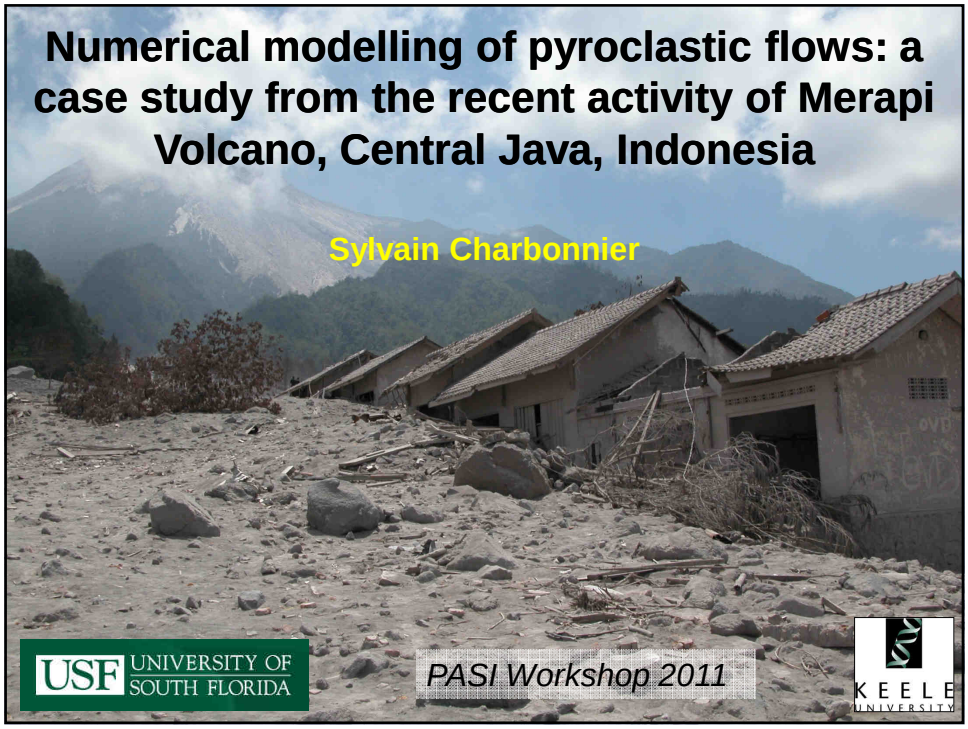
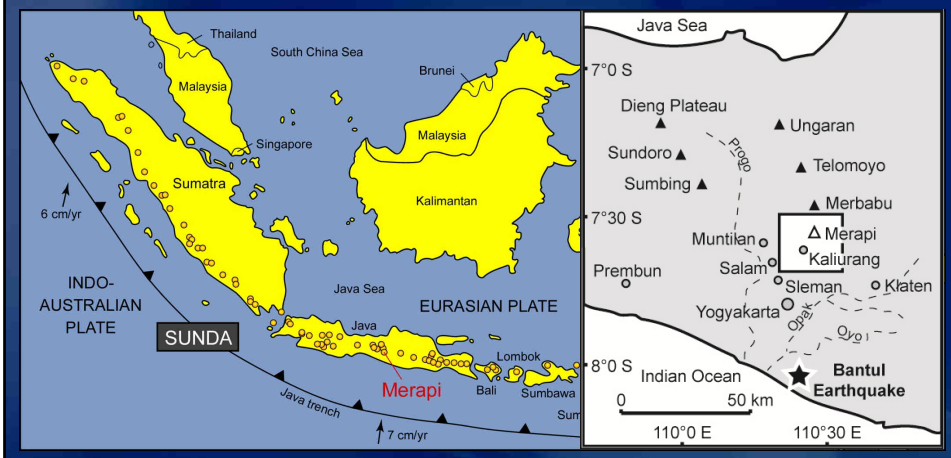
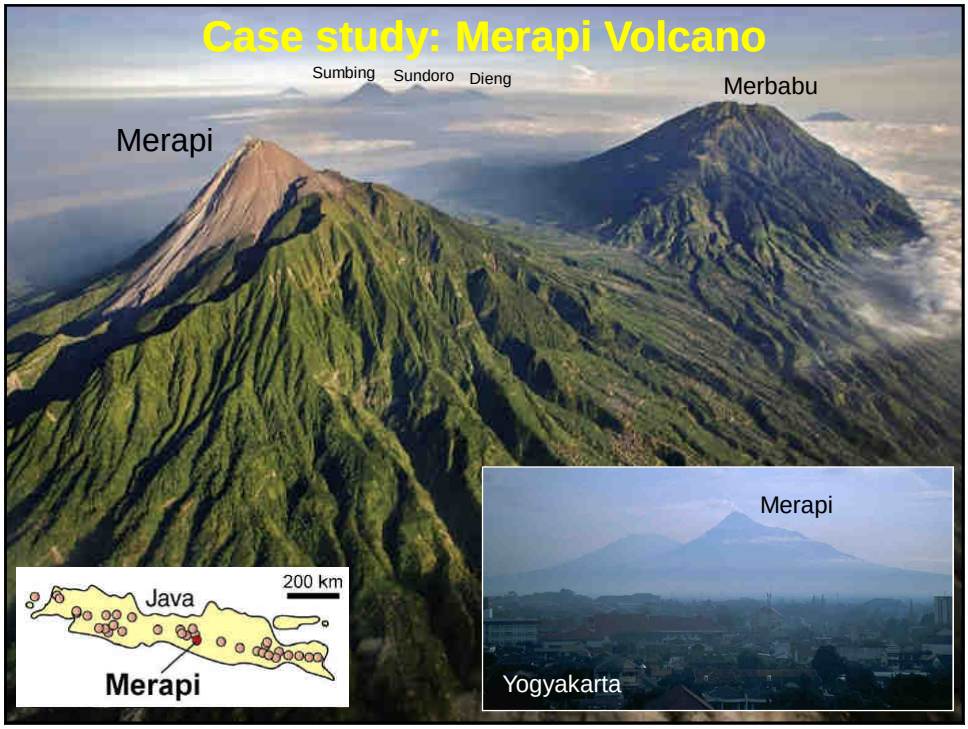


