What's All the Talc About? Air Entrainment in Dilute Pyroclastic Density Currents

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Motivation

Pyroclastic Density Currents (PDCs) are hot clouds of rock and gas that are denser than air. They pose hazards to life, health and property. The shape of a PDC, the distance it travels, and whether it lifts off are controlled by entrainment, the rate at which air mixes into the current. Understanding how entrainment controls PDC behavior can help us anticipate and mitigate this hazard.

Methods

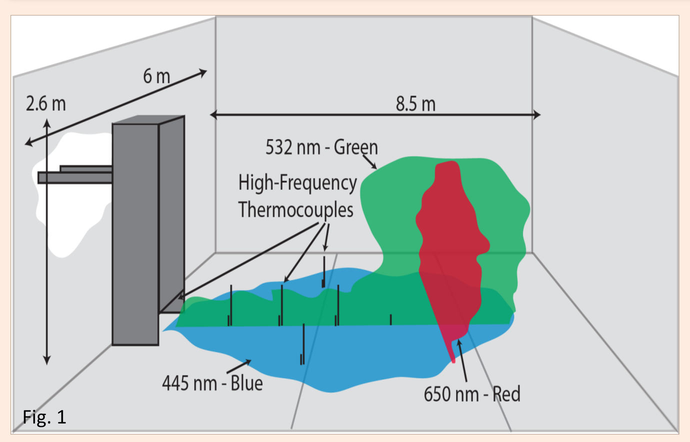


Fig. 1

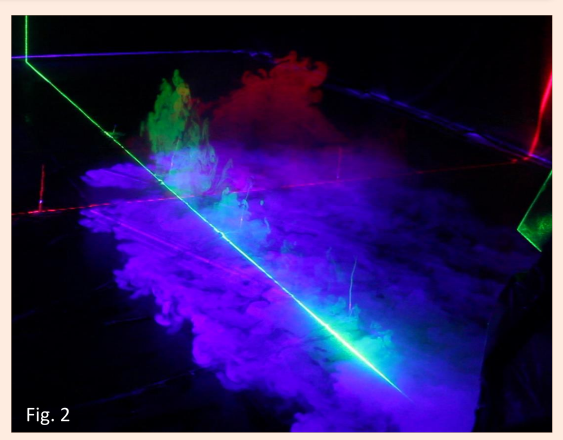
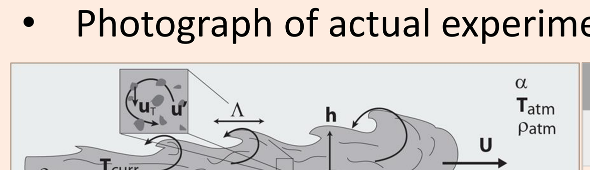


Fig. 2

- Experimental tank and dimensions (Fig. 1)
- Heated talc → poured onto conveyor belt → dropped into tank.
- Photograph of actual experiment (Fig. 2)



U – mean current velocity	u' – turbulent current velocity	u_T – particle fall velocity
ρ_{curr} – current density	ρ_{atm} – atmospheric density	h – current thickness
T_{curr} – current temperature	T_{atm} – atmospheric temperature	Λ - integral turbulent length scale

Fig. 3

	Scaling	Natural Dilute PDCs	Experiments
Re	$\frac{p_c U h}{\mu_{air}}$	10^8-10^{10}	10^3-10^4
Ri	$\frac{\rho_c g h}{\rho_{atm} U^2}$	0-10	0-20
Ri_T	$\frac{g \Delta T \propto h}{U^2}$	0-5	0-2
Fr	$\frac{U}{\sqrt{g' h}}$	~1	~1
S_T	$\frac{\tau u'}{f \Lambda}\left(1+\frac{\rho_c}{2\rho_p}\right)$	0.01-200	10^{-4}
Σ_T	$\frac{u_t}{u'}$	10^{-6}-10^5	<1
KE	$\frac{\rho_c U^2}{2}$	10^3-10^4 J/m³	0-1 J/m³
TE_b	$\rho_c \left(\frac{C_{p,curr}}{C_{p,atm}}\right) \propto g \Delta T h$	10^3-10^4 J/m³	0-0.3 J/m³

Table 2

- Cartoon demonstrating scaling with defined variables for experimental PDCs (Fig. 3)
- Scaling equations and comparisons between natural and experimental dilute currents (Table 2)

