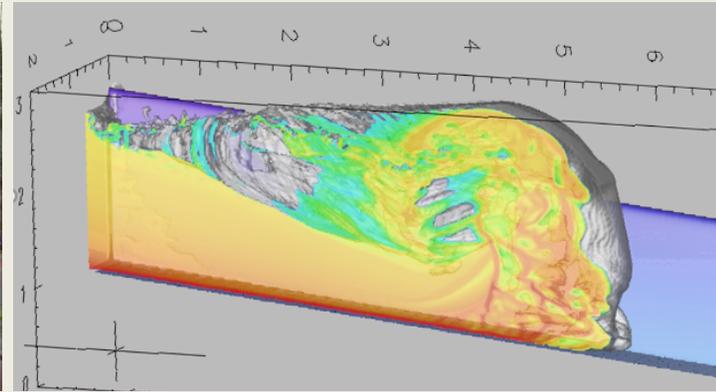


Granular and Fluid Instabilities in Explosive Volcanic Eruptions

Workshop on Multiphase Flow Science 2023



Joe Dufek University of Oregon, Center for Volcanology

Eric Breard, University of Edinburgh

Jordan Musser, National Energy Technology Laboratory



UNIVERSITY OF
OREGON



Critical moments in Plume and Gravity Current Evolution

5. Microphysical Interactions

Exp. In Talk

2. Compressible Effects

6. Entrainment in pyroclastic density current

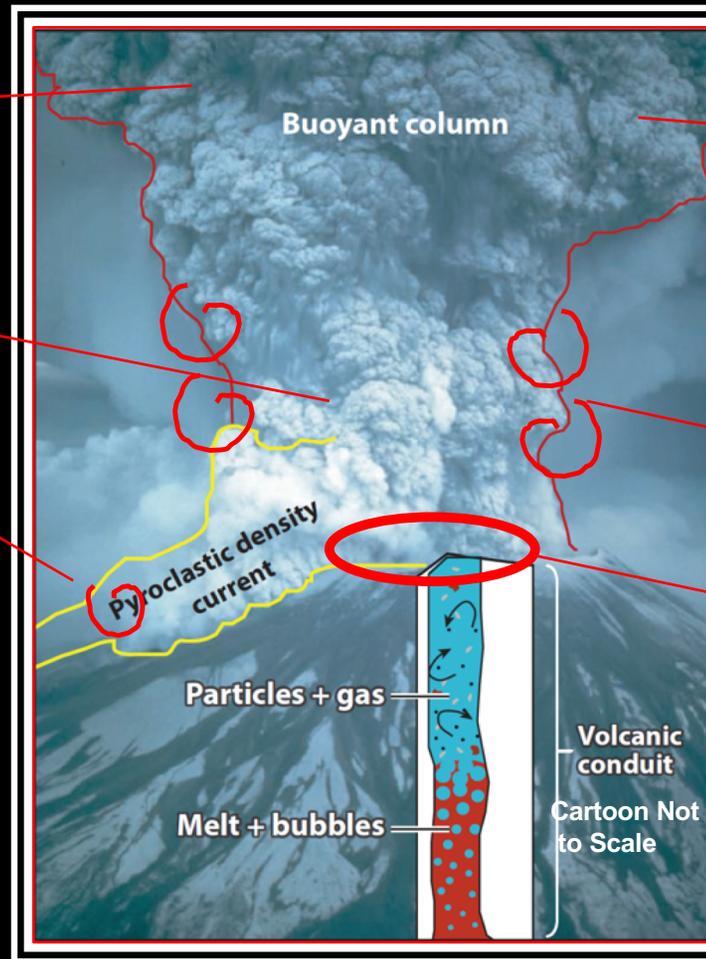
Sim. In Talk