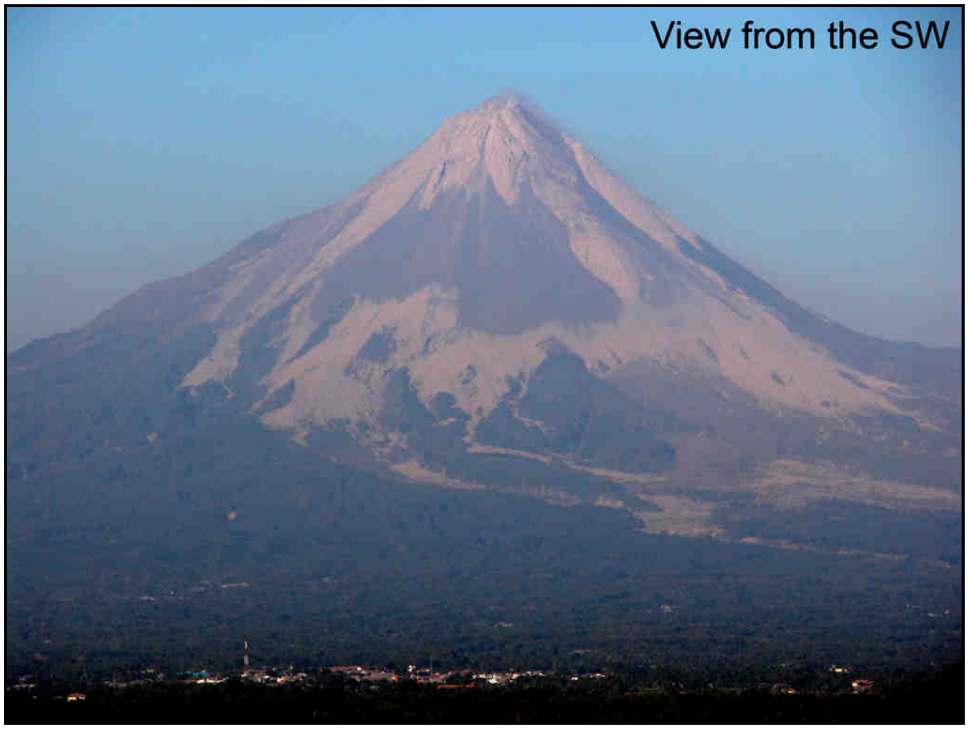
Case study: Merapi Volcano



About 60% of Indonesians live around 16 active volcanoes on the island of Java

Merapi, ranks second after Semeru as the most active volcano of Indonesia, and also second after Kelud in surface area at risk.


Case study: Merapi Volcano
Sumbing
Sundoro
Dieng
Merbabu
Merapi
Merapi
Yogyakarta
200 km
Java
Merapi


View from the SW

Eruptive history

• **~ 80 eruptions** since the **mid-1500s** and almost **half of these** have generated **small-volume pyroclastic flows** of various types, at least **12 of these** causing **fatalities**.

• periods of **lava dome growth:**

→ **dome-collapse pyroclastic flows**

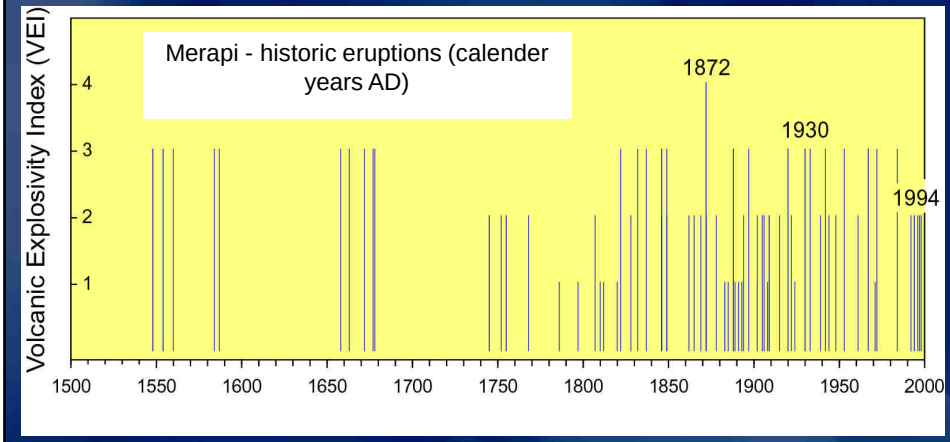
• large **vulcanian explosions:**

→ **fountain-collapse pyroclastic flows**

➡ Merapi often produced pyroclastic flows

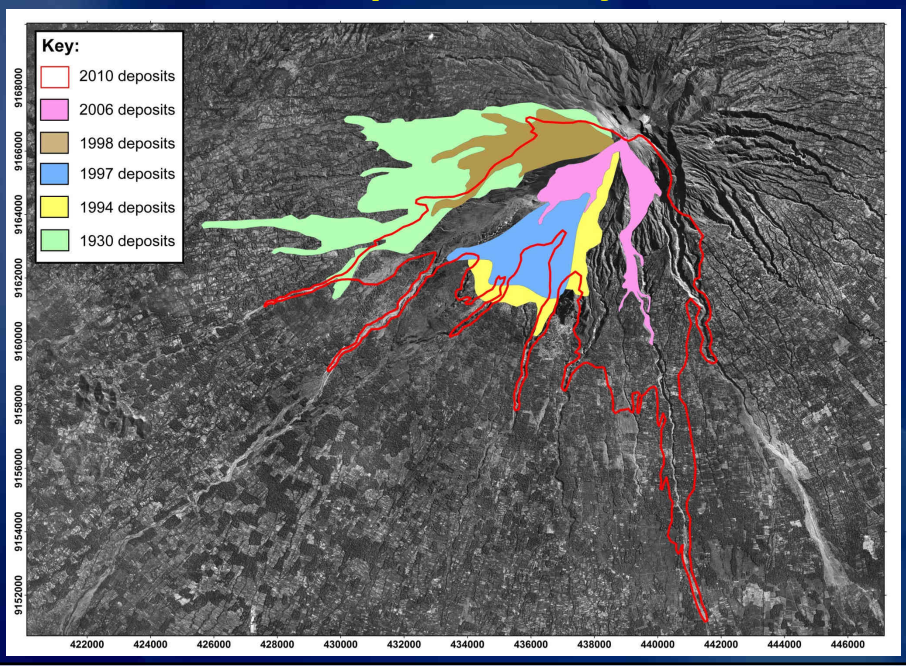
➡ More explosive eruptions in the past (explosion-type pyroclastic flows) compared with 20th century eruptions

Merapi: Recent and Historical Activity



- Frequent, quasi steady-state volcanic activity (lava dome extrusion)
- Intermittent gravitational dome-collapse or explosive phases resulting in small-volume pyroclastic flows

Eruptive history



Types of pyroclastic flows deposits at Merapi

Four types of pyroclastic flow deposits have been identified in the stratigraphic record of Merapi that can be distinguished on the basis of their characteristic lithologies. These include:

a) **Valley-confined block-and-ash flow deposits** that comprise dense blocks of pre-existing dome material in an ash matrix,

b) Pyroclastic flow deposits containing characteristic juvenile blocks with **cauliflower external morphologies**,