Measurements

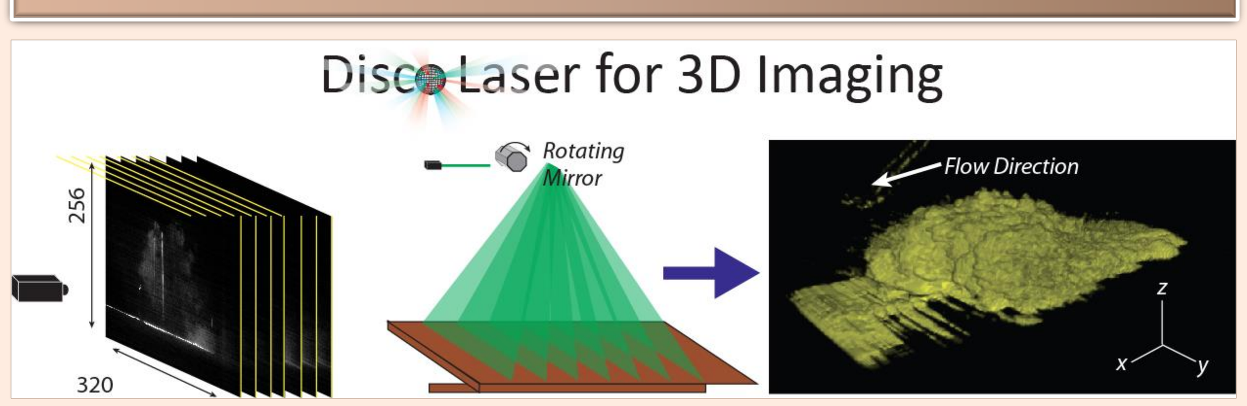


Fig 4.

Imaging experiments and collecting visual data (Fig. 4)

- Rotating lasers sweep tank at 12 hz • Field of view: 2x4 meters
- High speed camera at 1000 hz captures images of current
- Stitched images provide 3D picture of current during its evolution

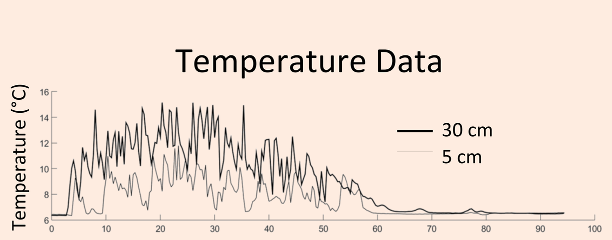


Fig. 5

Collecting temperature data (Fig. 5)

- 30 channels of thermocouples
- Area: 2x4 meters
- Records temperature data at 3 hz
Height off floor: 30 cm and 5 cm

Results

Entrainment (ϵ) is the rate at which air is mixed into the current over the velocity at which the current is moving. Entrainment in PDCs cause buoyancy reversal and liftoff, forming ash plumes.

$$\epsilon = \frac{U_e}{U_s}$$

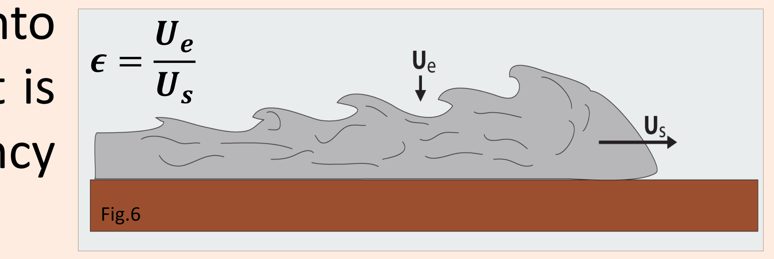


Fig.6

Parameter Space Explored

Initial Mass (g) △ ~ 1000 □ ~ 1500 ▷ ~ 2300

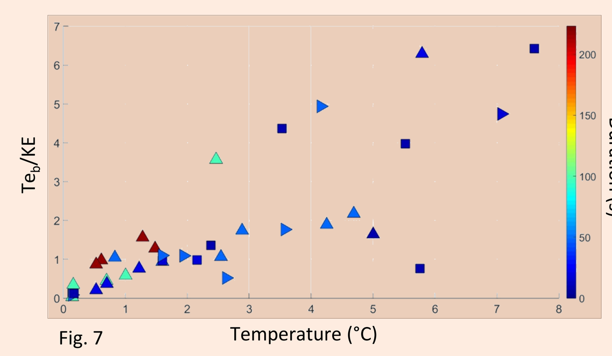


Fig. 7

Mean temperature differences within the currents range from 0.1 to 7.6°C. TE_b/KE ranges from 0.03 to 6.4.

