Fluid Dynamics of Pyroclastic Density Currents

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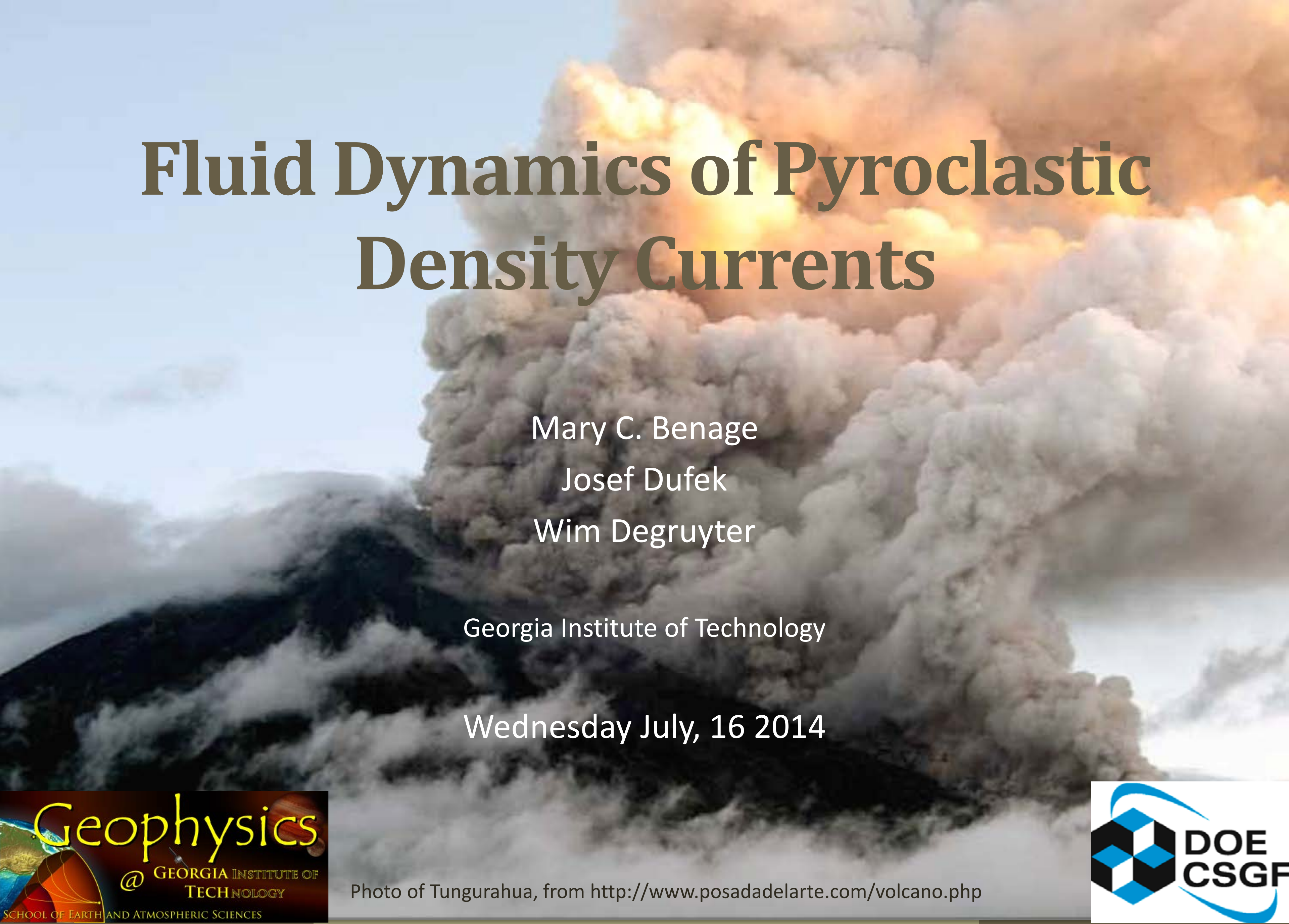