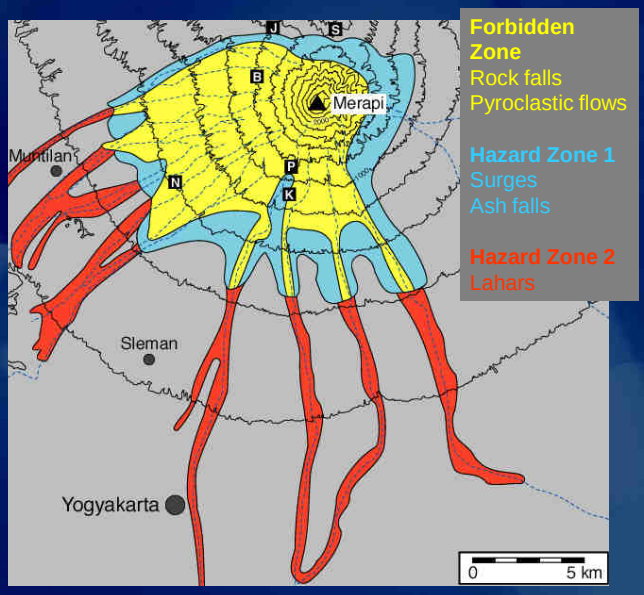
c) Pyroclastic flow deposits rich in **breadcrust components**,

d) Deposits dominated by **low density pumice clasts.**

Volcanic Hazard at Merapi

- 1.1 million inhabitants in 300 villages above 200 m in elevation.
- Yogyakarta is a city of around 500,000 people located ≈35 km south to the summit
- 440,000 people are at relatively high risk in areas prone to pyroclastic flows, surges, and lahars
- At least 80,000 people (maybe twice as much as in 1976) live or work daytime at increased risk in the "forbidden zone".

Volcanic Hazard Map



Modelling approach

Evaluation of geophysical mass flow models → key conditions that control flow behaviour + better assess the potential hazard of different type of flows.

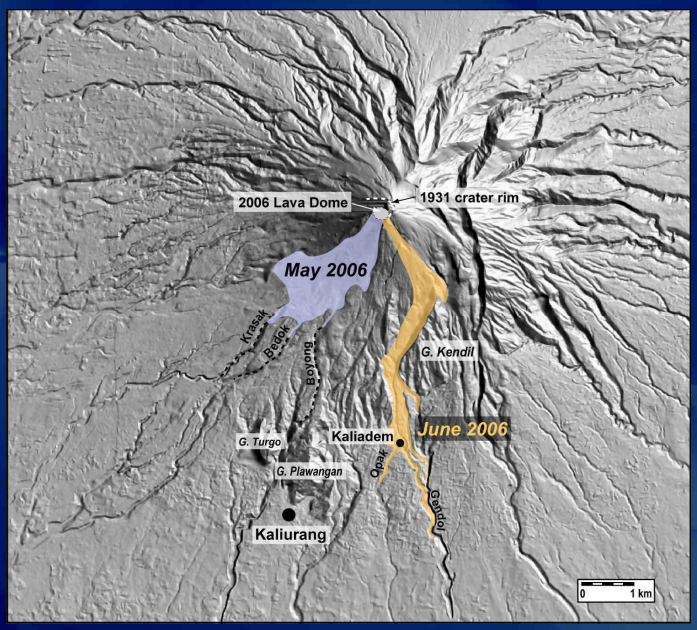
Detailed study of the **June 2006 Block-and-ash flow deposits**

3D deposit architecture of the flows → key flow parameters + conceptual model of transport and deposition

Integration into **numerical simulations** of Block-and-ash flows at Merapi + **Evaluation** of **geophysical mass flow models**:

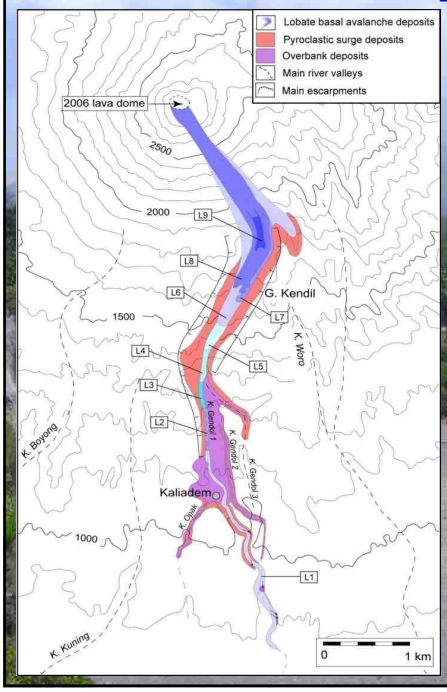
TITAN 2D **VOLCFLOW**

Case study: The 2006 eruption



Charbonnier and Gertisser (2008). J. Volcanol. Geotherm. Res.

The lower Gendol River valley filled with block-and-ash flow deposits from June 2006



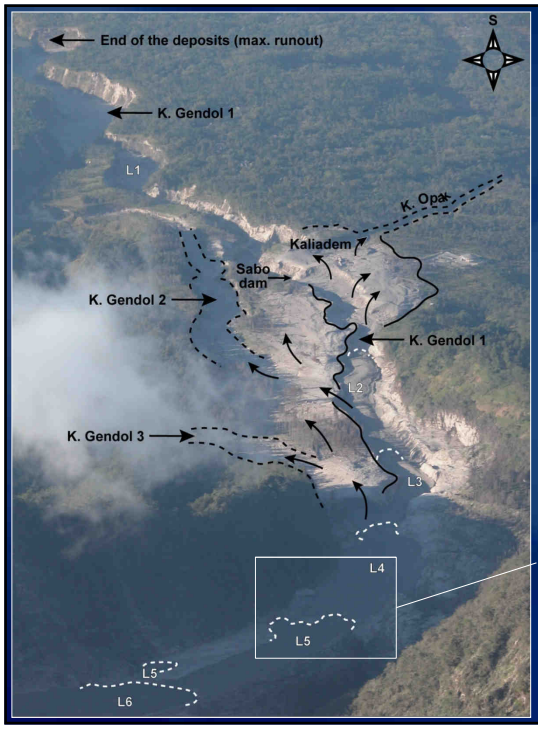
- **Volume estimates** covered by:

Basal avalanche deposits: ~ 7.7 x 10^6 m^3 89%

Overbank deposits: ~ 0.8 x 10^6 m^3 9%

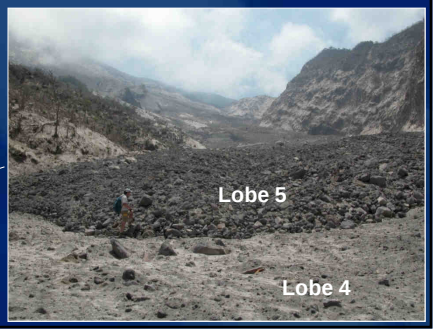
Pyroclastic surge deposits: ~ 0.2 x 10^6 m^3 2%