7. Erosion/sed. In pyroclastic density current

4. Sorting/Sedimentation of particles from plume

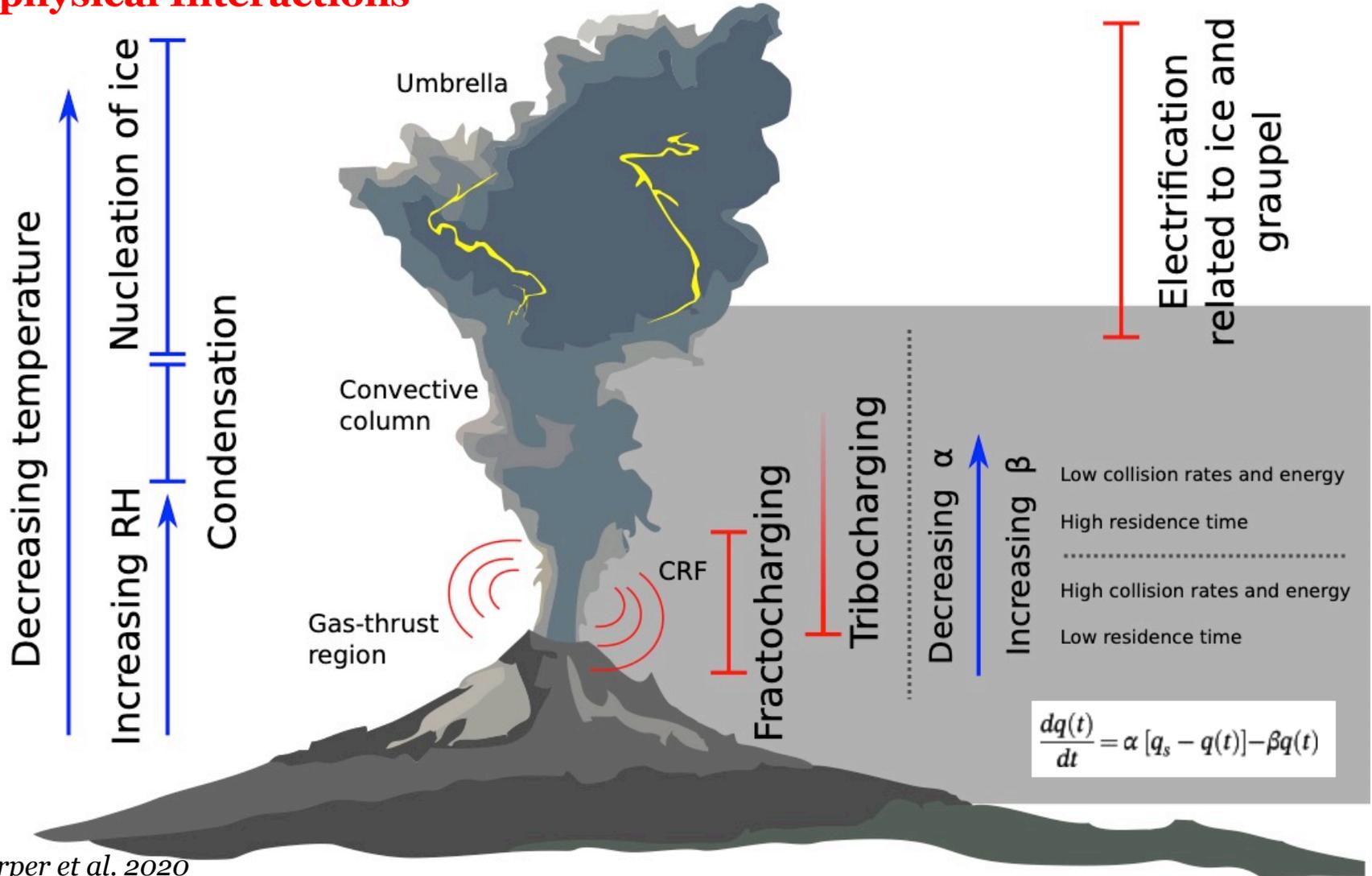
3. Near Vent Entrainment

1. Acceleration to Choked Conditions

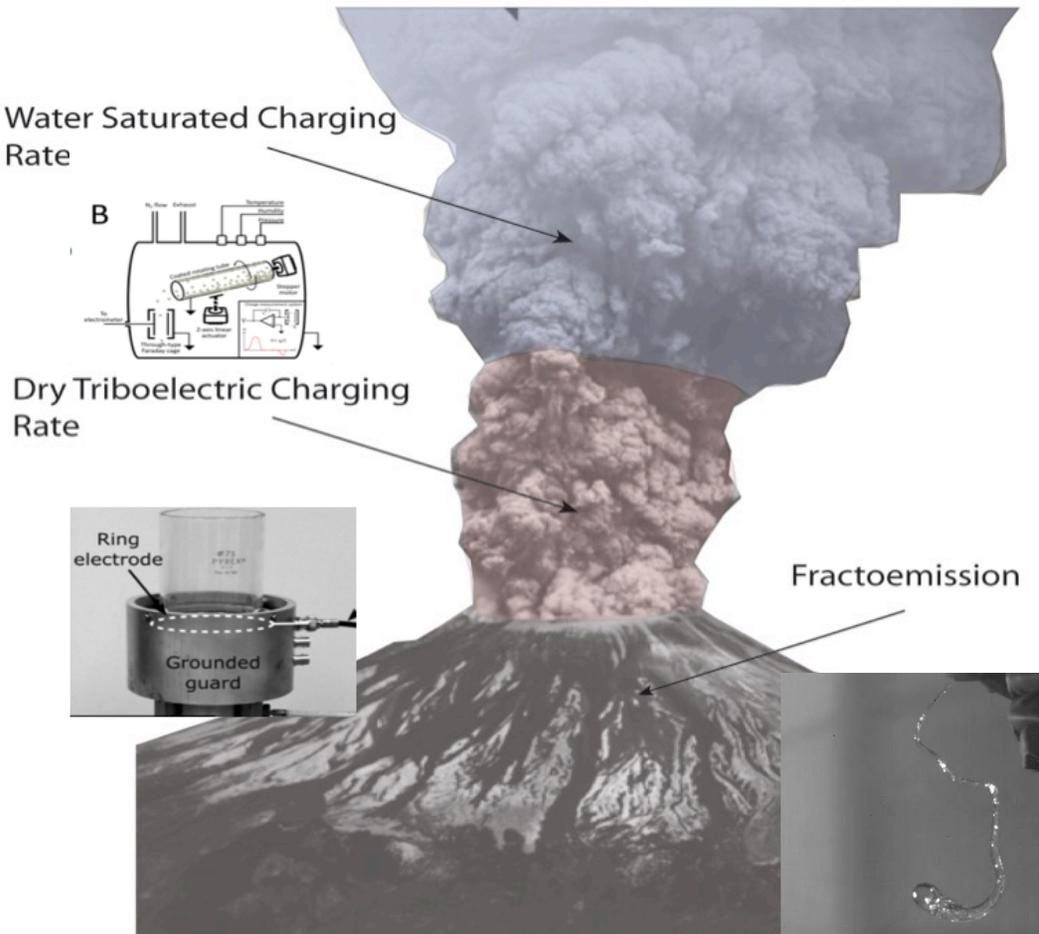


May 18, 1980
Eruption of Mount St. Helens

Microphysical Interactions

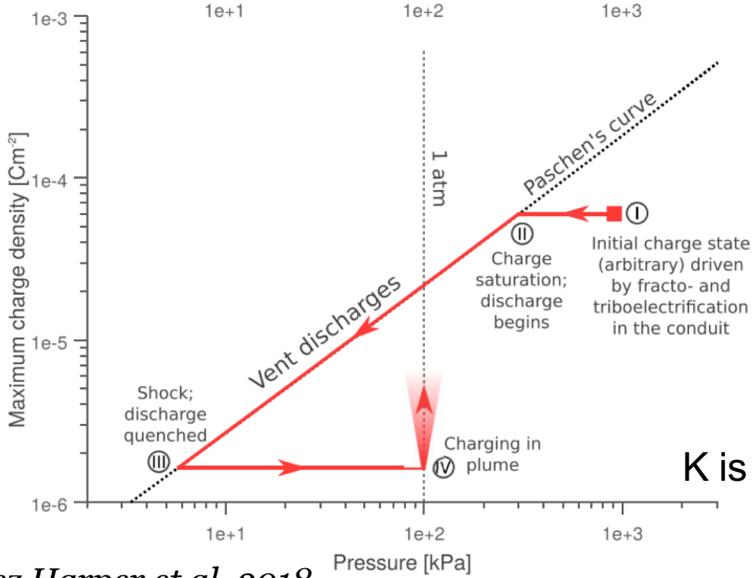
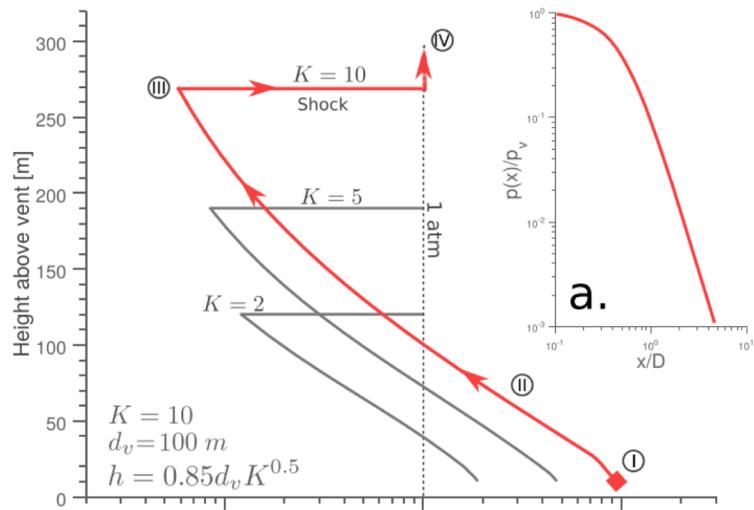


An Illustration of a Combined Experiment-Observation-Computational Approach: Electrical Charging Mechanisms

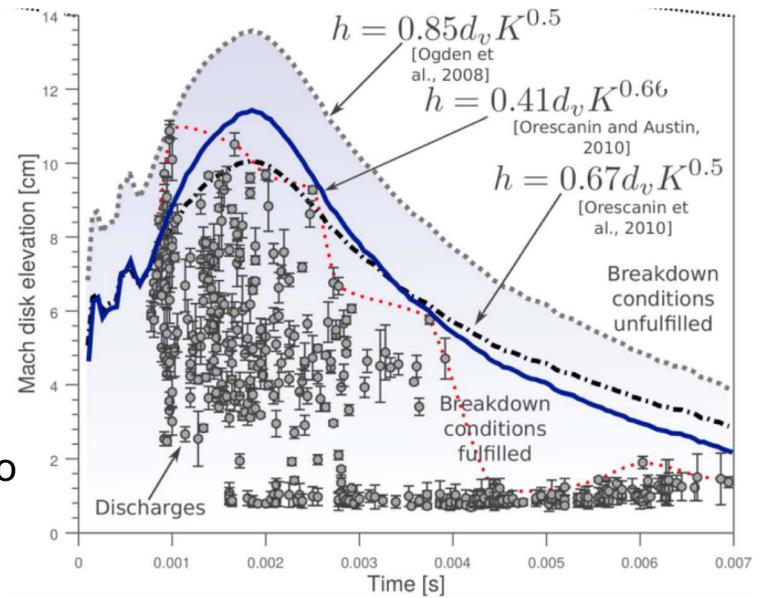
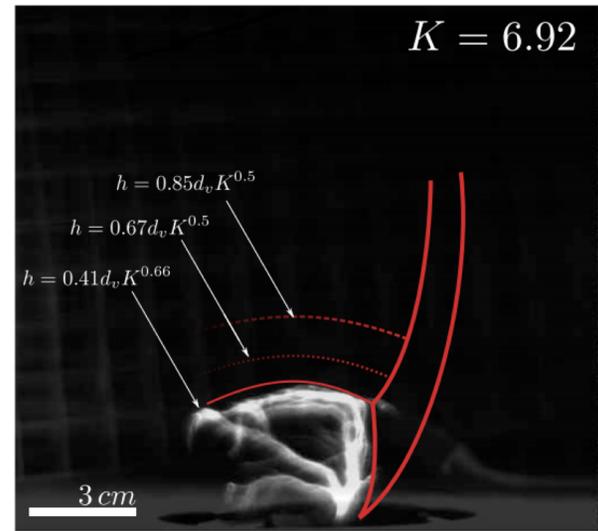