Photo of Tungurahua, from http://www.posadadelarte.com/volcano.php

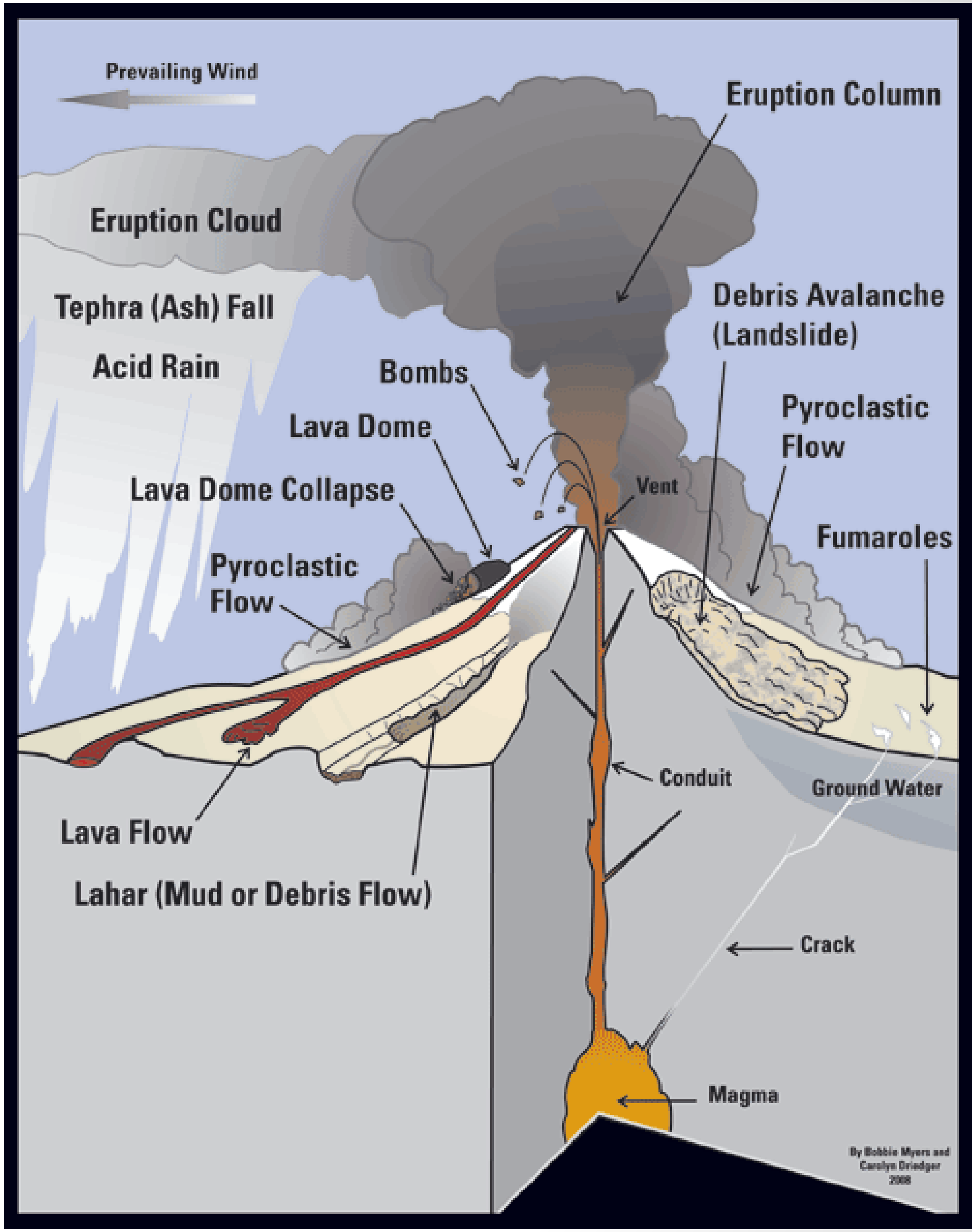
Motivation

- Pyroclastic Density Currents (PDCs) the most dangerous local hazard.
- Understand current dynamics and potential hazards
- No direct observations of internal forces, concentration gradients, temperature

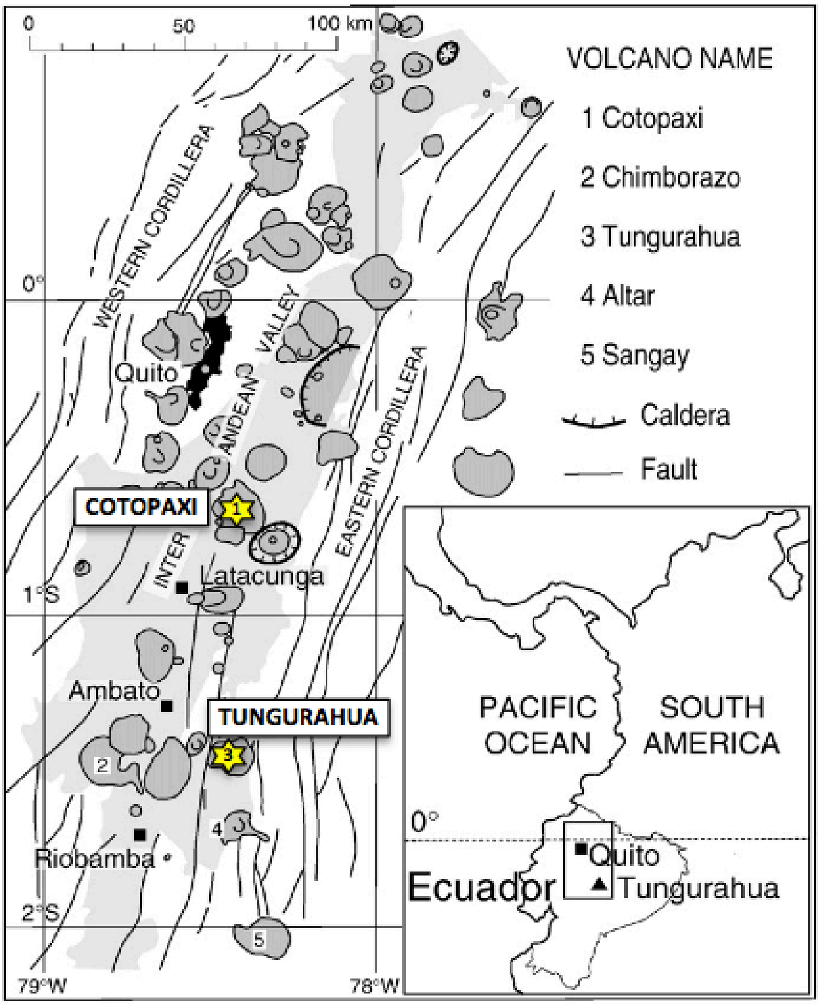
Unzen Volcano. Photo by Setsuya Nakada, 1993 (Kyushu University)