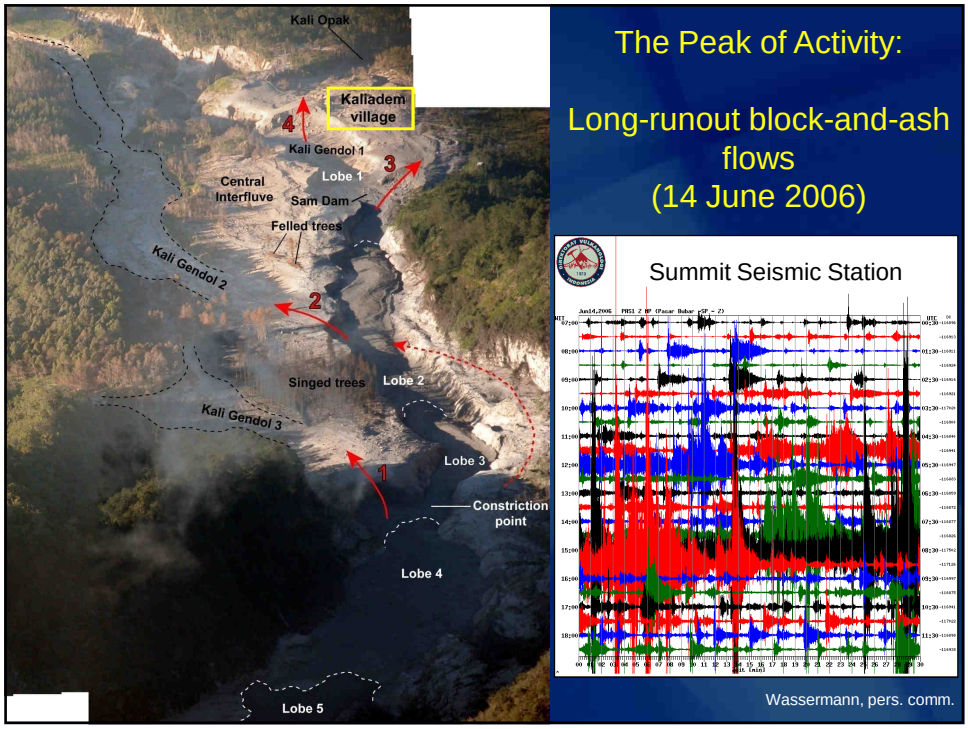
→ **Total deposited material: ~ 8.7 x 10^6 m^3**

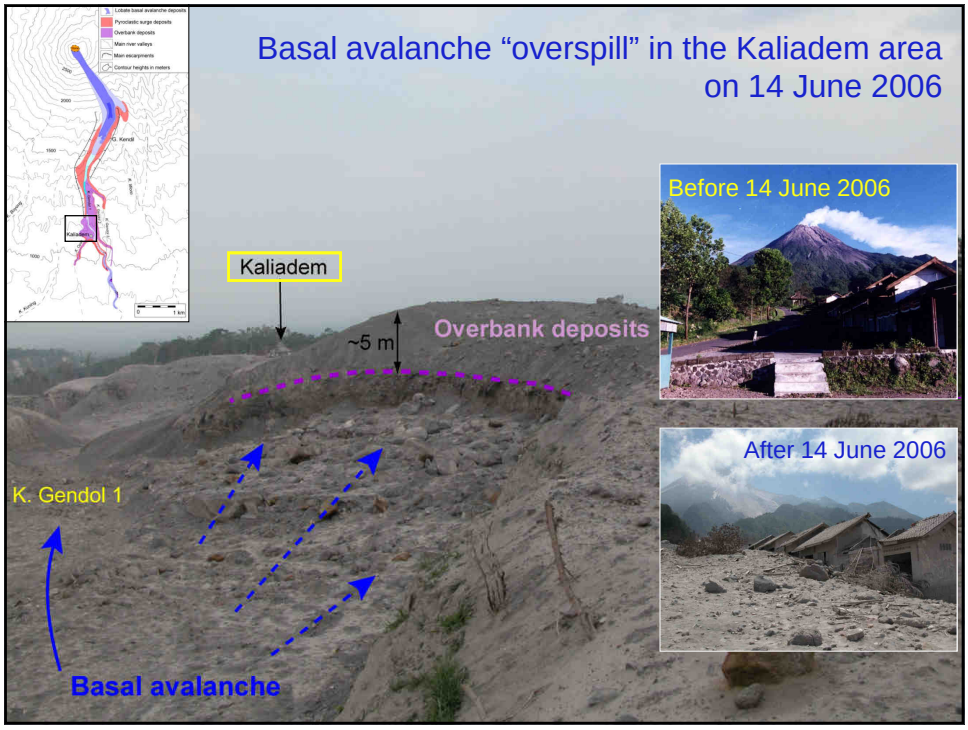


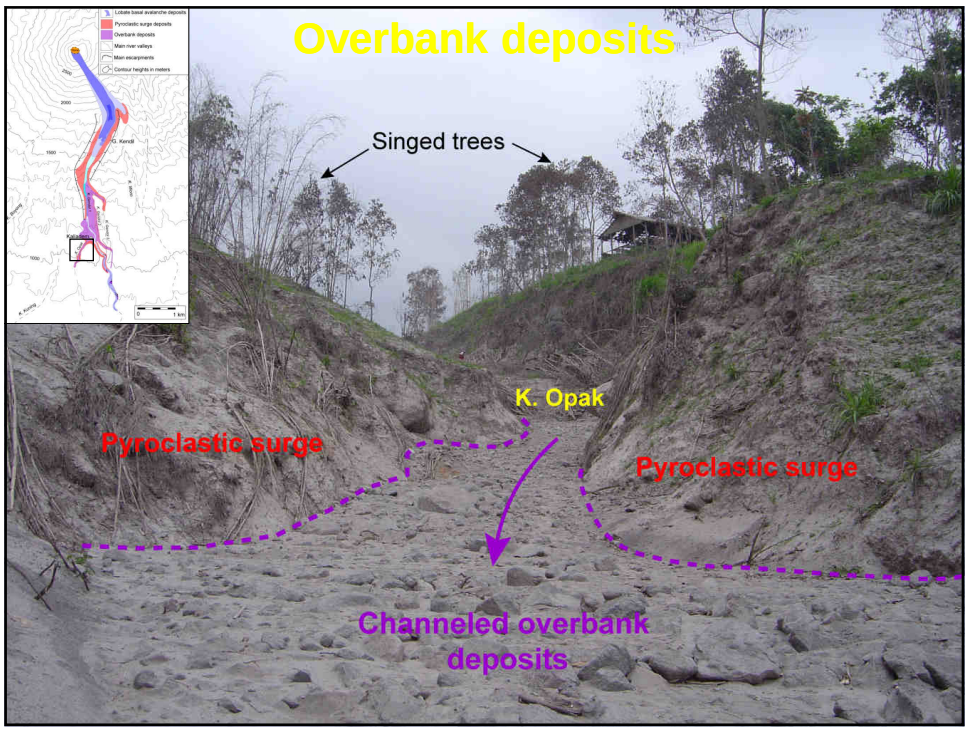
Short- to medium-runout block-and-ash flows (Post-14 June 2006)

- Restricted to proximal and medial valleys (< 4 km from the summit)
- Deposition on slopes ~20° with unconfined morphologies
- Lobate fronts with coarse margins




Kali Opak
Kalladem village
4
Kali Gendol 1
3
Lobe 1
Central Interfluve
Sam Dam
Felled trees
Kali Gendol 2
2
Singed trees
Lobe 2
Kali Gendol 3
Lobe 3
1
Constriction point
Lobe 4
Lobe 5
The Peak of Activity:
Long-runout block-and-ash flows
(14 June 2006)
Summit Seismic Station
Wassermann, pers. comm.


