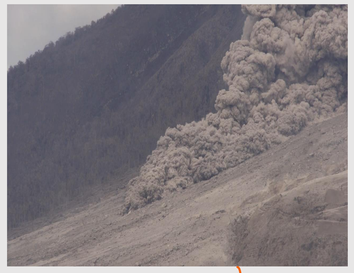
3D Turbulence and Air Entrainment in Pyroclastic Density Currents from Video Analysis

Ajayi Ayomide[1,2] and Benjamin J. Andrews[2]

[1]University of Maryland, Department of Geology. [2]Smithsonian Institution, National Museum of Natural History, Department of Mineral Sciences.

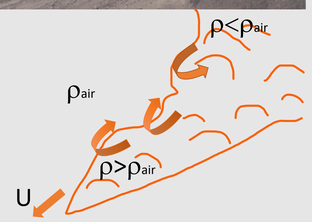
Introduction

- Pyroclastic Density Current (PDCs) are mixtures of hot gas, volcanic ash and rocks that flow along the ground away from a volcano.
- PDCs can entrain air through turbulent mixing. Air entrainment allows the flow to form plumes that may rise/lift off the ground.



- We used video of the 2014 Sinabung eruption to measure entrainment. "credit: M.Szeglat".

Pyroclastic flow going down the side of Sinabung volcano.



Sketch of entrainment into the flow. The eddies closer to the ground have turbulence going clockwise and the rising plumes are moving anti-clockwise.

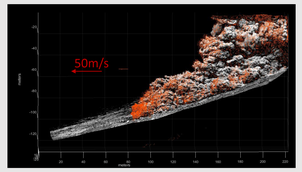
U= velocity
ρ= density
ρ_{air}= air density

Importance

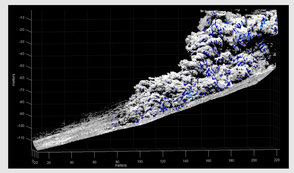
- Air entrainment in PDCs affects how far PDCs travel and how high the plumes rise thus affecting hazards to people and aviation.

Results

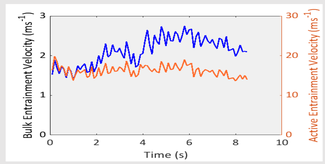
PDC going down the slope with the plumes rising. "credit: M.Szeglat".



3D velocity from first image.



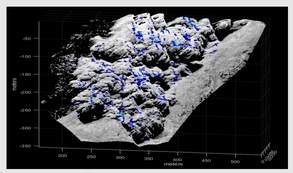
3D surface entrainment field from first image.



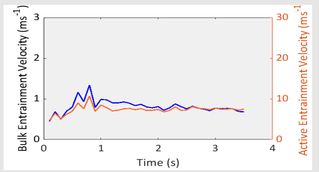
3D air entrainment rate.

- Bulk entrainment velocities of < 3m/s.
- Entrainment occurs over ~ 10% of PDC surface.
- Active entrainment velocities of 7-20m/s.

The PDC flowing down steep slope of Sinabung volcano near the vent. "credit: M.Szeglat".

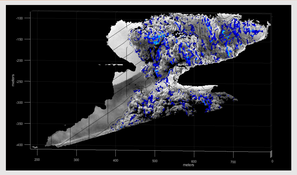


3D surface entrainment field from first image.

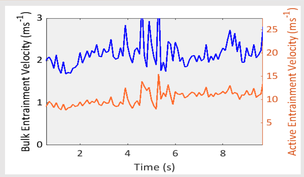


3D air entrainment rate.

PDC flowing across lower flank and generating large plume. "credit: M.Szeglat".



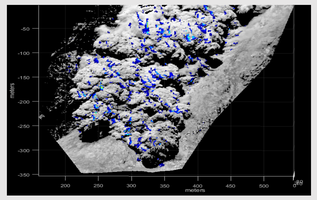
3D surface entrainment field from first image.



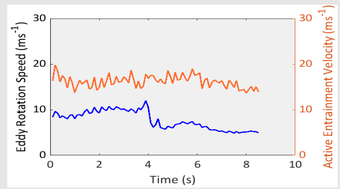
3D air entrainment rate.

Discussion

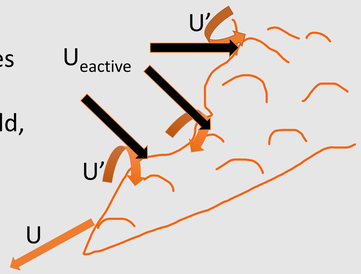
- PDCs entrain air turbulently; our results quantify turbulent entrainment but not entrainment through other mechanisms (e.g., lobe-and-cleft structures).



- Turbulent entrainment does not occur uniformly over the current surface; only about 10% of surface actively entrains air.
- Active entrainment velocity is an order of magnitude greater than the bulk velocity: $U_{eactive}$ = ~10 U_{ebulk} .
- Active entrainment velocity is more than twice the eddy rotation rate (or >4 times the characteristic turbulent velocity U').



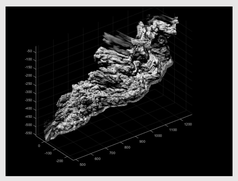
- Entrainment velocities are controlled by the turbulent velocity field, with entrainment exceeding the turbulence intensity.



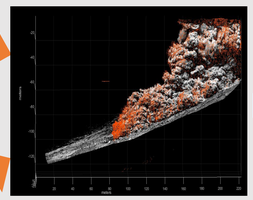
Methods

Made video clips from original video and separated each frame for analysis. "credit: M.Szeglat".

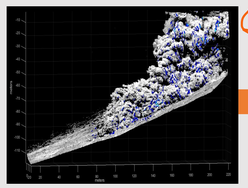
2D velocity field generated from image cross-correlation. "credit: M.Szeglat".



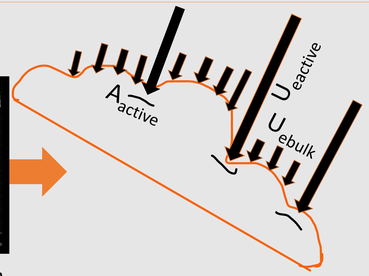
3D surface model from single camera technique (Coonin and Andrews, 2020).



Projected the 2D velocity field onto 3D surface to obtain 3D turbulent velocity field. Scale field using topographic features.



Entraining regions (blue) are areas (A_{active}) with inward directed velocities. Total entrainment (V) is sum of inward velocities.



Bulk entrainment velocity: $U_{ebulk} = V/A$.
Active entrainment velocity: $U_{eactive} = V/A_{active}$.

References

- Coonin A and Andrews BJ, 2020. AGU Fall Meeting, V008-0013
- Global Volcanism Program, Sinabung volcano. https://volcano.si.edu/volcano.cfm?vn=261080
- Google Earth, 2021.

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