Background

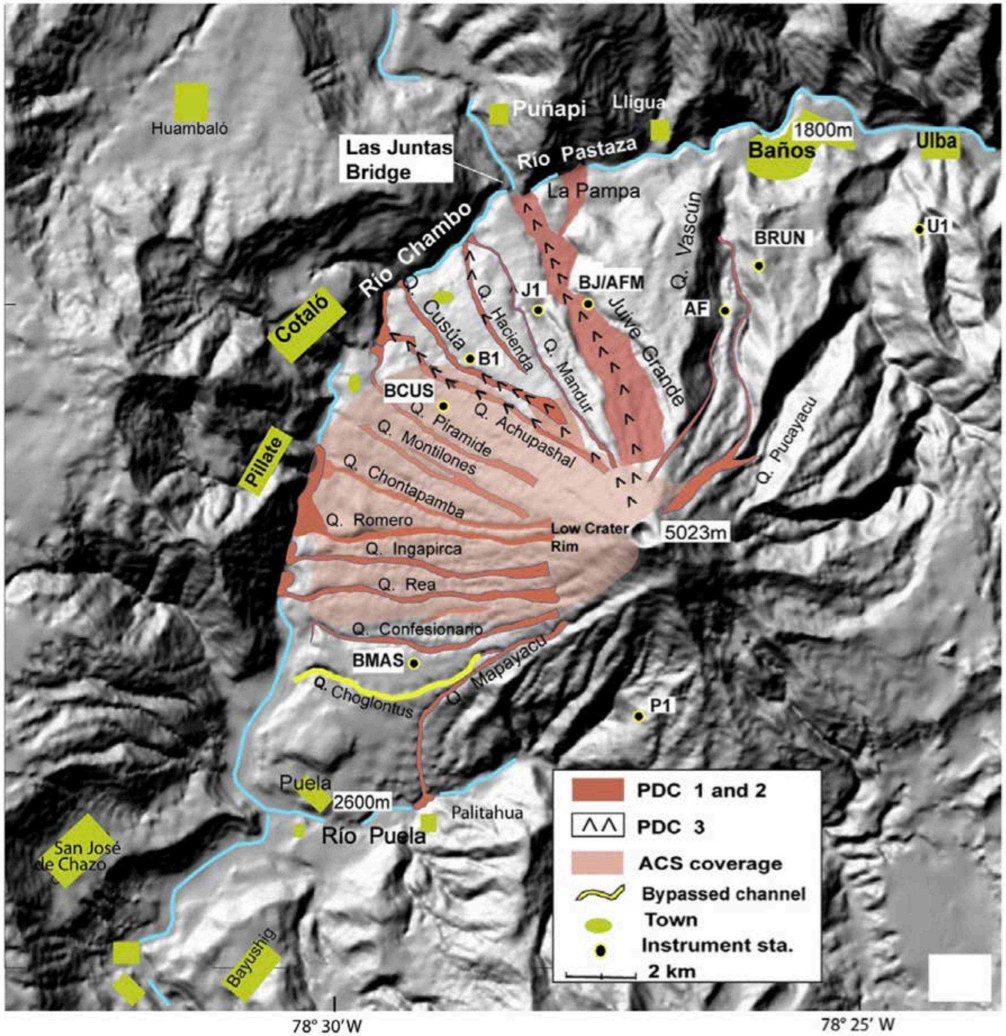
- SiO_2 melt with dissolved volatiles
- Volcanic eruptions composed of ash (micrometers), large particles, hot gases.
- Initial conditions mostly unknown
- Deposits used to infer transport process



Tungurahua



0
50
100 km
VOLCANO NAME
1 Cotopaxi
2 Chimborazo
3 Tungurahua
4 Altar
5 Sangay
Caldera
Fault
WESTERN CORDILLERA
INTER ANDEAN VALLEY
EASTERN CORDILLERA
Quito
COTOPAXI
Latacunga
Ambato
TUNGURAHUA
Riobamba
0°
1°S
2°S
79°W
78°W
PACIFIC OCEAN
SOUTH AMERICA
Ecuador
Quito
Tungurahua



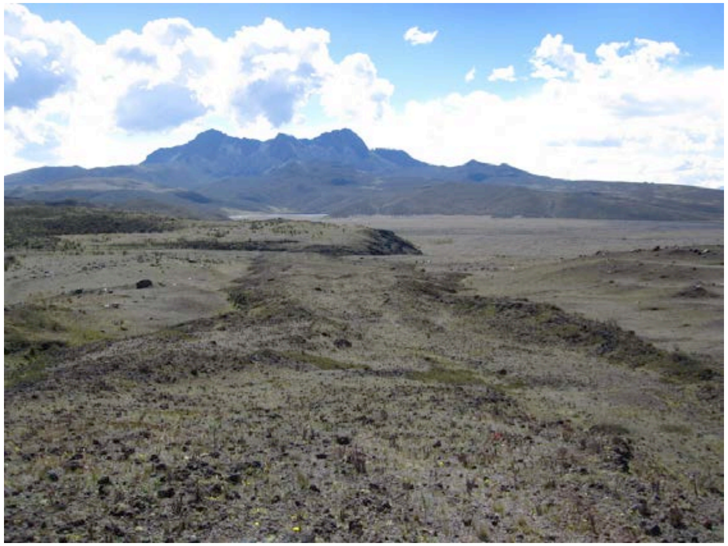
Huambaló
Puñapi
Lligua
Las Juntas Bridge
Río Pastaza
1800m
Baños
Ulba
La Pampa
Río Chambo
Cotaló
Pillate
Q. Vascún
BRUN
U1
J1
BJ/AFM
AF
Cusúa
Q. Hacienda
Q. Mandur
Juive Grande
B1
BCUS
Q. Piramide
Q. Achupashal
Q. Montilones
Q. Chontapamba
Q. Pucayacu
Q. Romero
Low Crater Rim
5023m
Q. Ingapirca
Q. Rea
Q. Confesionario
BMAS
Q. Mapayacu
Q. Choglontus
P1
Puela
2600m
Río Puela
Palitahua
San José de Chazo
Bayushig
PDC 1 and 2
PDC 3
ACS coverage
Bypassed channel
Town
Instrument sta.
2 km
78° 30' W
78° 25' W

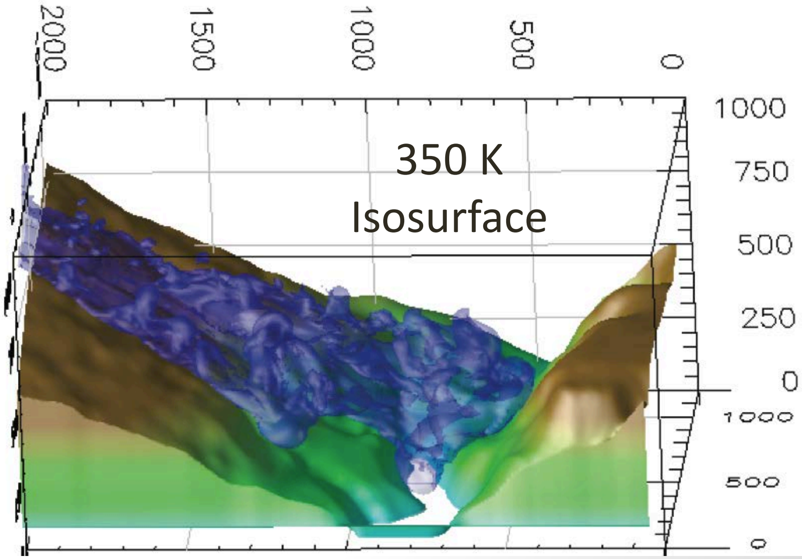
Tungurahua Eruption Feb. 1, 2014

Volcanic Deposits

Multiphase Numerical Models

- Quantify the forces and examine the interworking dynamics of PDCs.
  - Concentration Profiles
  - Entrainment of Air
  - Flow Transformation
  - Influence of topography