Josh Mendez Harper

Mendez Harper and Dufek, 2015



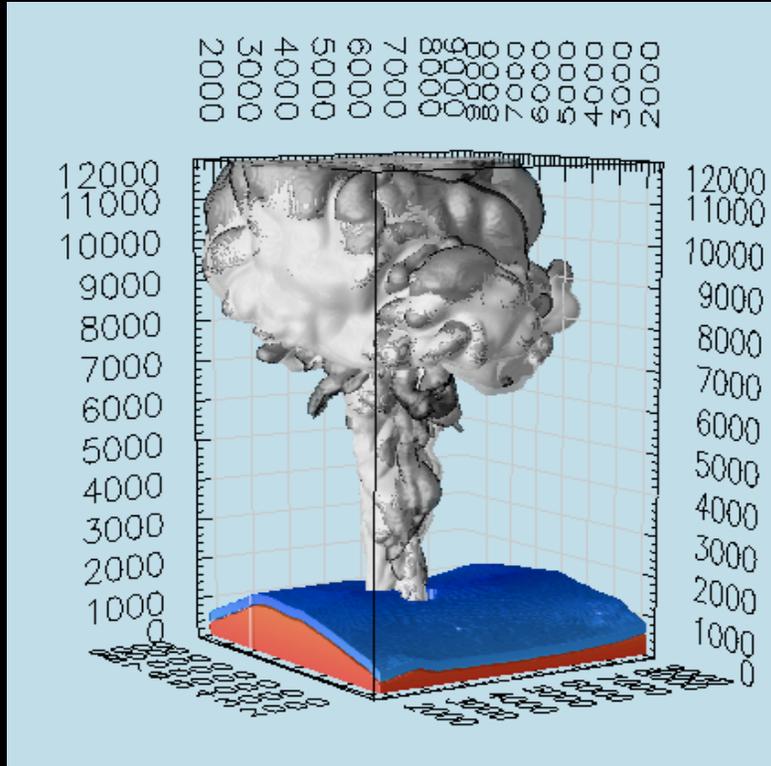
K is overpressure ratio





Aggregation and water adsorption

Volume Flux Magma = $2.8 \times 10^3 \text{ m}^3/\text{s}$



- 100 % Relative Humidity
- 10^{-5} Volume Fraction Particles



Telling and Dufek, GRL

Particle Laden Gravity Currents



PDC– Mt. St. Helens



Volcanic Eruption - Io

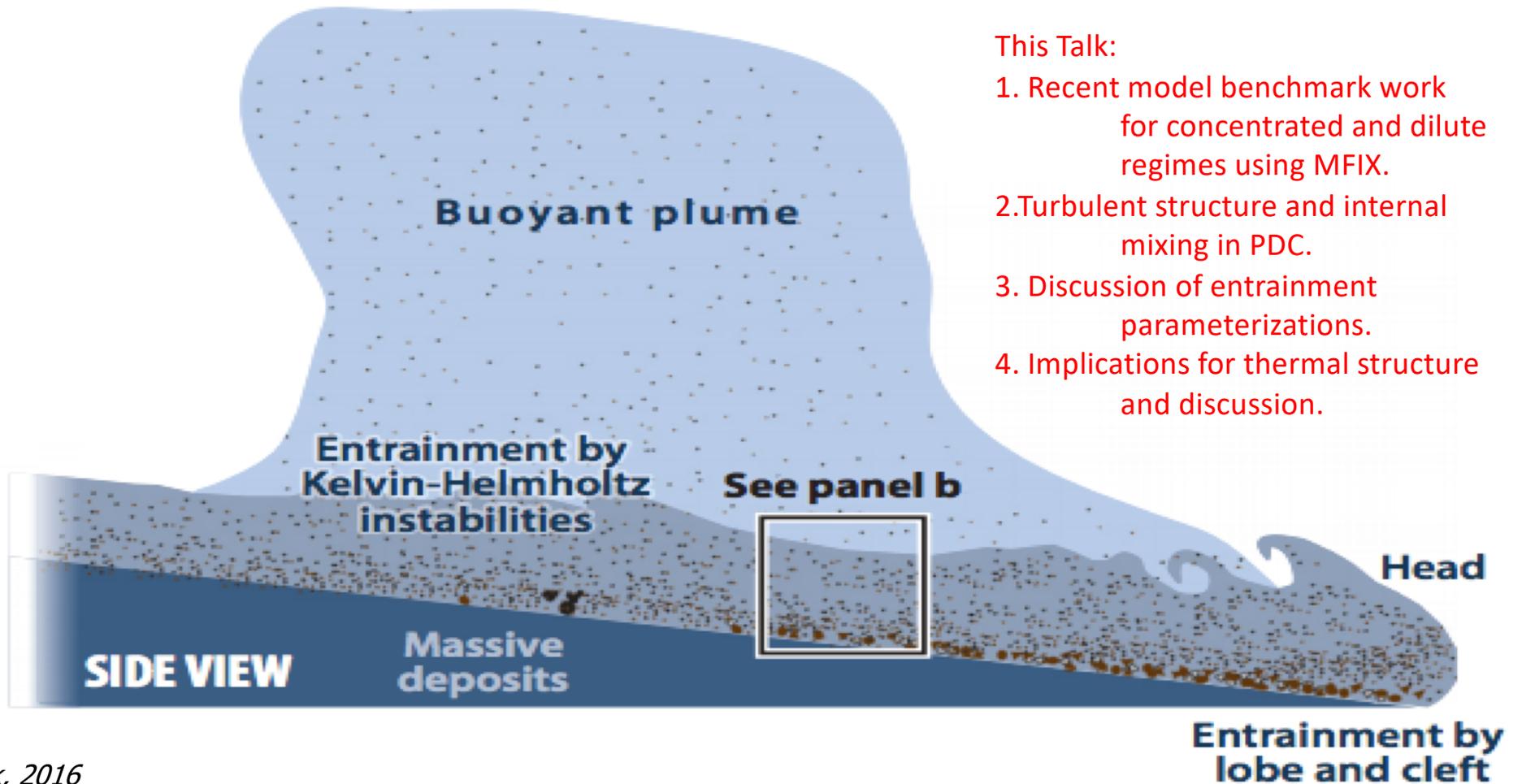


Dust Storm – Martian North Pole



Snow Avalance - Rockies

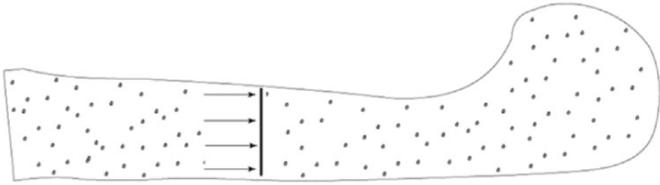
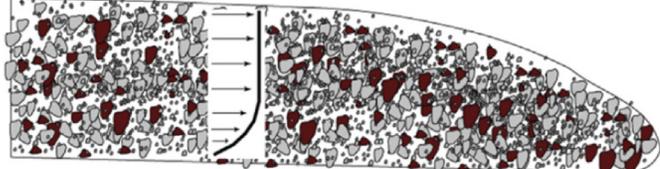
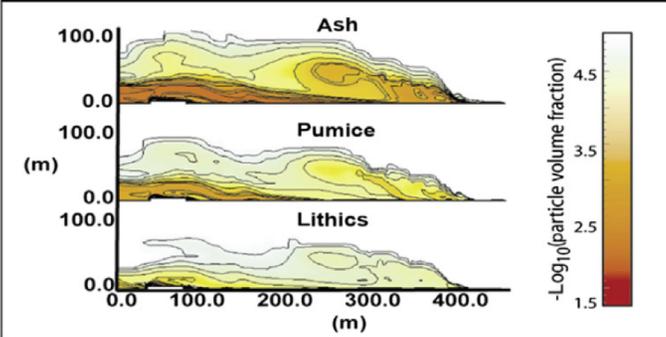
A Compressible Gas Phase Modulates the Dynamics of PDC in Several Ways



This Talk:

1. Recent model benchmark work for concentrated and dilute regimes using MFIX.
2. Turbulent structure and internal mixing in PDC.
3. Discussion of entrainment parameterizations.
4. Implications for thermal structure and discussion.

Modelling PDC

	<p>Dilute, 1D models</p> <ul style="list-style-type: none">-Turbulent, homogeneous flows (particles suspended by turbulence)-Front condition given by constant Froude number
	<p>Depth-averaged coulomb models</p> <ul style="list-style-type: none">-Thin, concentrated flows-Frictional interaction at the bed controls flow motion
	<p>Multiphase models</p> <ul style="list-style-type: none">-Separate conservation equations for multiple particle types-Drag between the gas and particles transmits momentum between phases

Mean Field Multifluid Equations

Continuity

$$\frac{\partial}{\partial t'} (\alpha^m \rho') + \frac{\partial}{\partial x'_i} (\alpha^m \rho' u'_i) = 0$$

Momentum

$$\frac{\partial(\alpha \rho' u'_i)}{\partial t'} + \frac{\partial(\alpha \rho' u'_i u'_j)}{\partial x'_i} =$$

LES Closure Scheme
Granular Stress Closure Scheme

$$\left[\frac{N(\alpha, e)}{\rho \mathbf{M}_0^2} \right] \frac{\partial(P')}{\partial x'_i} + \left[\frac{1}{\mathbf{Re}} \right] \frac{\partial}{\partial x'_i} [\tau_{ij}'] - \left[\frac{1}{\mathbf{St}} \right] ({}^1 u'_i - {}^2 u'_i) + \left[\frac{1}{\mathbf{Fr}_d^2} \right] \alpha \hat{e}_g$$

Thermal Energy

$$\rho' c'_p \left[\frac{\partial T'}{\partial t'} + U'_i \frac{\partial T'}{\partial x'_i} \right] = \left[\frac{1}{\mathbf{Pe}} \right] \frac{\partial q'}{\partial x'_i} + \left[\frac{1}{\mathbf{Th St}} \right] (T'_p - T'_f)$$

Subscripts:

$m=1,2,3$ (1 is gas phase and 2 and 3 are particle phases)

$s,p=2$ and 3 (particle phases)

