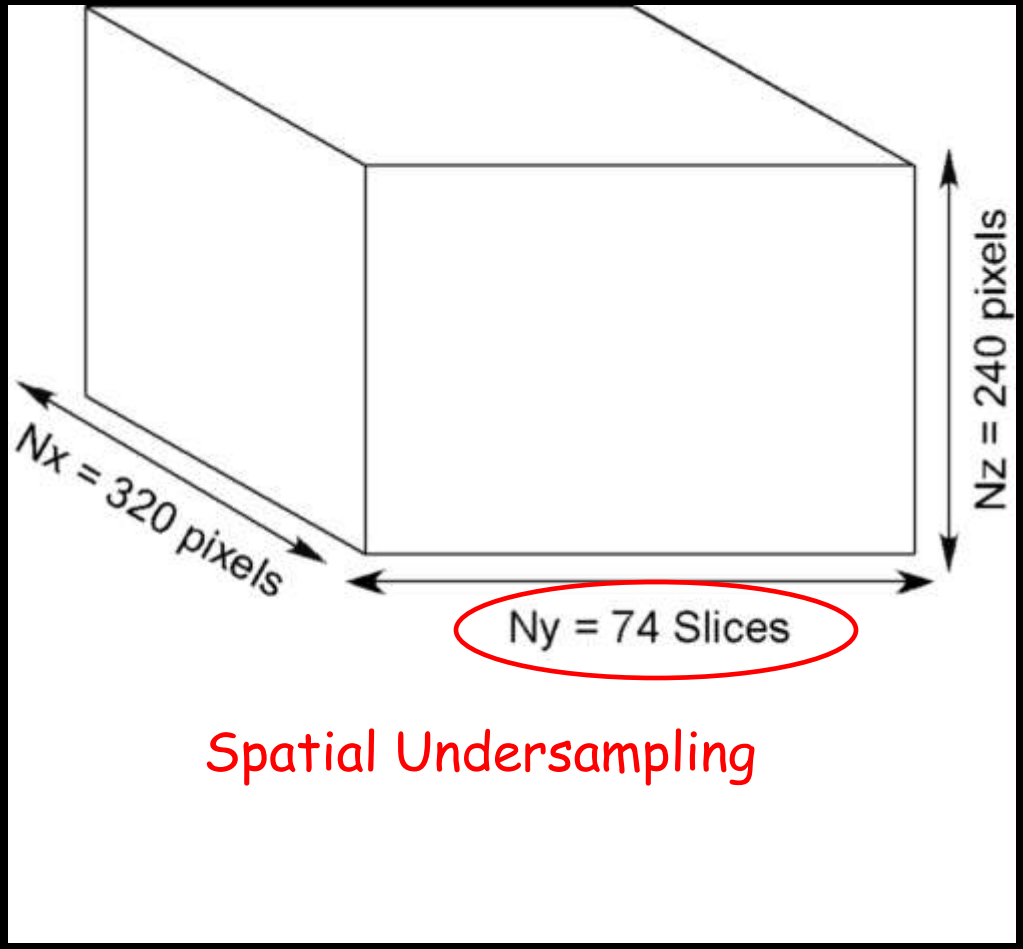
*(ie, where's the mixing?)*



# Correcting Artifacts




Spatial Undersampling