Computational Challenges

- Multiple scales of fluid flow
- Multiple concentrations
  - Dense to dilute
- Large scale 3D models
- Interaction with topography

Multiphase Numerical Models

Conservation of Mass

$$\frac{\partial}{\partial t}\left(\alpha_g \rho_g\right)+\frac{\partial}{\partial x_i}\left(\alpha_g \rho_g u_{g,i}\right)=0$$

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s\right)+\frac{\partial}{\partial x_i}\left(\alpha_s \rho_s u_{s,i}\right)=0$$

Conservation of Thermal Energy

$$\alpha_g \rho_g c_{Pg}\left(\frac{\partial T_g}{\partial t}+u_{g,i}\frac{\partial T_g}{\partial x_i}\right)=\frac{\partial q_g}{\partial x_i}-\overline{H}_{gs}$$

$$\alpha_s \rho_s c_{Ps}\left(\frac{\partial T_s}{\partial t}+u_{s,i}\frac{\partial T_s}{\partial x_i}\right)=\frac{\partial q_s}{\partial x_i}+\overline{H}_{gs}$$

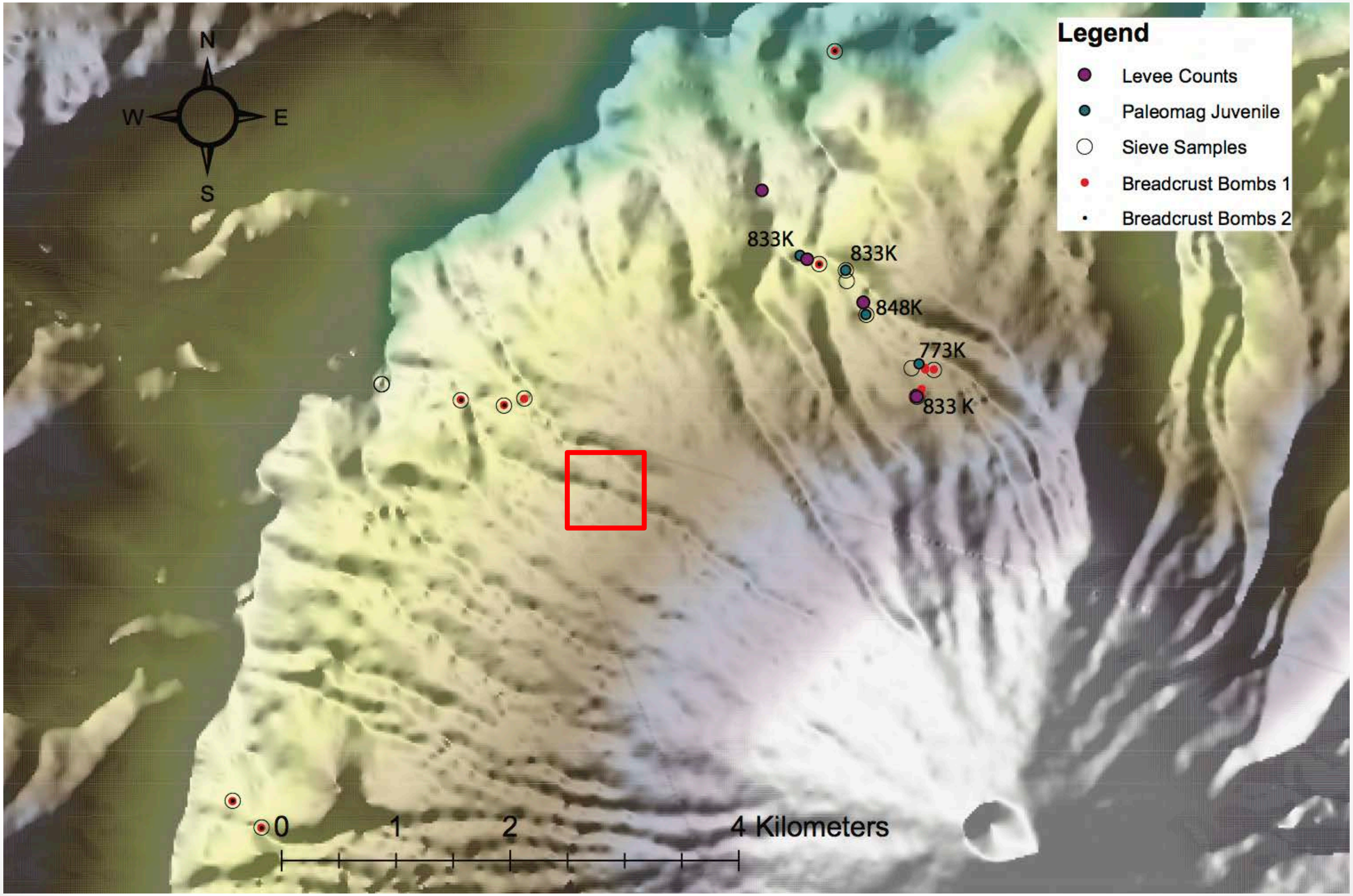
Conservation of Momentum

$$\frac{\partial}{\partial t}\left(\alpha_g \rho_g u_{g,i}\right)+\frac{\partial}{\partial x_i}\left(\alpha_g \rho_g u_{g,i} u_{g,j}\right)=\frac{\partial P_g}{\partial x_i}\delta_{ij}+\frac{\partial \tau_{g,ij}}{\partial x_j}+I_i+\alpha_g \rho_g g_i$$

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s u_{s,i}\right)+\frac{\partial}{\partial x_i}\left(\alpha_s \rho_s u_{s,i} u_{s,j}\right)=\frac{\partial P_s}{\partial x_i}\delta_{ij}+\frac{\partial \tau_{s,ij}}{\partial x_j}-I_i+\alpha_s \rho_s g_i$$