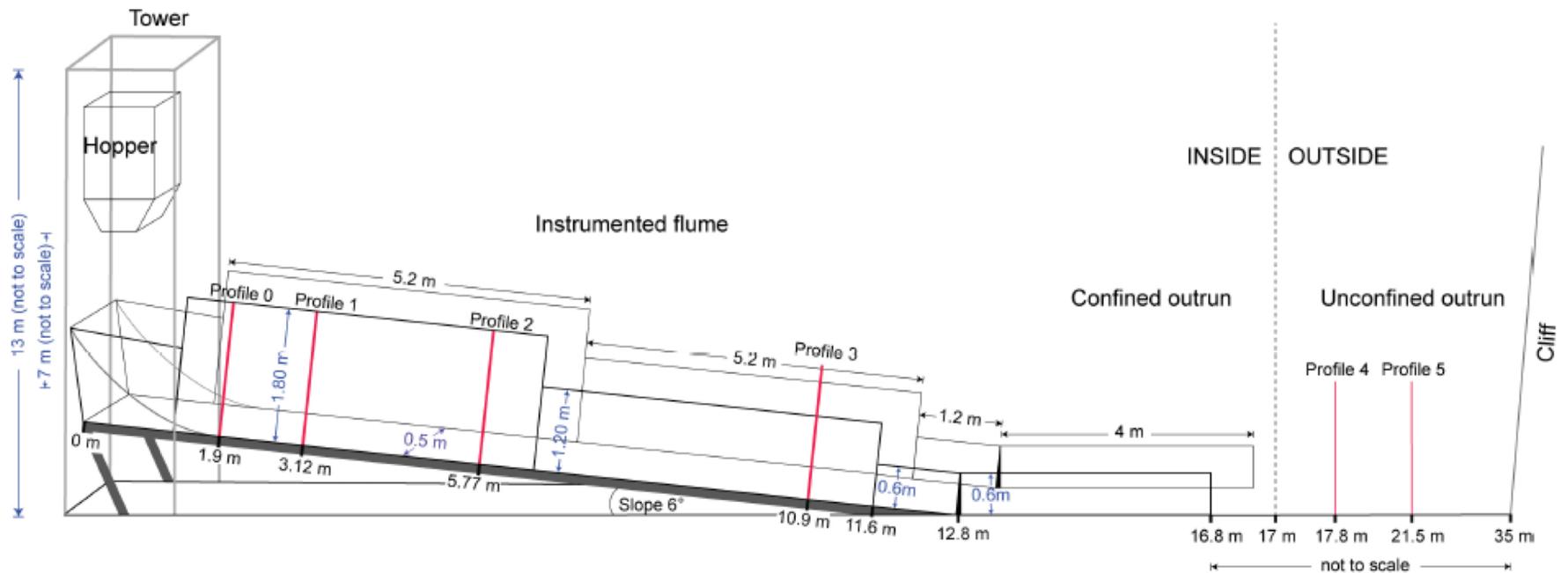
$i,j=1,2$ (indices for spatial direction)

$$\frac{H_0 U_0}{\sqrt{g_0} H^*}$$

Using MFX solver

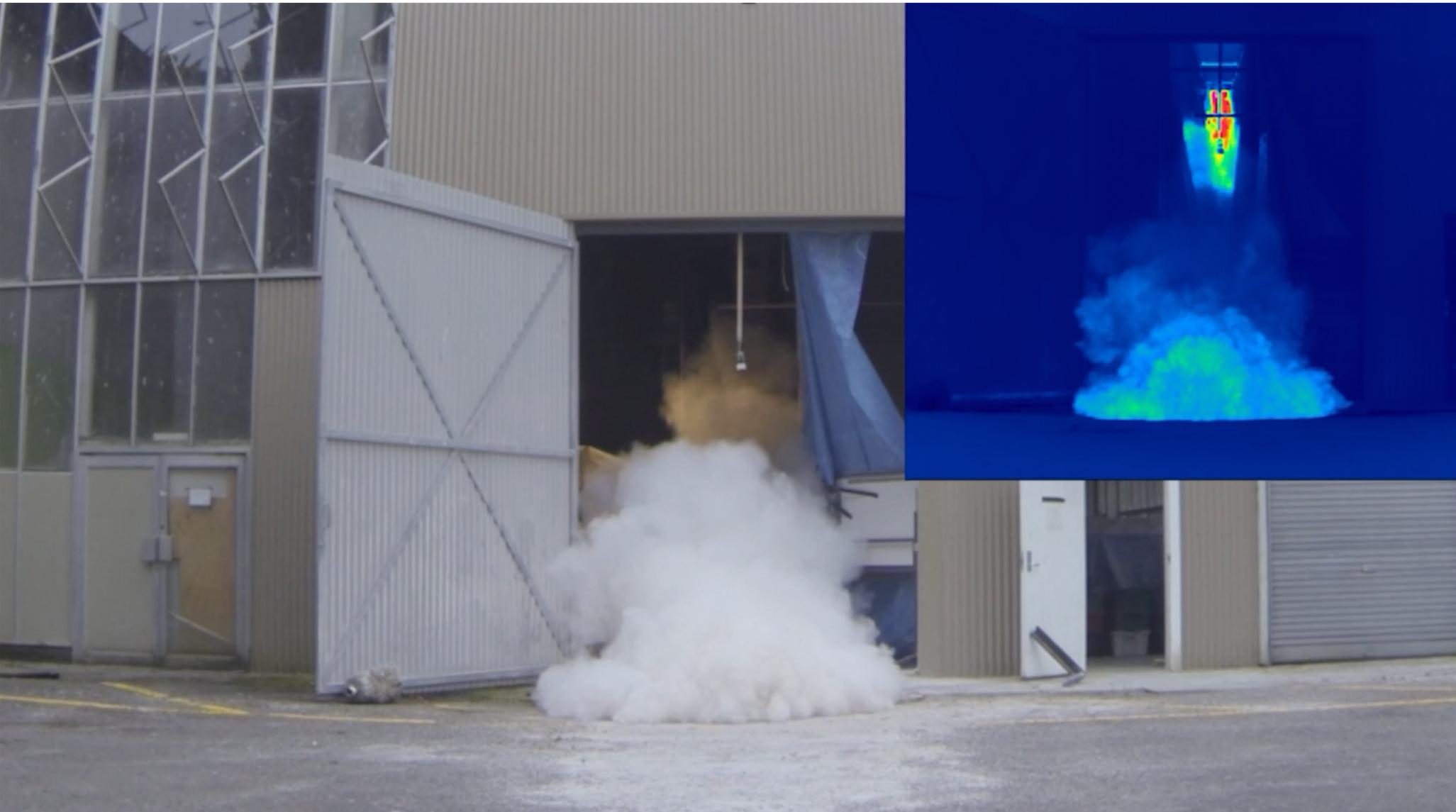
PELE Experiments – Validation in Dilute and Mixed Regimes

Boundary conditions

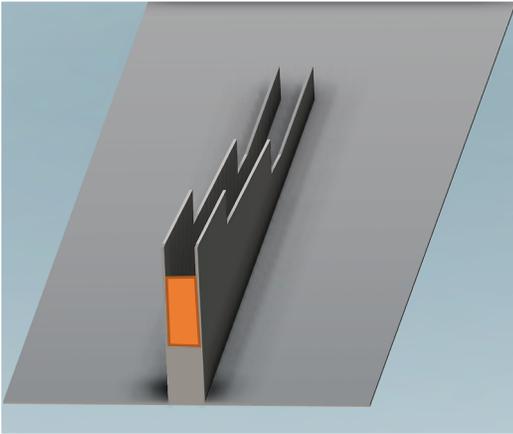


Cerminara et al, 2018

Lube et al., 2015

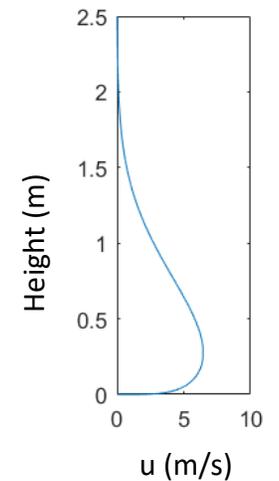


Initial and boundary conditions: inlet conditions



Mass inflow boundary conditions are derived from experimental data:

- 1) Set a vertical velocity profile for the u (parallel to slope) velocity component
- 2) Set a temperature profile to gas and solid
- 3) Used the Sauter mean diameter of 36 microns.
- 4) Solid density = 2385.93 Kg/m^3
- 5) Grid resolution of 0.015 m

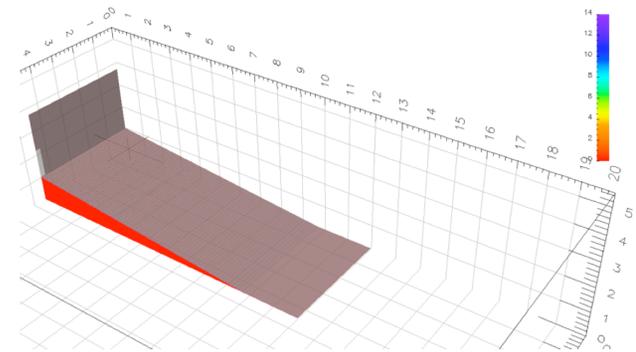
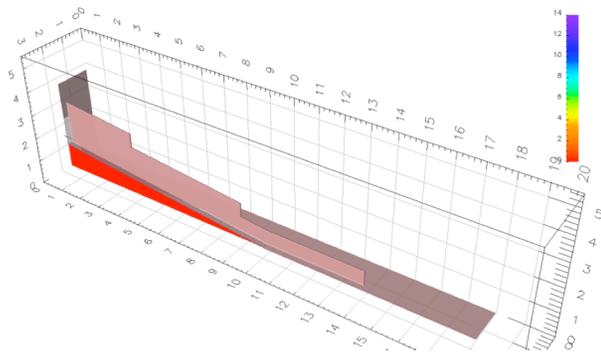