Basal avalanche "overspill" in the Kaliadem area on 14 June 2006
Kaliadem
~5 m
Overbank deposits
Before 14 June 2006
After 14 June 2006
K. Gendol 1
Basal avalanche



	Short- to medium-runout block-and-ash flows	Long-runout block-and-ash flows
Generation mechanisms	Short and discrete (< 1 min.) dome-collapse events	Sustained (tens of mins.), multiple-pulses (2-10) dome-collapse events
Area covered	< 300 000 m^2	> 300 000 m^2
Deposited volume	< 1×10^6 m^3	> 1×10^6 m^3
Runout distance	< 4 km	> 4 km
Slopes of deposition	~20°	< 20°
Velocity	15-30 $m.s^{-1}$	15-45 (25-60 for surges) $m.s^{-1}$
Mobility parameters	ΔH/L: 0.4-0.6 $A/V^{2/3}$: 20-30 A/L^2: 0.01-0.02	ΔH/L: 0.3-0.4 (0.1-0.2 for overbank flows) $A/V^{2/3}$: ~45 (~20 for overbank flows) A/L^2: 0.02 (0.03-0.06 for overbank flows)
Transport mechanisms	Quasi-steady to unsteady granular flow	Unsteady, cohesionless grainflows with inertial flow regime
Deposition mechanisms	Similar to granular-free surface flow on unconfined planes	Stepwise aggradation of granular-dominated pulses
Flow types	Basal avalanche	Basal avalanche, Overbank flows, Ash-cloud surges
Associated deposits	Channelled	Channelled, Overbank, Surge
Deposit morphology	Unconfined	Confined with overbanking
Lithology	> 80% juvenile clasts, outer part of the lava dome	Accidental lithic content increases downstream Overbank deposits enriched in low-density clasts
Granulometry	Bimodal distribution, poorly sorted ($\sigma_\varnothing$ from 3.8 to 4), $Md_\varnothing$ from -5 to -1, ash content from 40 to 55 wt%	Polymodal distribution, poorly sorted ($\sigma_\varnothing$ from 2.9 to 4.2), $Md_\varnothing$ from -3.5 to -0.2, ash content from 40 to 70 wt%
Seismic signal	Single pulse < 3 mins.	Multiple-pulses > 3 mins.

Geophysical mass flow models

TITAN 2D model

- Linux platform
- Mohr-Coulomb Frictional behaviour
- Adaptive gridding with mesh refinement/unrefinement
- Parallel (MPI) processing on supercomputer (2-64 processors)
- Access to source code
- Stopping criteria
- Multiple visualization platforms

VOLCFLOW model

- Windows with Matlab
- Mutiple and user-defined behaviours
- Finite volume solver with fast and accurate numerical solutions
- Single processor simulations
- No Access to source code
- Flexibility of Matlab
- Multiple output parameters

Models evaluation criteria

• A series of evaluation criteria has been developed for the determination of best-fit input parameters that form the basis for evaluating the validity of our models:

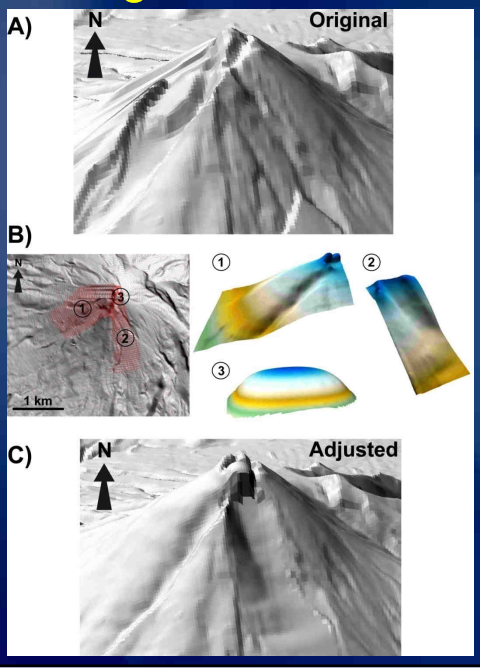
1. Runout distance of the simulated flows should match those of the lobe fronts as mapped in the field

2. Distribution of the deposits and deposited volume should fall within the range of those of the actual flows

3. Velocities of the flows and deposit thicknesses should be comparable to those calculated and observed in the field

4. Flow simulations of long-runout flows must escape from channel confines to fill the interfluves area (in particular the area around Kaliadem) and to be re-channeled into the adjacent valleys

Digital Elevation Model adjustments



A. 3D view of the old summit area from the original DEM

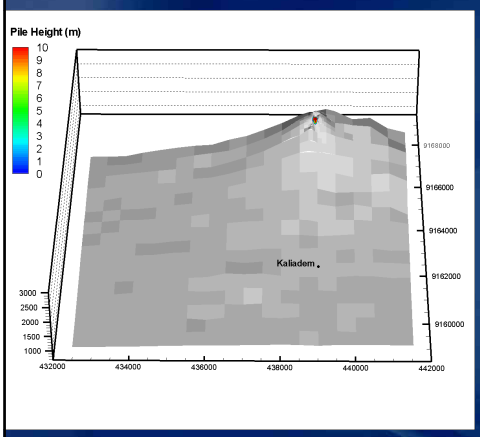
B1. Filling of the southwestern flank

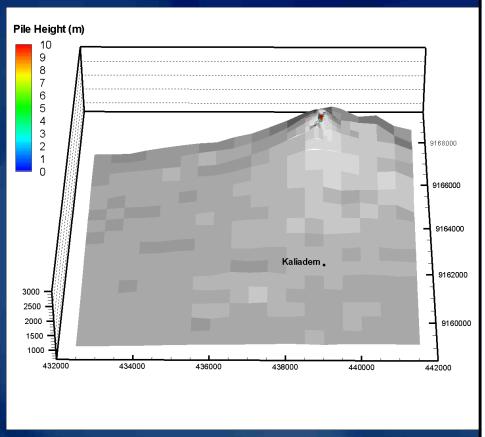
B2. Collapse structure on the upper southern slopes