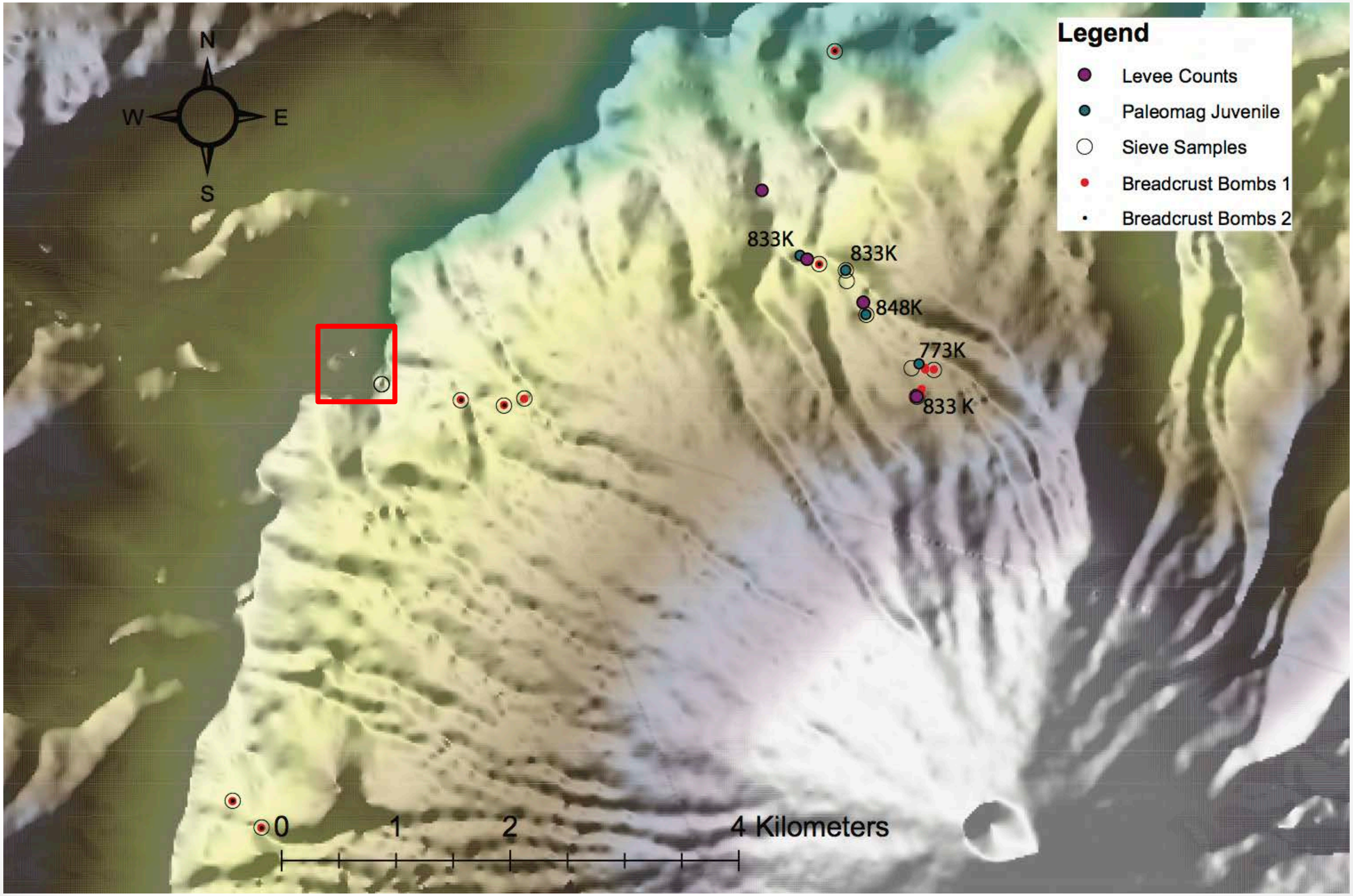
Dufek et al., 2009

Achupashal



N
W
E
S
Legend
Levee Counts
Paleomag Juvenile
Sieve Samples
Breadcrust Bombs 1
Breadcrust Bombs 2
833K
833K
848K
773K
833 K
0
1
2
4 Kilometers

Achupashal



N
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833K
848K
773K
833 K
0
1
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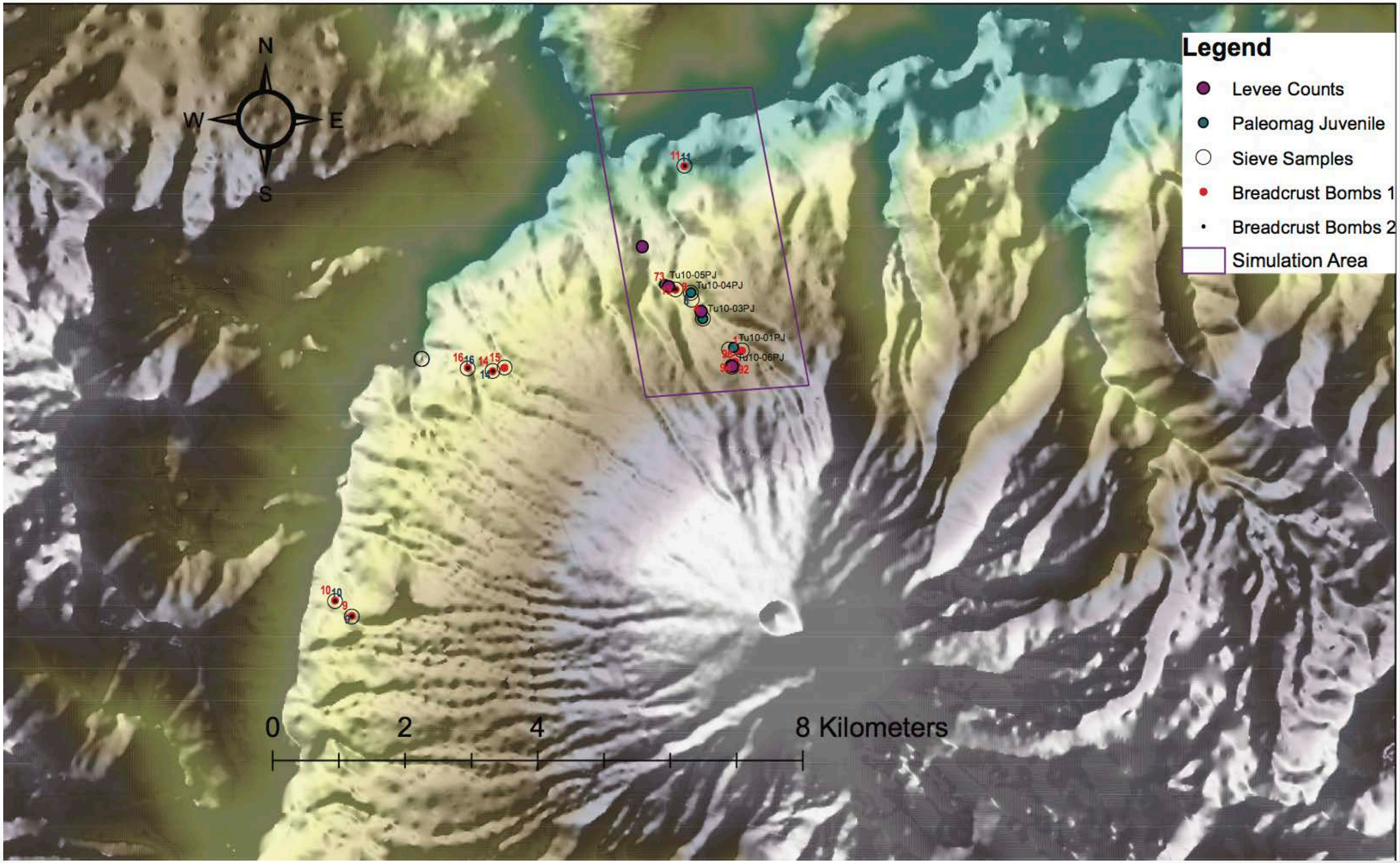
Achupashal – Dense to Dilute Flow