Exp. 1 – PELE comparison, channelized

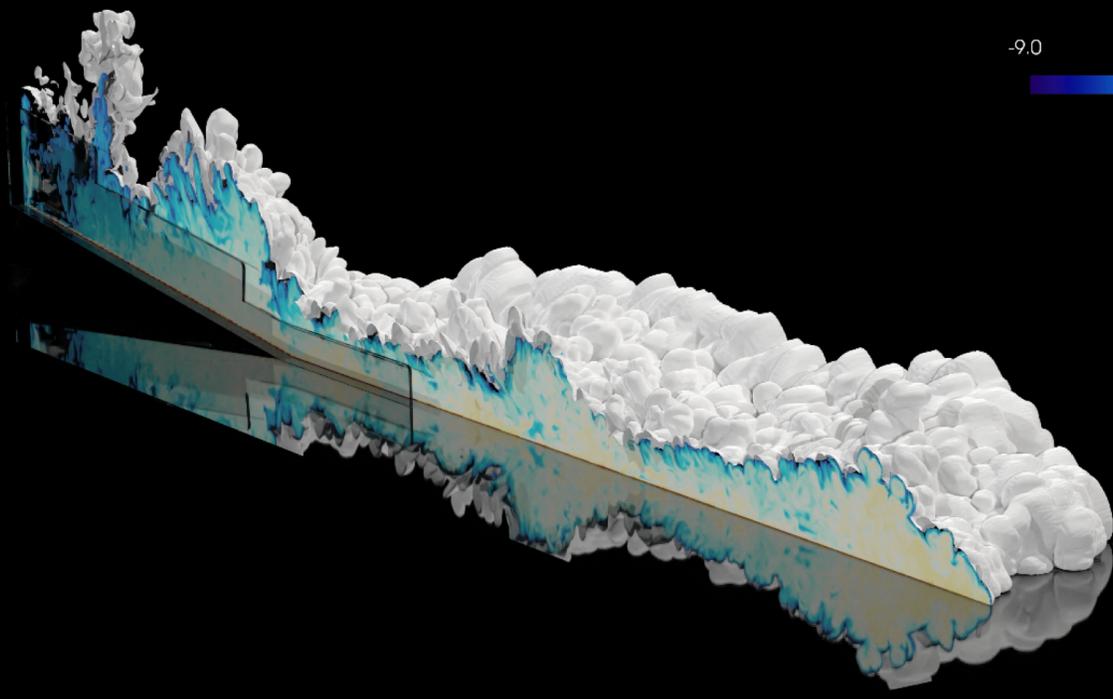
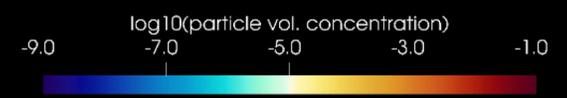
Exp. 2 – Hot, channelized flow

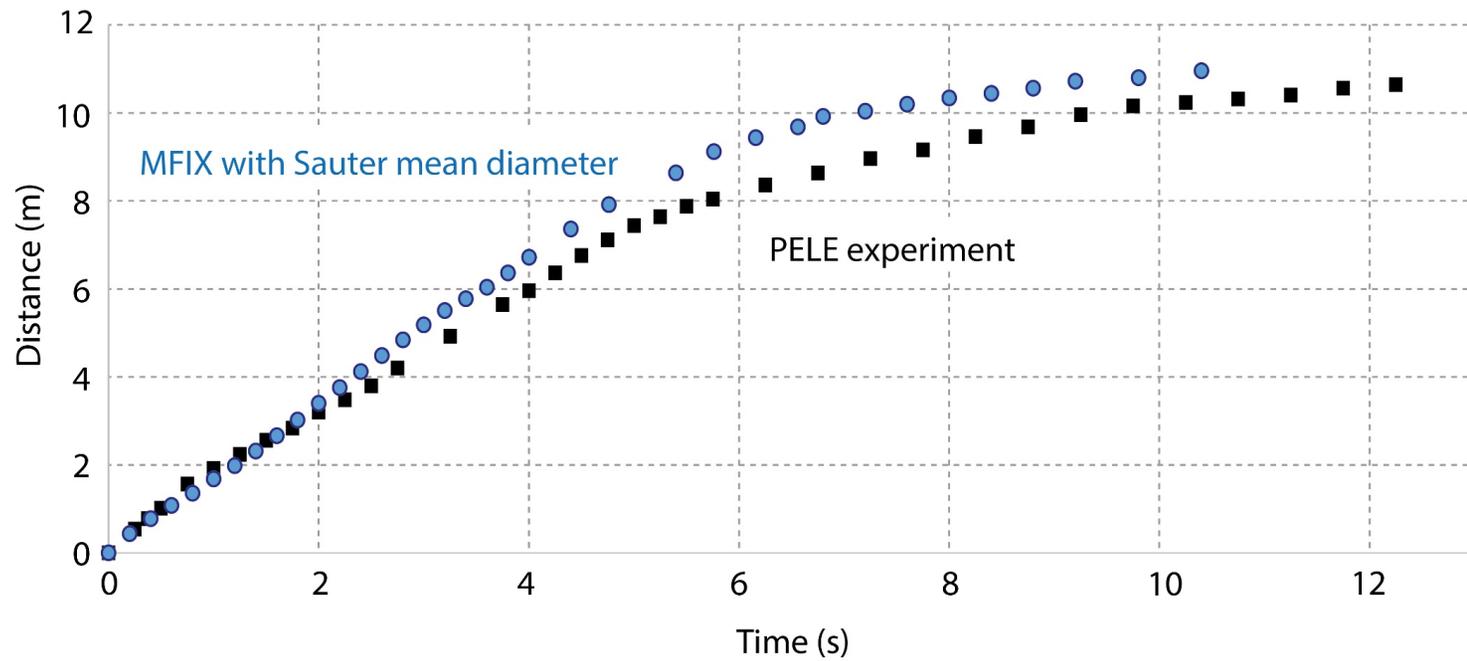
Exp. 3 – Cold, unconfined

Exp. 4 – Hot, unconfined



Time: 9.20 s

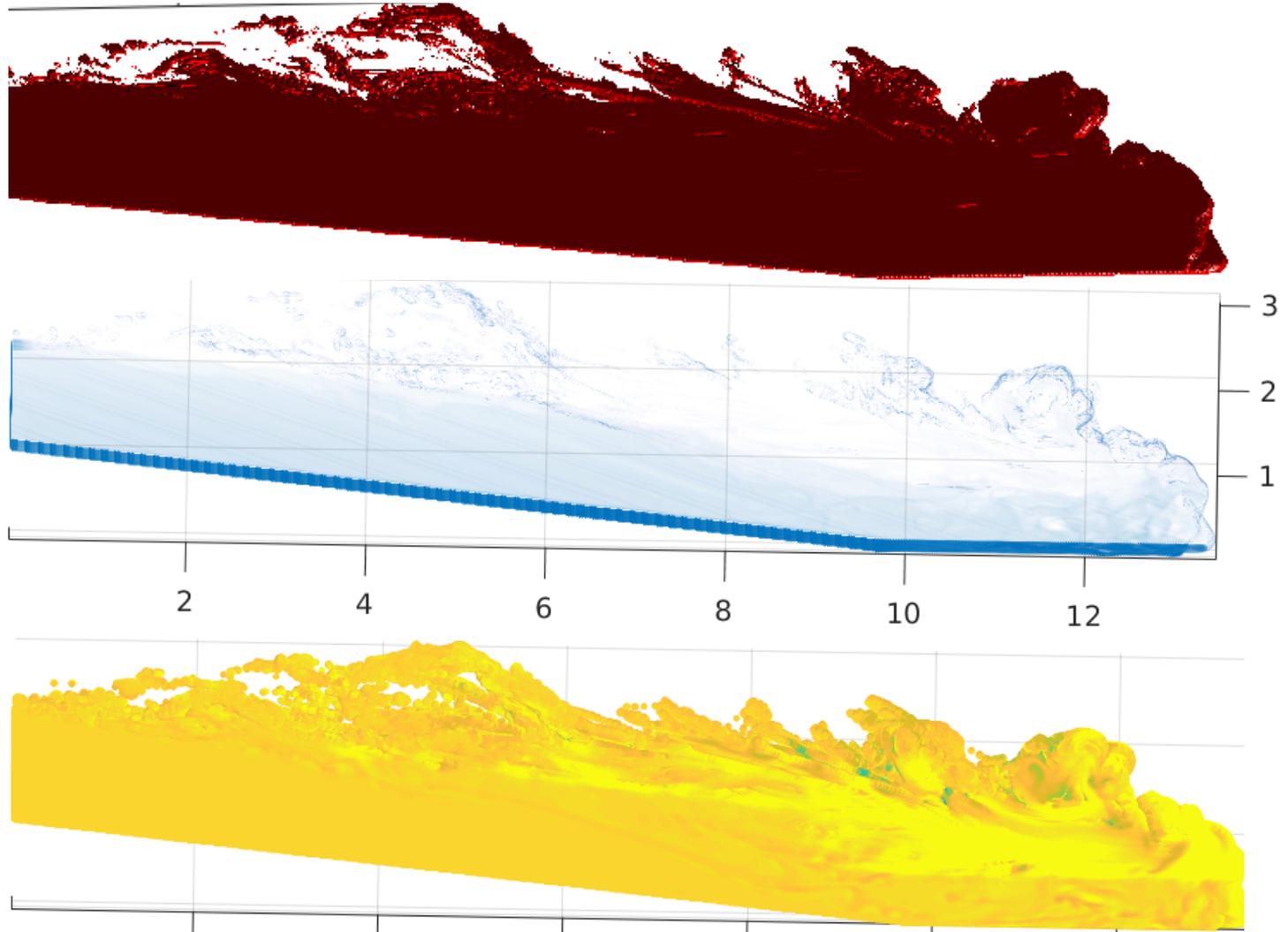




- Flow front kinematics are better matched if the domain outside the channel is large enough to capture cross-stream ambient air entrainment in the flow