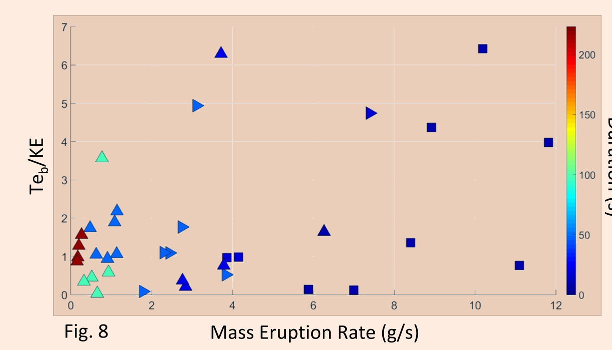


Fig. 8

Mass eruption rates for experiments range from 0.15 to 45.6 (g/s).

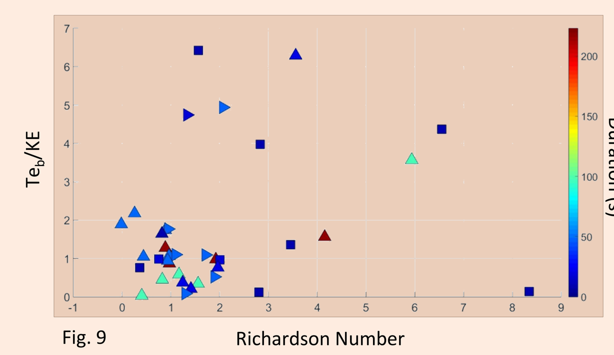


Fig. 9

Richardson number for currents range from ~ 0 to 26.9.

Representative Experiments

Both experiments have a duration of 50 seconds. **a-c.** 1000 g at 150°F **d-f.** 1000 g at 300°F

- Cooler currents do not lift off.
  - Spread along tank floor
- Talc particles have ambient temperatures
- As current is fed upstream:
  - Entrains air through current head and body
  - Develops wide current front
  - Dissipates horizontally

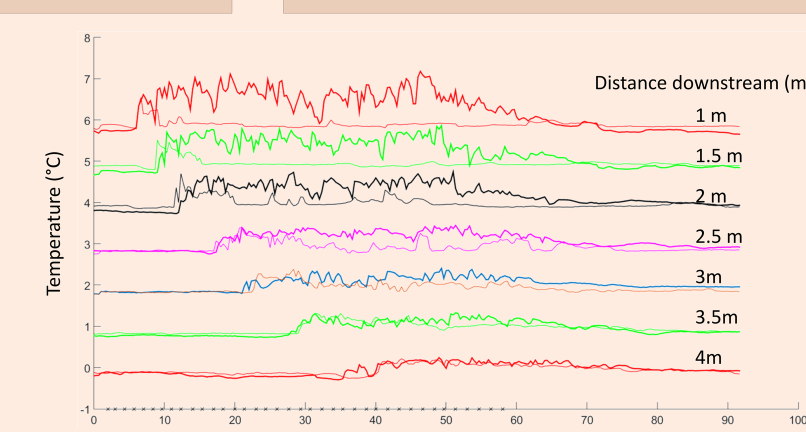


Fig. 10

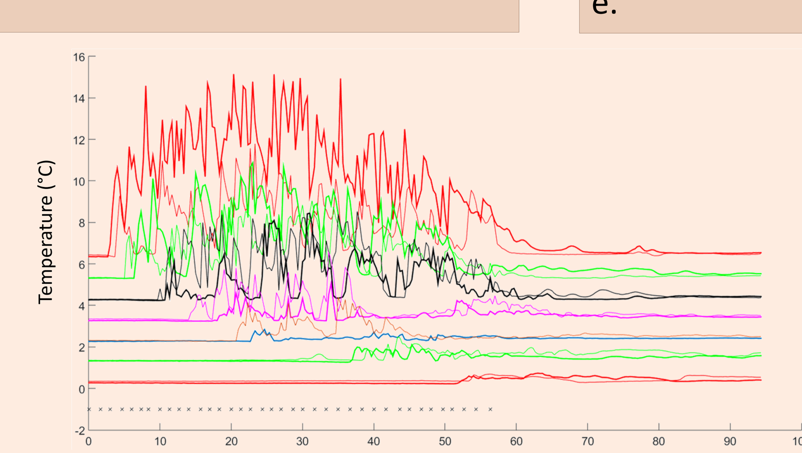


Fig. 11

- Hotter currents liftoff, forming plumes
  - Travel downstream in a confined space.
- Talc particles hotter than ambient air
- As current is fed upstream:
  - Entrains air through head and body
  - Air entrainment leads to thermal expansion
  - Expands and lifts off vertically as a plume