Volum
Partic

10^{-5} G
10^{-2} B

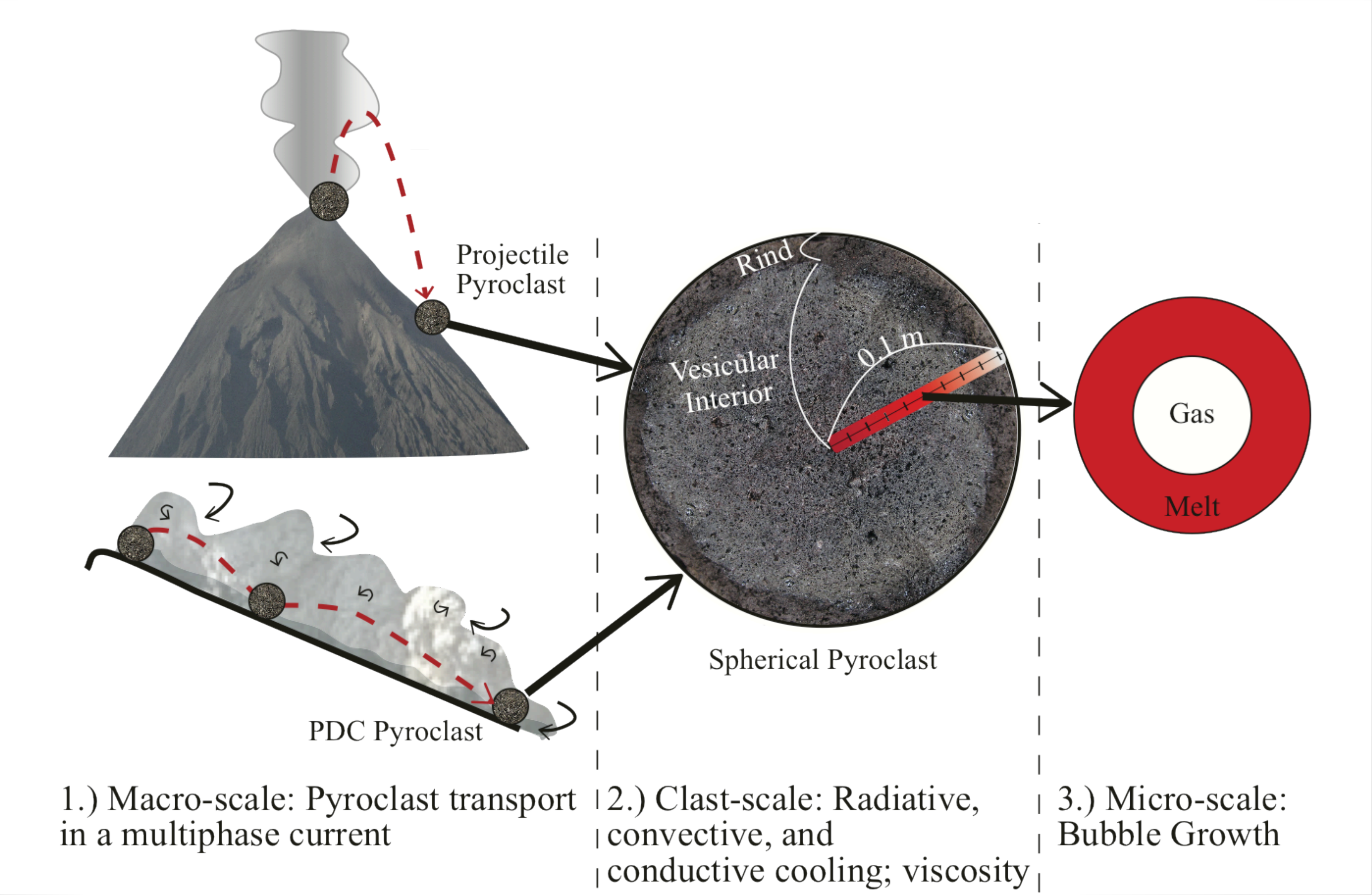
3D – Multiphase Models



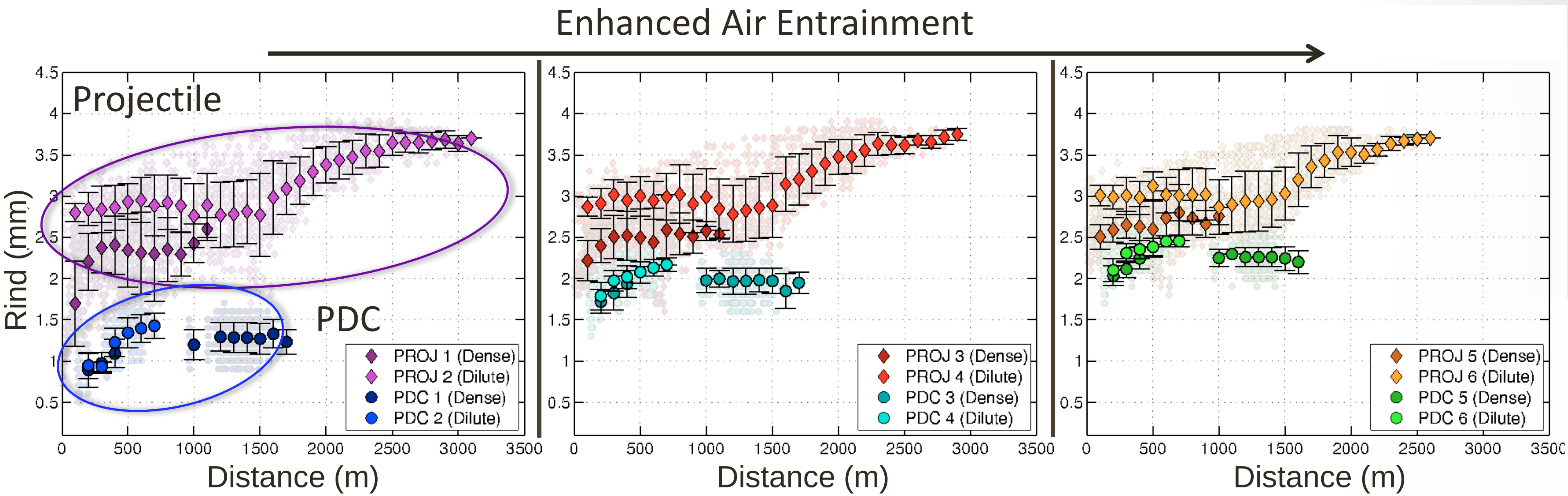
Juive Grande – Particle Conc.

Juive Grande – Temperature

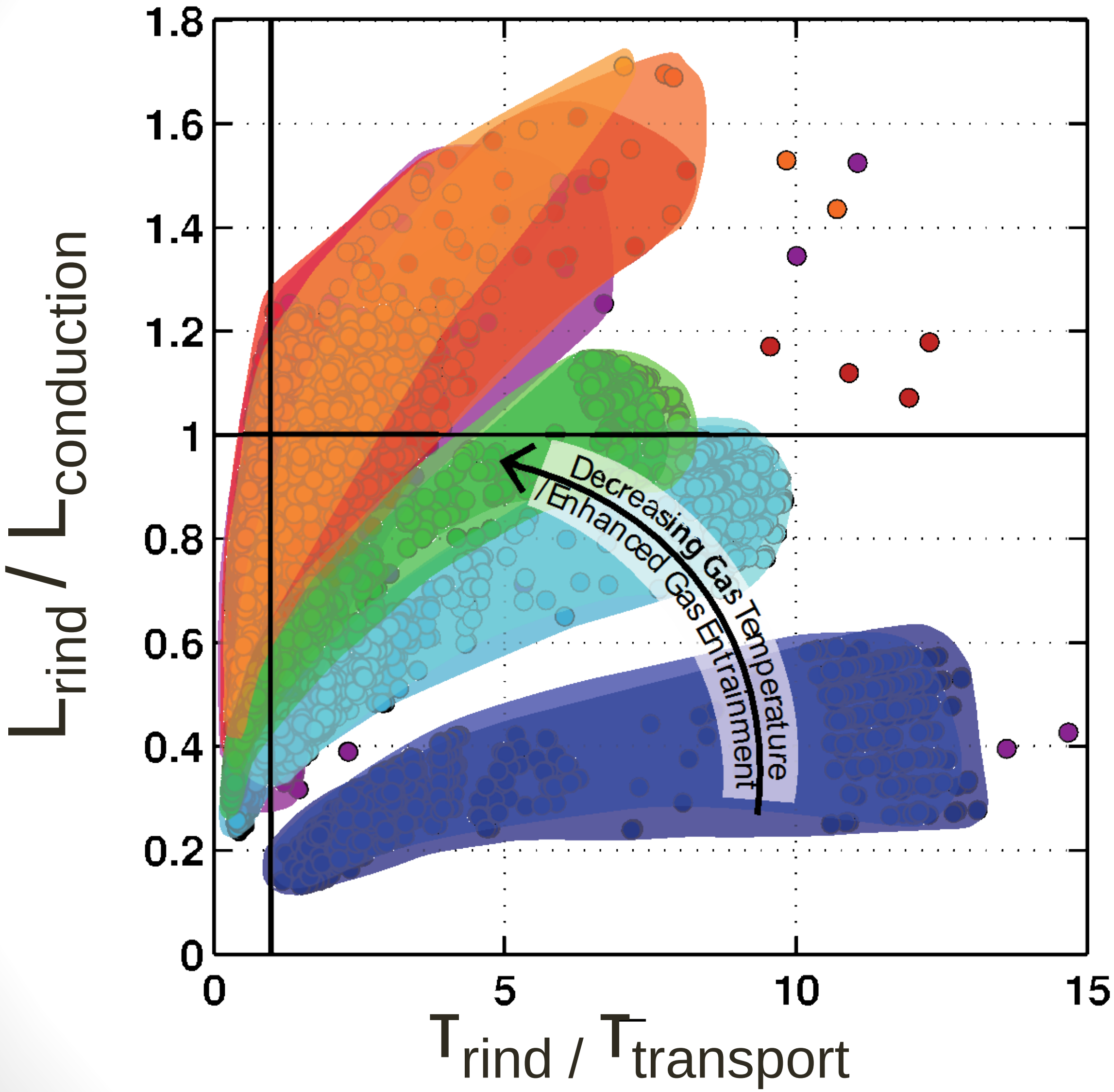
Model Schematic



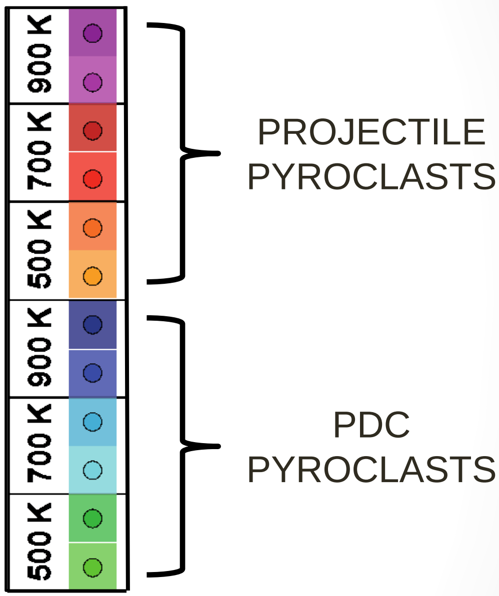
Cooling → Rind Thickness



Regime Diagram



L_{rind} : rind thickness (mm)
$L_{conduction}$: conductive length scale for pyroclast transport time (mm)