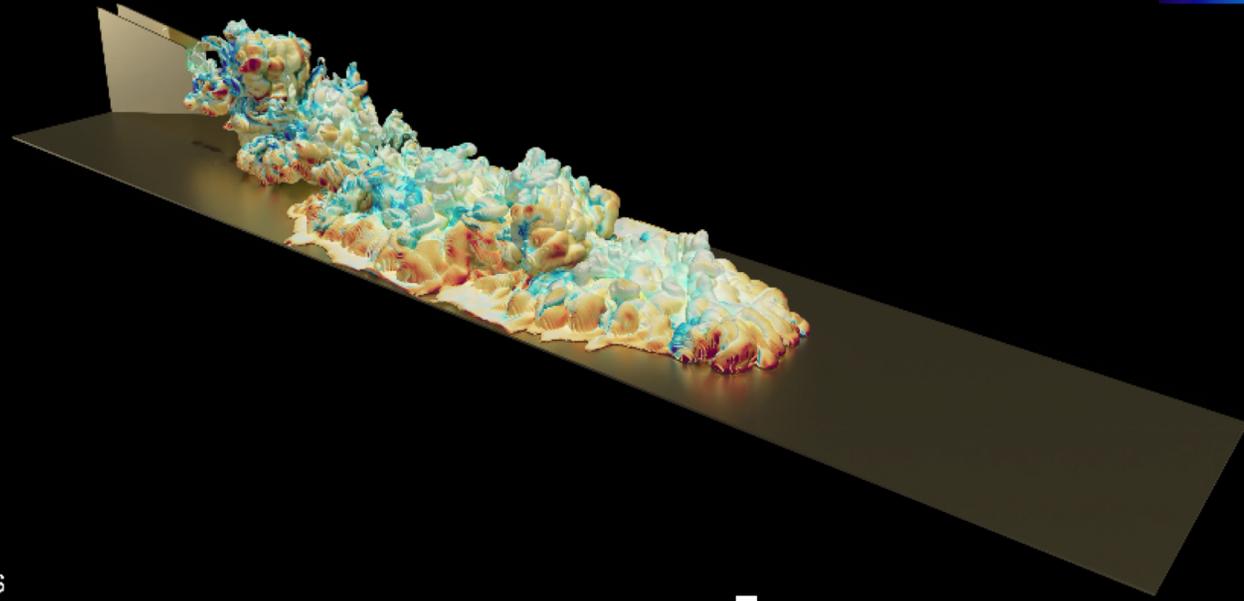
Computing Entrainment

1. Determine an isosurface of volume fraction of particles using a marching cubes algorithm.
2. For each part of the surface assign a normal vector and area.
3. Interpolate the 3D gas velocity field to the points on the isosurface and compute the dot product to determine flux.
4. Normalize with cross-stream velocity.



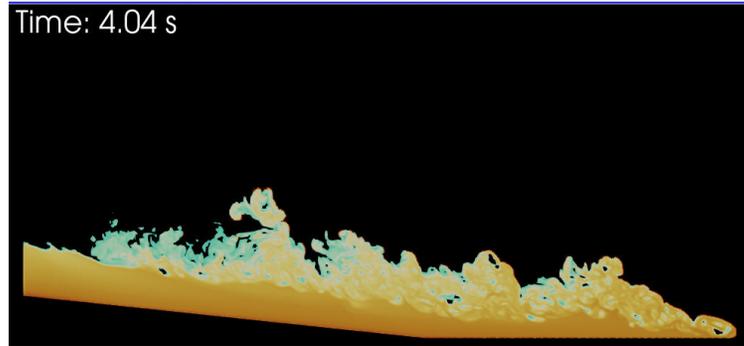
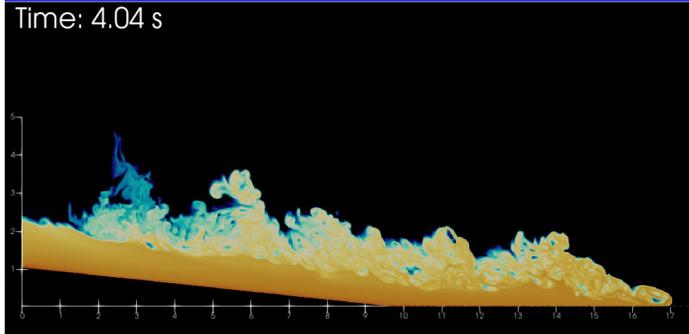
Local entrainment/expansion coefficient

-1.0 -0.5 0.0 0.5 1.0



Time: 5.00 s

10^{-6} Volume Fraction



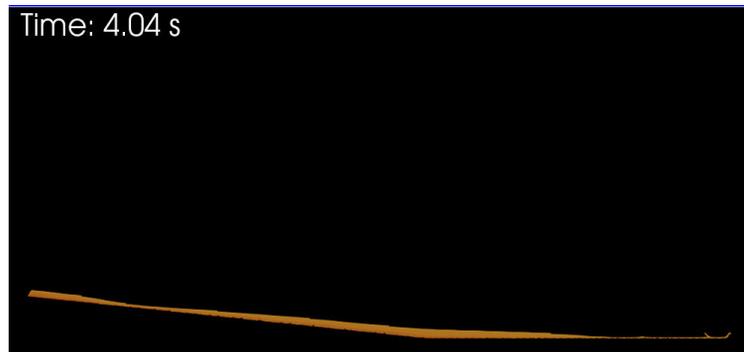
Isosurface = 1×10^{-6} Particle
Volume Frac

$$\bar{E} = .19$$



Isosurface = 1×10^{-4} Particle
Volume Frac

$$\bar{E} = .06$$



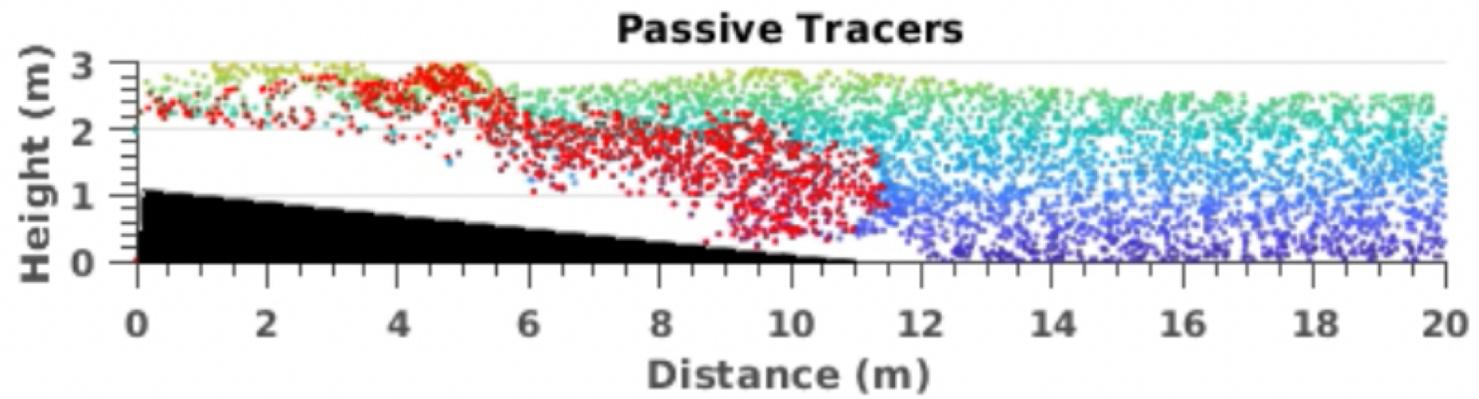
Isosurface = 1×10^{-3} Particle
Volume Frac

$$\bar{E} = .02$$

Values are
dependent on
selection of
volume fraction.