Discussion

Initial Mass (g) △ ~ 1000 □ ~ 1500 ▷ ~ 2300

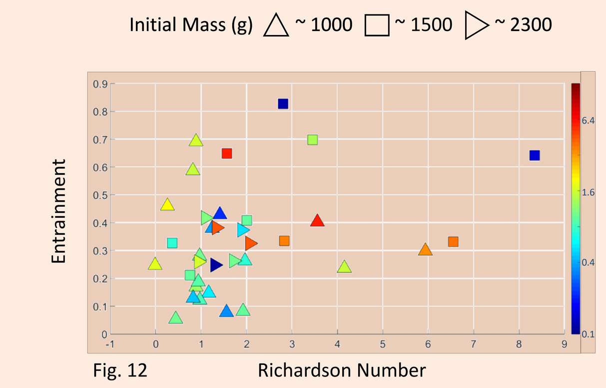


Fig. 12

- Bulk entrainment rates range from < 0.1 to > 0.7 prior to current liftoff
- Bulk entrainment does not show simple systematic variation with Ri or TE_b/KE

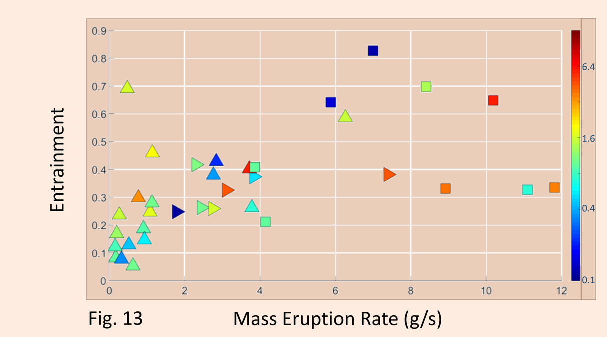


Fig. 13

- Bulk entrainment increases with Mass Eruption Rate

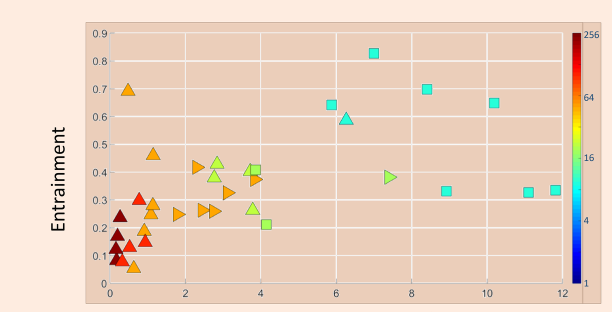


Fig. 14

- Eruption duration appears to control bulk entrainment: short eruptions have higher entrainment than longer eruptions

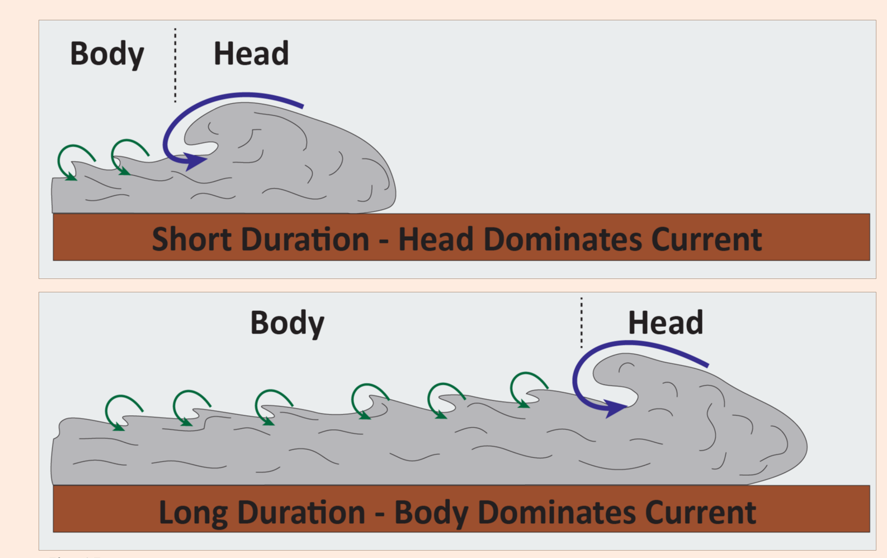


Fig. 15

- **Different parts of PDCs have different entrainment rates**
- **Current heads entrain air very efficiently: > 0.5**
- **Current bodies entrain air less efficiently but at rates comparable to previous predictions: ~ 0.1**

Fig. 16

Experimental volcanology enable scientists to safely study the behavior of dangerous and unpredictable volcanic events (Fig. 16).

Fig. 17

June 25, 1997 PDC destroys landscape and kills over two dozen people. Soufriere Hills Volcano, Montserrat, West Indies (Fig. 17).

Acknowledgments and References

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