τ_{rind} : time bubble growth is terminated in the rind (s)
$\tau_{transport}$: time pyroclast comes to rest (s)

Conclusions

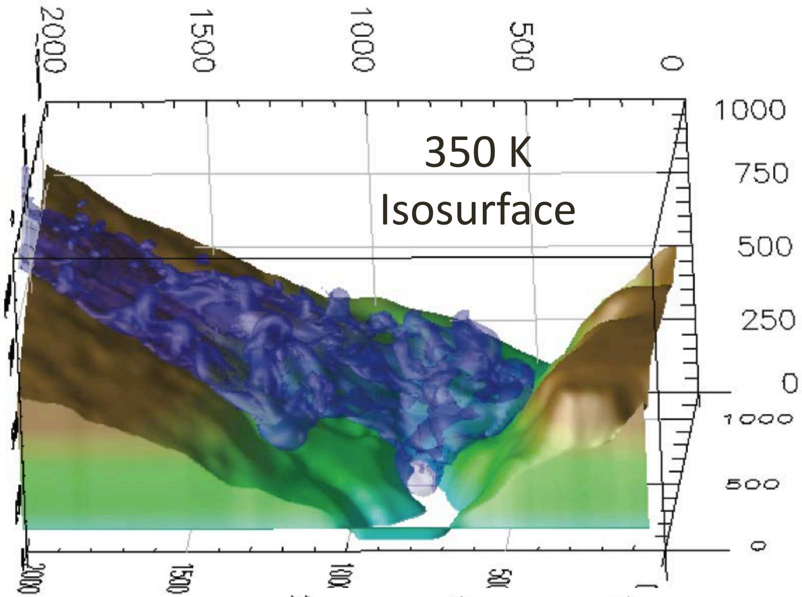
Multiphase Numerical Models:

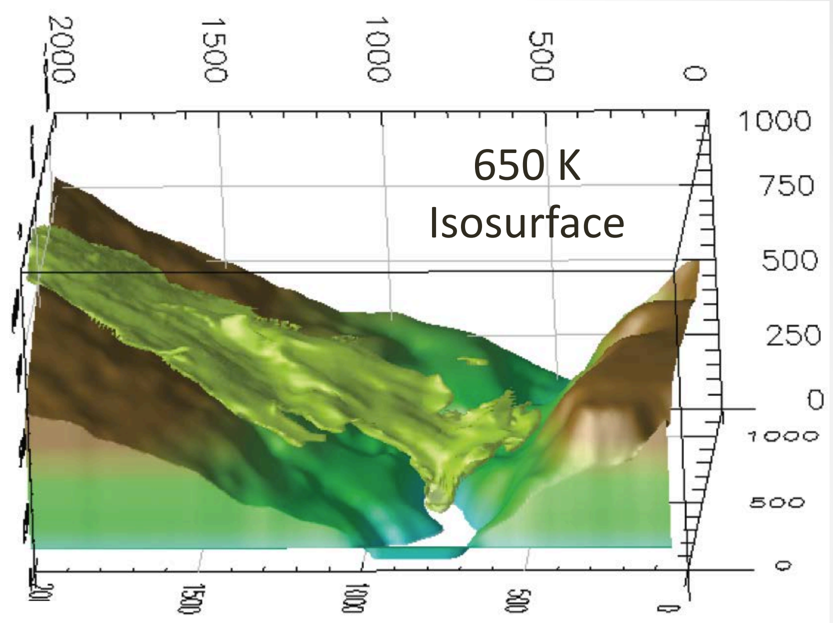
- able to solve complex multiscale fluid dynamics
- able to match observed dynamics and deposit characteristics
- Insight into entrainment of ambient air, concentration gradients, and temperatures of PDCs
- Breadcrust bomb morphology (i.e. rind thickness) is the result of transport regime, transport properties, and pyroclast properties.
  - Numerical in-situ thermometer

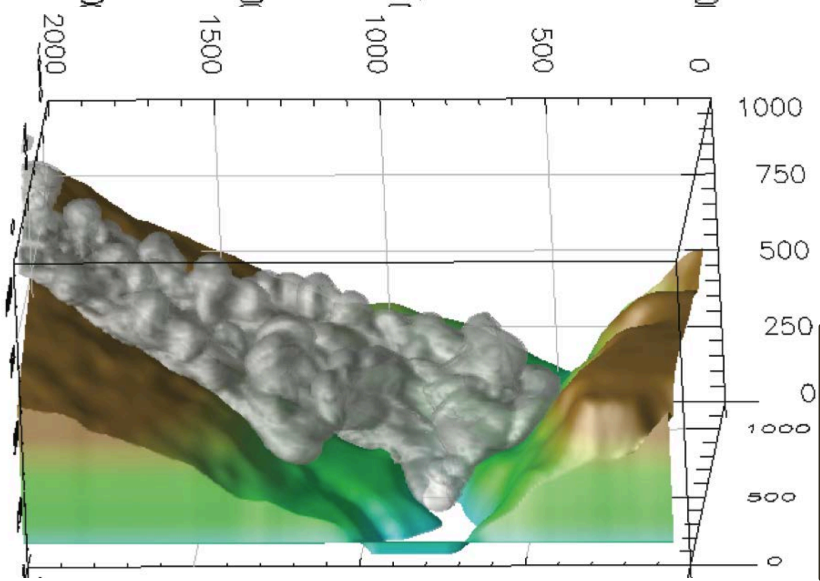
Thank You

- DOE-CSGF for the incredible support and opportunities
- CSGF Fellows
- Volcanology Group at GT

Entrainment







10^{-4} Volume Fraction Isosurface

*scale in meters

*Figures from:
Flow Transformation in Pyroclastic Density Currents: Entrainment and Granular Dynamics during the 2006 eruption of Tungurahua
by Dufek et al. (V23C-2833)