0 17 m

Passive Tracers give insight in to the entrainment mechanism



● Entrained Parcel

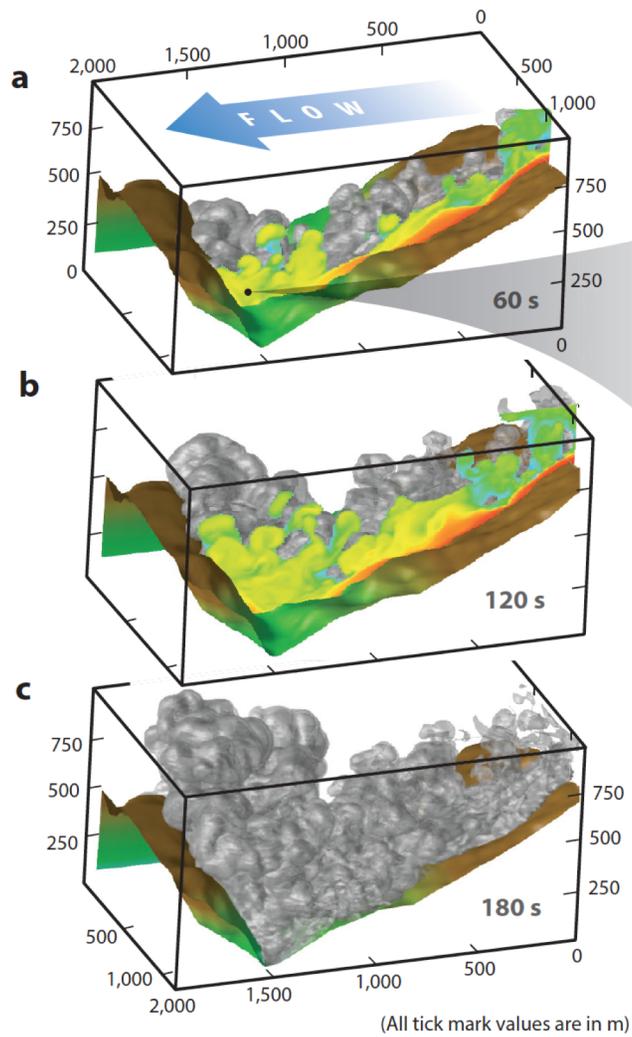
**Eruption of Tungurahua, Ecuador
Flow Transformation and Bed Interaction**



July 2006







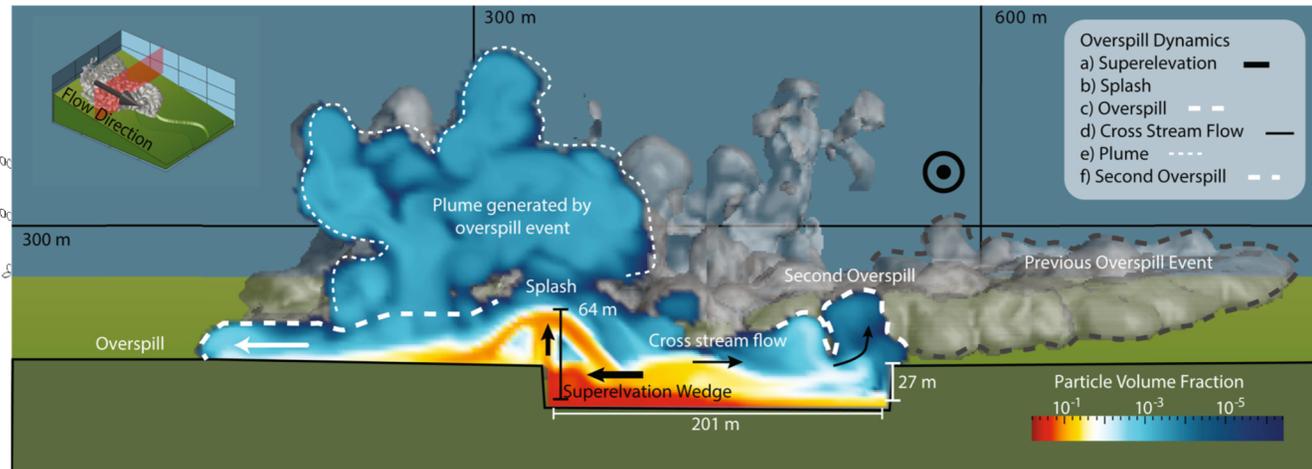
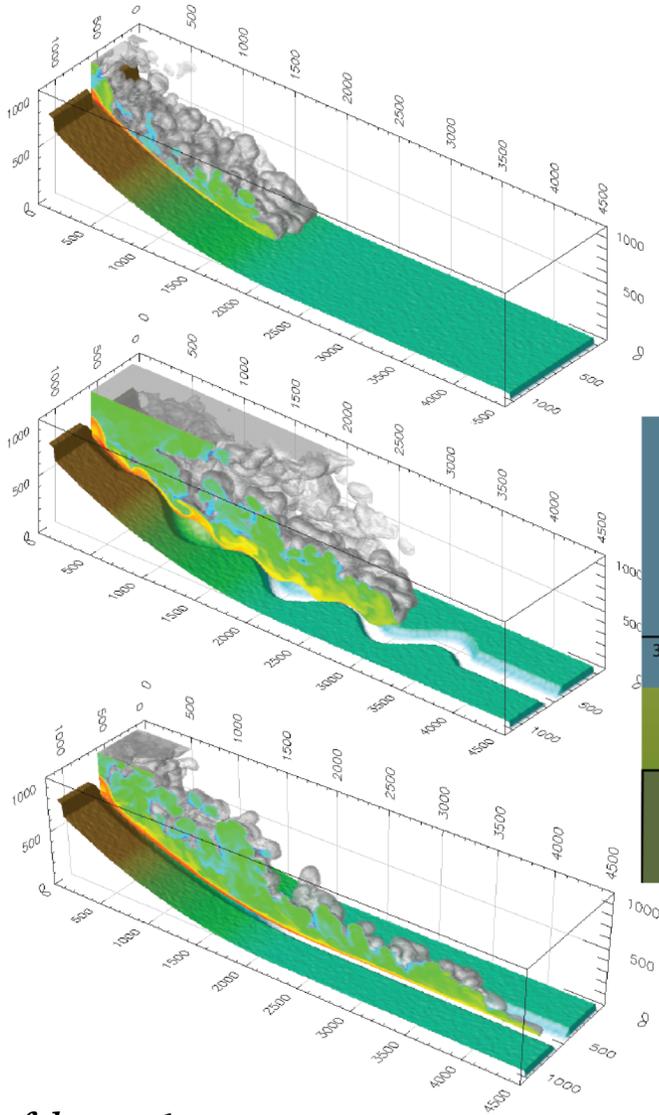
Bed forms:
Tungurahua 2006 eruption, Ecuador