B3. new 2006 lava dome

C. 3D view of the new summit area from the adjusted DEM

TITAN 2D calibration





Internal friction angle: 30 °

Basal friction angle: 16 °

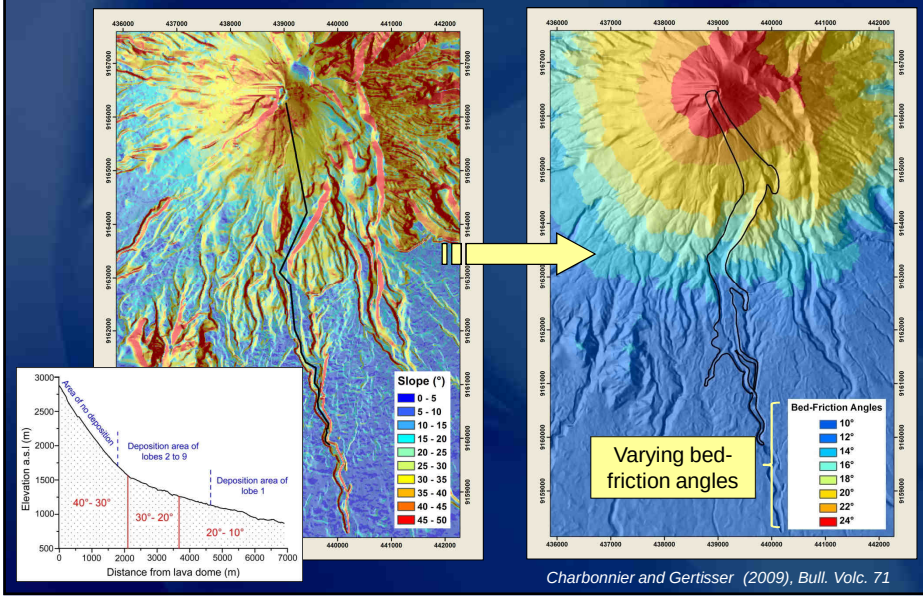
Internal friction angle: 30 °

Basal friction angle: 20 °

None of the simulations using a single bed friction is capable of reproducing the path and extent of the actual events.

TITAN 2D calibration

✓ **GIS-based classified map**: Slope map + Elevation profile → Bed-friction map



Charbonnier and Gertisser (2009), Bull. Volc. 71

Short- to medium-runout BAFs: Best-fit parameters

TITAN 2D

Dimensions of initial pile:

Length: 100 m

Width: 70 m

Max. Thickness: 10 m

Orientation angle: -90°

Source characteristics:

Number of flux sources: 1

Mean flux: 4 kg/m².s

Active duration of collapse: 50 sec

Flow parameters:

Internal friction angle: 30°

Basal friction angle: 16° - 28°

Initial volume: 0.8×10^6 m³

VolcFlow

Source conditions:

Length: 150 m

Width: 150 m

Number of flux sources: 1

Active duration of collapse: 50 sec

Flow parameters:

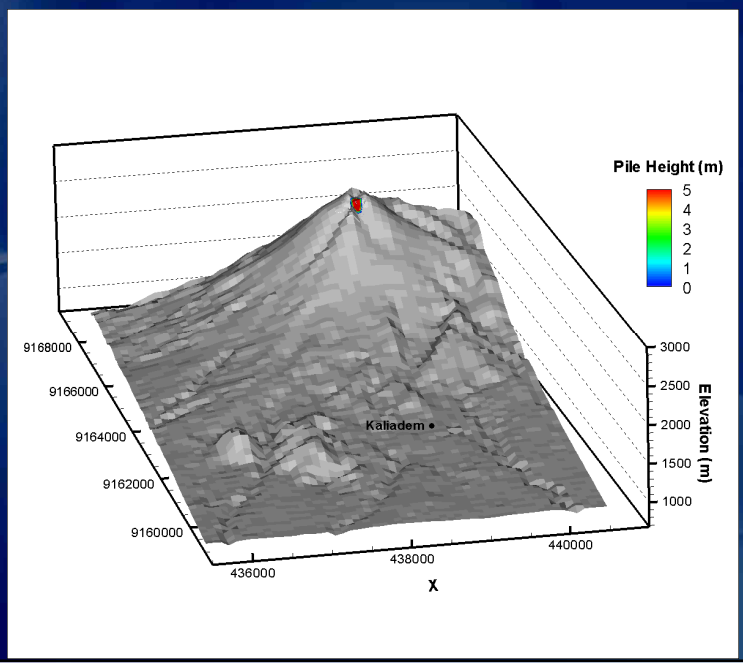
Constant retarding stress: 7 500 Pa

Coeff_u2: 0.01

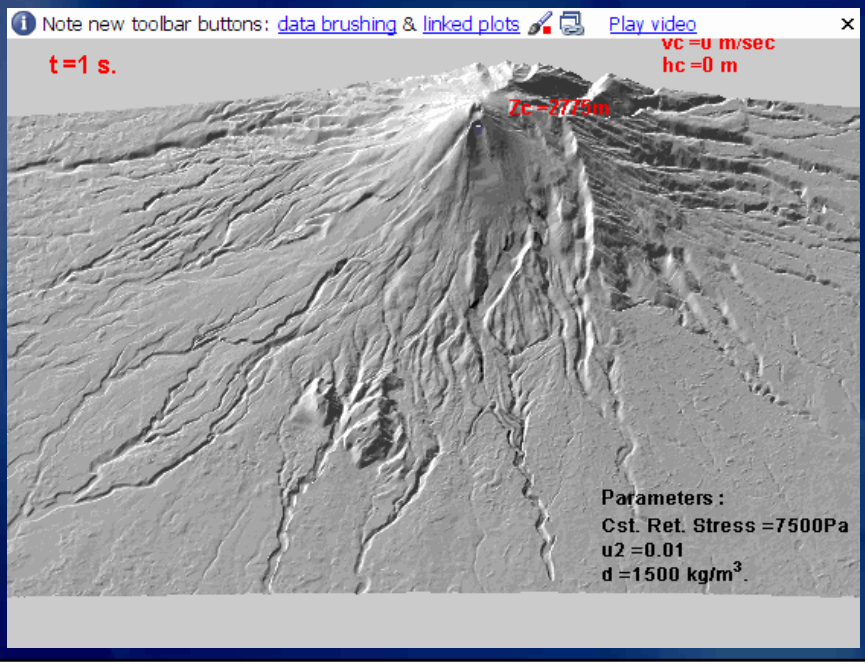
Density: 1500 kg.m³

Initial volume: 0.8×10^6 m³

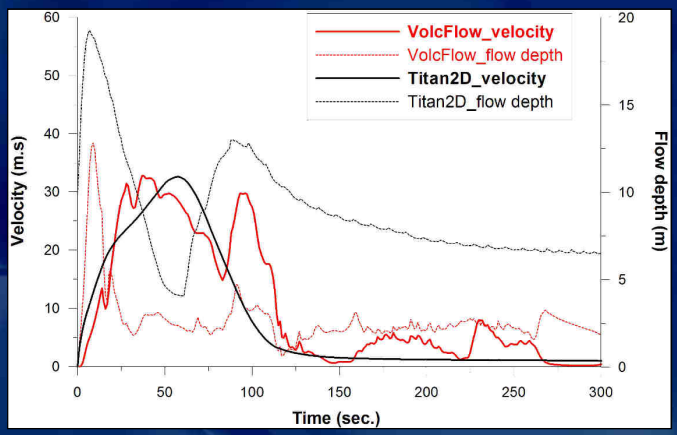
Short- to medium-runout BAFs: TITAN 2D



Short- to medium-runout BAFs: VolcFlow

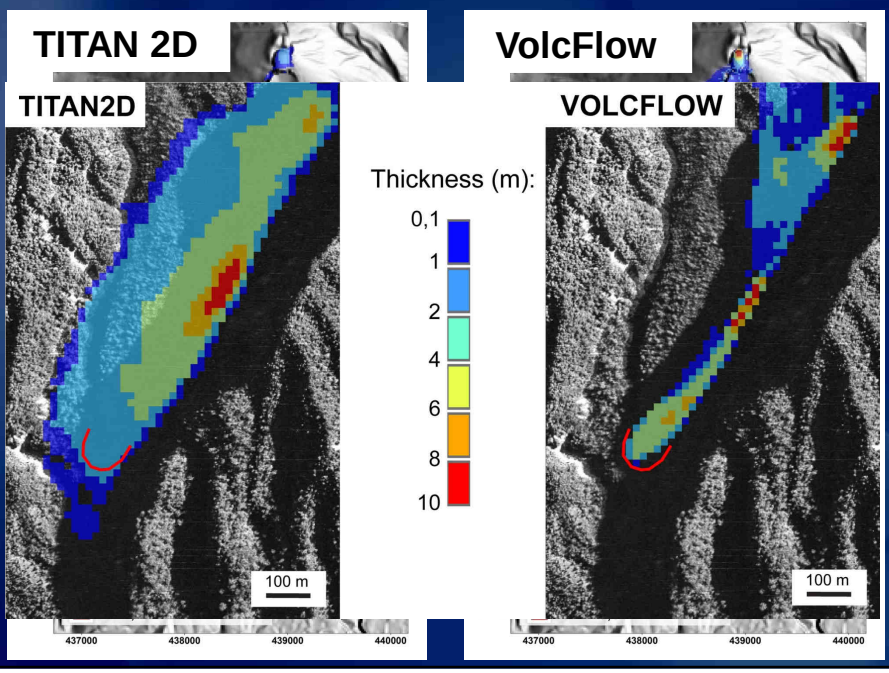


Short- to medium-runout BAFs: Results



	Lobe 5	TITAN 2D	VolcFlow
Flow duration (sec.)	-	210	275
Max. cent. velocity ($m.s^{-1}$)	-	34.3	33.2
Area covered (km^2)	0.21	0.34	0.73
Deposited volume (10^6 m^3)	0.64	0.69	0.61
Runout distance (km)	3.3	3.4	3.3

Short- to medium-runout BAFs: Results



Long-runout BAFs: Best-fit parameters

TITAN 2D

Dimensions of initial pile:

Length: 100 m

Width: 70 m

Max. Thickness: 20 m

Orientation angle: -90°

Source characteristics:

Number of flux sources: 5

Mean flux: 4 kg/m².s

Active duration of collapse: 300 sec

Flow parameters:

Internal friction angle: 30°

Basal friction angle: 10 - 24°

Initial volume: ~4×10⁶ m³

VolcFlow

Source conditions:

Length: 150 m

Width: 150 m

Number of flux sources: 1

Active duration of collapse: 150 sec

Flow parameters:

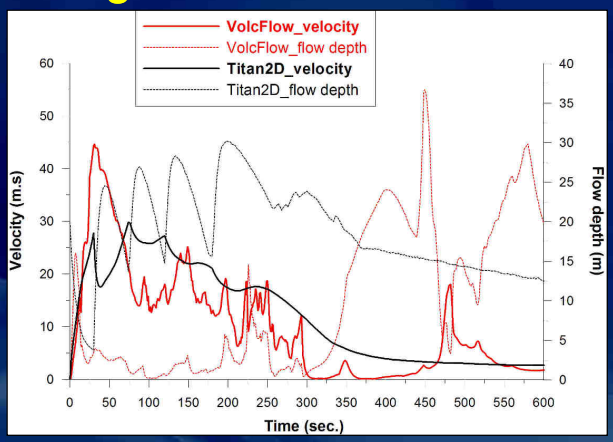
Constant retarding stress: 3 500 Pa

Coeff_u2: 0.01

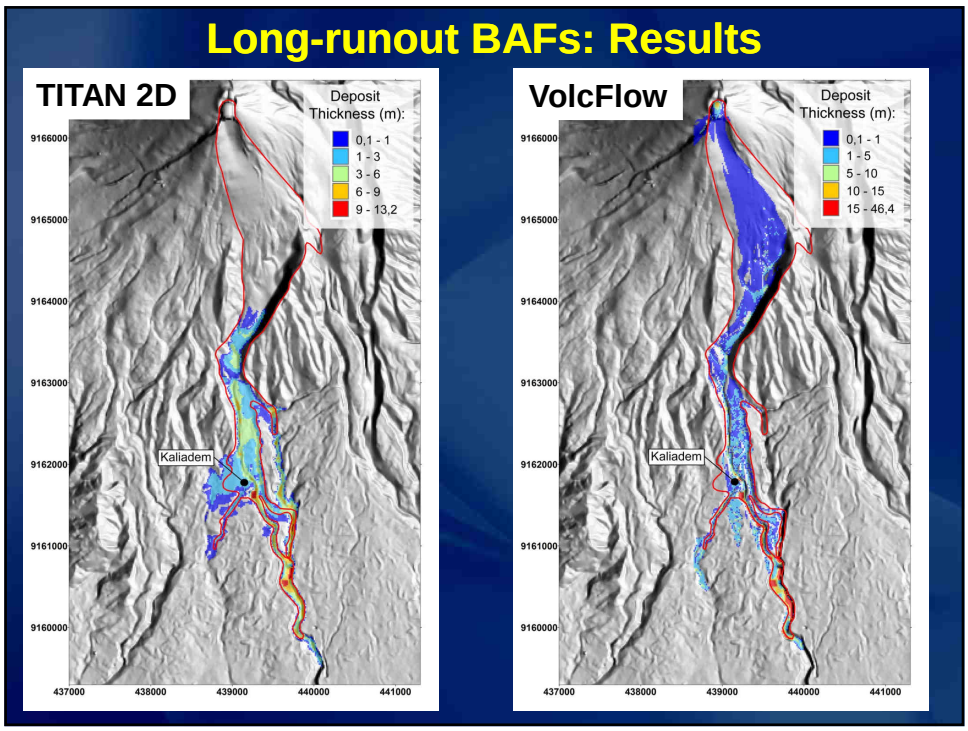
Density: 1200 kg.m³

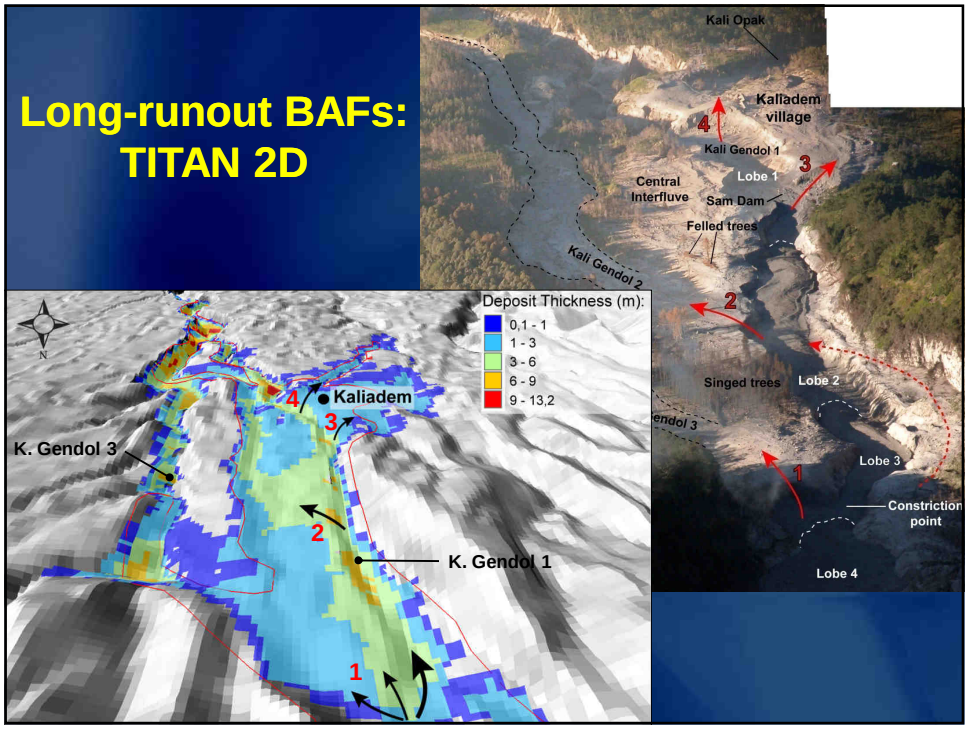
Initial volume: 5.8×10⁶ m³

Long-runout BAFs: Results

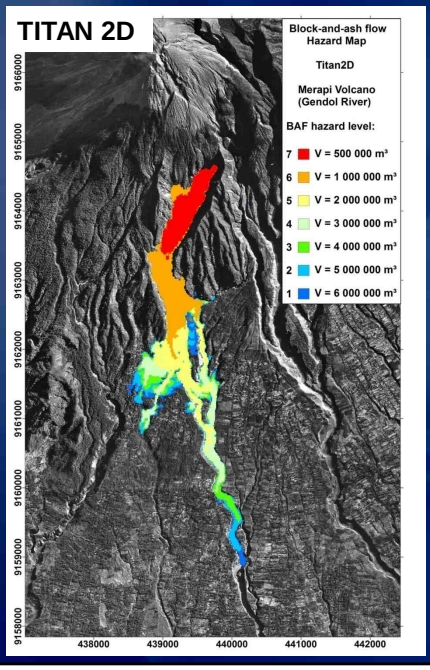


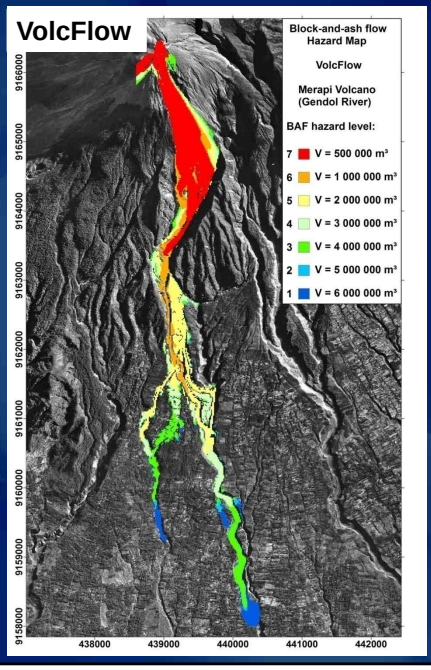
	14 June p.m. 2006	TITAN 2D	VolcFlow
Flow duration (sec.)	-	~1200	~700
Max. cent. velocity (m.s⁻¹)	43.8	29.8	44.6
Area covered (km²)	1.29	1.56	2.03
Deposited volume (10⁶ m³)	~3.5	3.62	3.50
Runout distance (km)	7.0	7.5	7.2


Long-runout BAFs: Results
TITAN 2D
Deposit Thickness (m):
0,1 - 1
1 - 3
3 - 6
6 - 9
9 - 13,2
Kaliadem
VolcFlow
Deposit Thickness (m):
0,1 - 1
1 - 5
5 - 10
10 - 15
15 - 46,4
Kaliadem
9166000
9165000
9164000
9163000
9162000
9161000
9160000
437000
438000
439000
440000
441000


Long-runout BAFs: TITAN 2D
Kali Opak
Kaliadem village
Kali Gendol 1
Lobe 1
Central Interfluve
Sam Dam
Felled trees
Kali Gendol 2
Singed trees
Lobe 2
Lobe 3
Constriction point
Lobe 4
Deposit Thickness (m):
0,1 - 1
1 - 3
3 - 6
6 - 9
9 - 13,2
Kaliadem
K. Gendol 3
K. Gendol 1
N
1
2
3
4

BAF Hazard Assessment in the Gendol river





Summary and Outlook

- **"Realistic" numerical models require:**

► **Model calibration** using **well-constrained field parameters** (thickness variations, velocity, deposit distribution, transport and emplacement mechanisms of associated flows)

► **Incorporation of a suitable empirical law** into the model (varying bed friction angles or constant retarding stress)

► **A realistic set of input parameters** (incl. Digital elevation model)

- **Modelling ouput:**

► **Flow depths and velocities**

► **Runout distances, Inundation areas and Volumes of different types of BAFs**

► **Key parameters that control flow behaviour**

➡ Basis for estimating the areas and levels of hazards associated with BAFs and for improving disaster mitigation plans at Merapi

Our Ultimate Aim...

Establish TITAN2D/VolcFlow as predictive tools in future eruption at Merapi


Acknowledgements
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