From Figure 1e



Allison Kubo
Hutchison

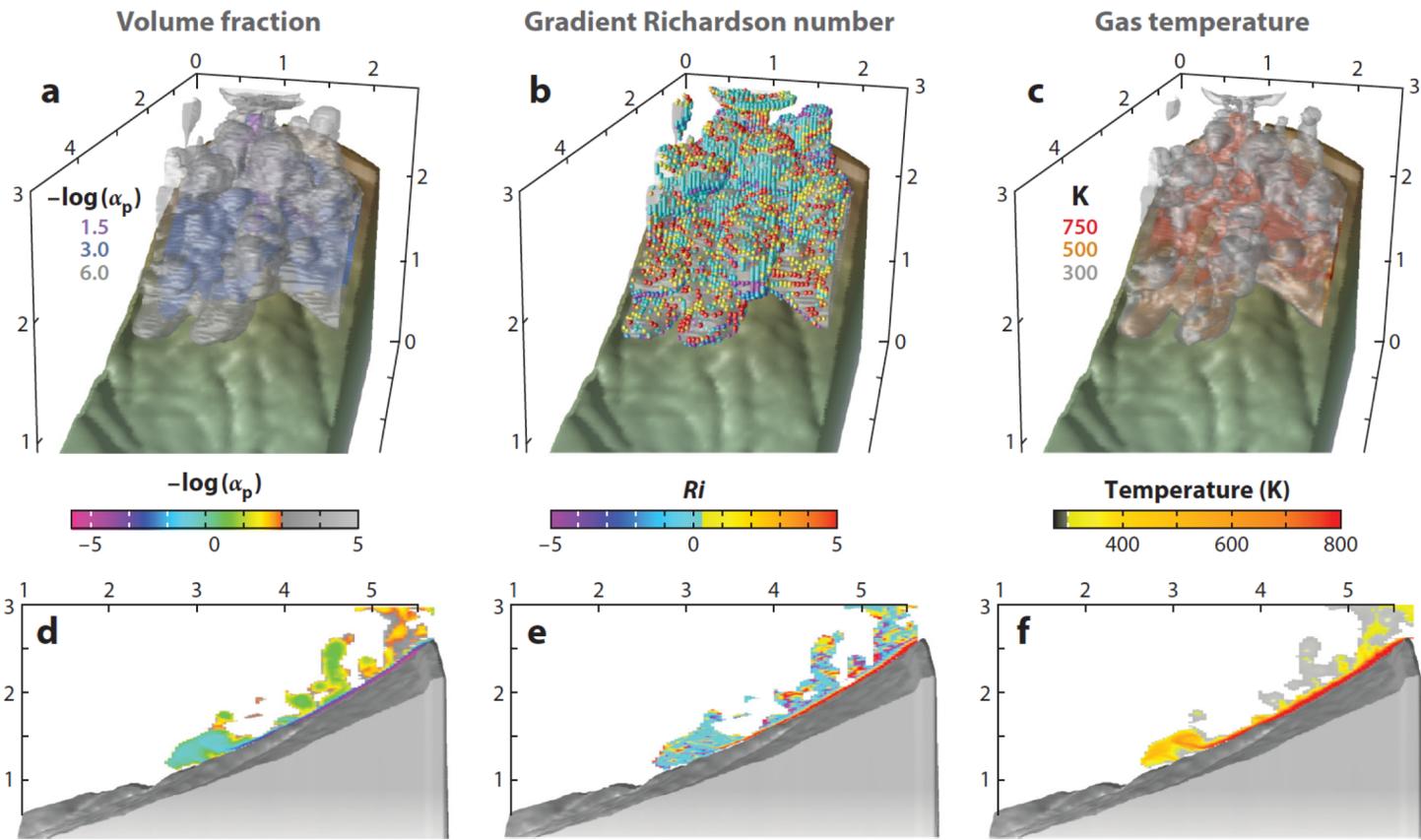


Dufek, 2016

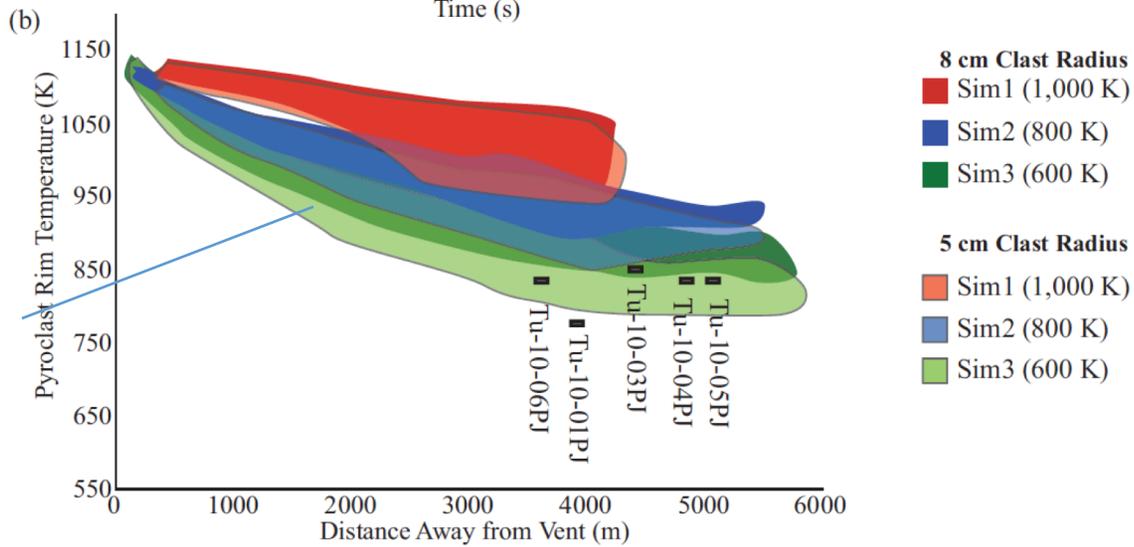
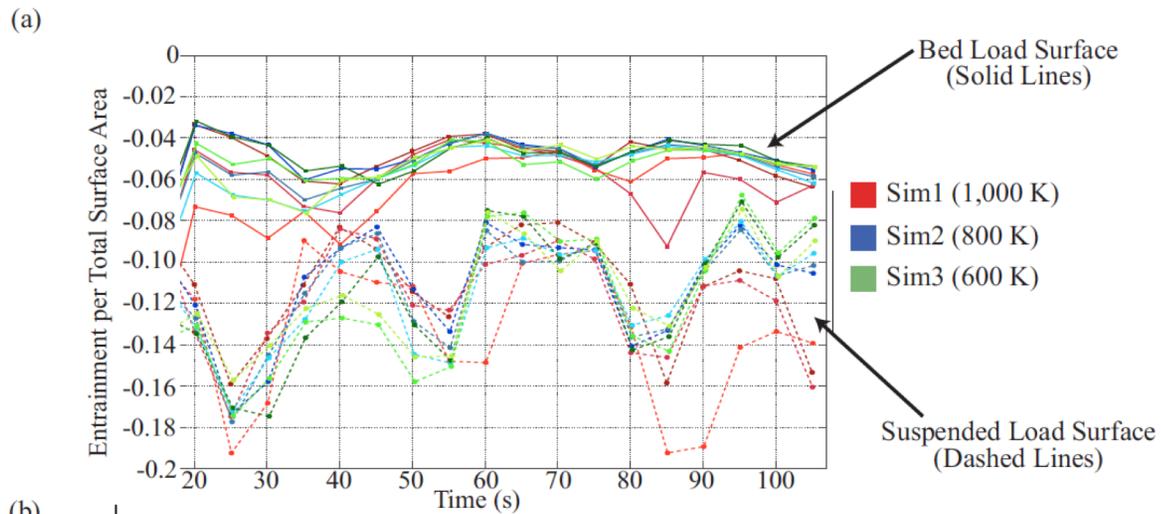
Kubo Hutchison and Dufek, 2021



Mary Benage

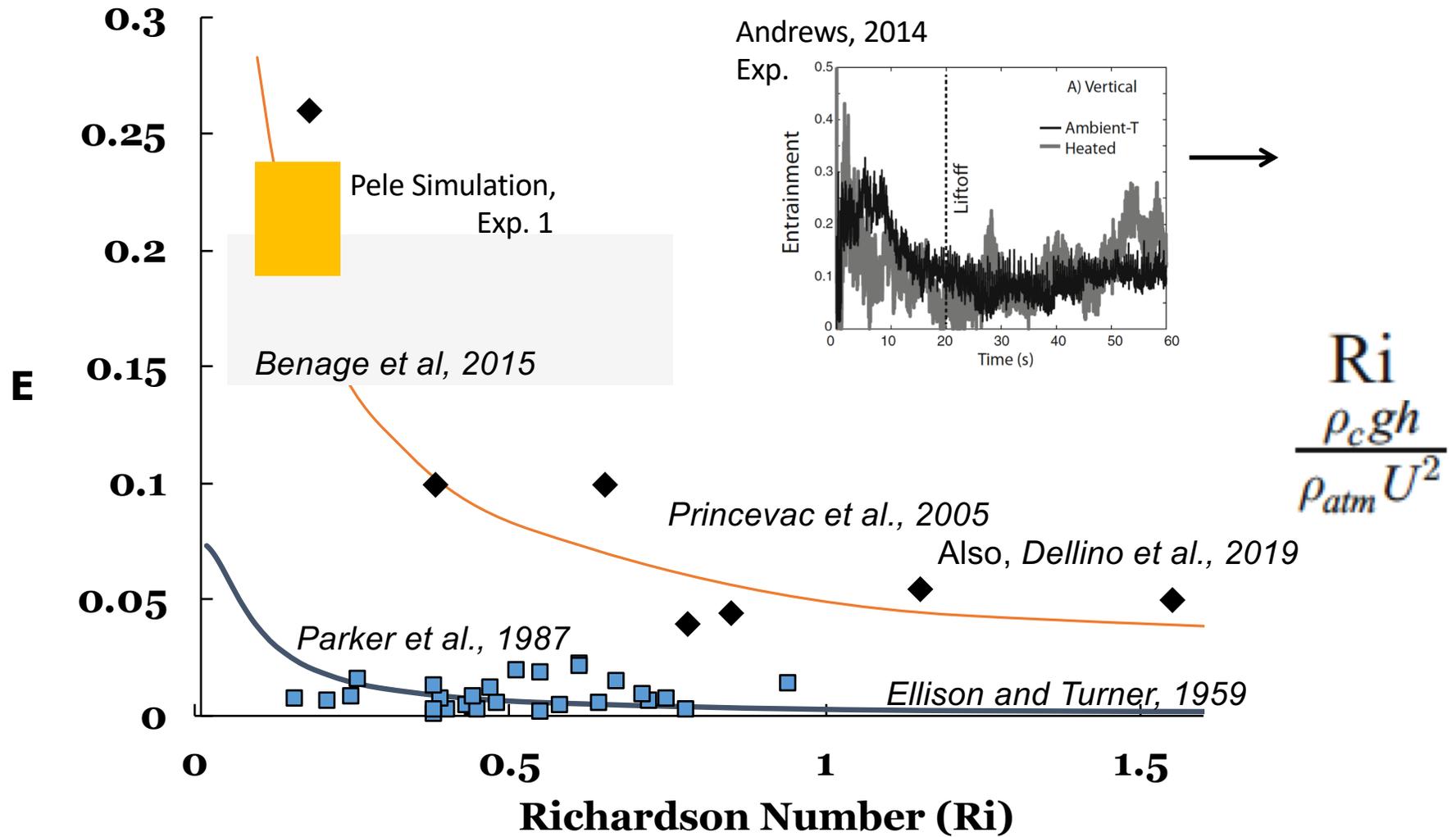


Benage, Dufek and Mothes, 2015



From Lagrangian tracers with Embedded bubble growth

Entrainment Summary



Summary

Microphysical interactions are not only important for conservation relationships but may yield insight into detecting obscured physical processes.

Tiered geophysical benchmarking exercises have value in determining the sensitivity of numerical approaches and understanding fundamental physics.

Entrainment coefficients are sensitive to choice of entraining surface and some work needs to be done in transmitting this information in a dynamically relevant way to simplified approaches.

Entrainment and mixing structure is particularly relevant to the thermal structure of these currents.

Flow transformation (dilute-dense, etc), are common in the transport of PDC.

EXTRA SLIDES