Experimental study of the surface thermal signature of gravity currents: Application to the assessment of lava flow effusion rate

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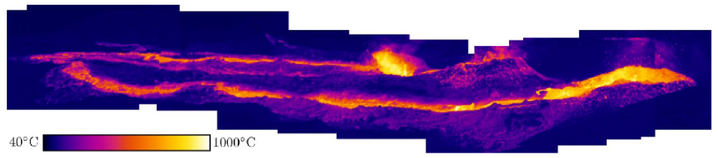
(1) Introduction

Thermal surface energy is currently used as a time-independent proxy to assess an effusion rate Q for lava flows (Harris et al., 2007) :

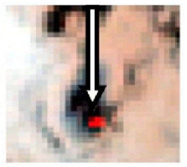
$\varepsilon\sigma\,(T_{top}^4 - T_a^4)$: radiative heat flux
$\lambda\,(T_{top} - T_a)$: convective heat flux
A_T: lava area

$$Q = \frac{\varepsilon\sigma(T_{top}^4 - T_a^4) + \lambda(T_{top} - T_a)}{\rho(C_p\Delta T + \phi c_L)} A_T$$

$\rho C_p \Delta T$: heat advected along the the flow
$\rho\phi c_L$: heat generated by crystallization



Infrared image of multiple vents and channels, on 15 October 2010, La Reunion Island (OVPF).



SEVIRI image over La Reunion Island, March 2007 (Hirn et al., 2009)

What is the surface thermal evolution of a flow simultaneously spreading and cooling?

(2) Reference model = horizontal, isoviscous gravity current supply at constant rate

a - Theoretical model

Spreading (Huppert, 1982)

$$\text{Radius } \alpha \left(\frac{Q^3}{\mu}\right)^{\frac{1}{8}} t^{\frac{1}{2}}$$

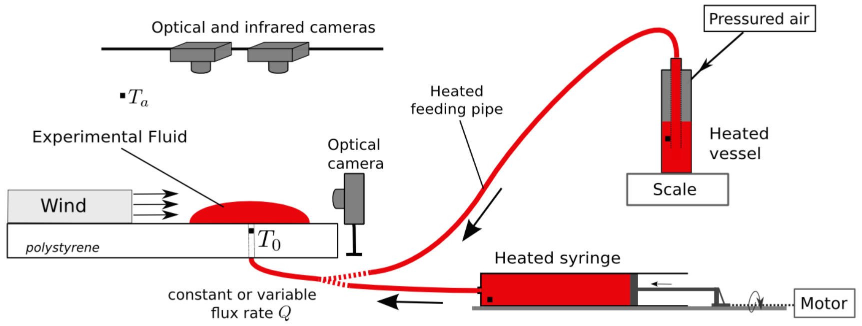
$$\text{Height } \alpha \,(\mu Q)^{\frac{1}{4}}$$

Q: flux rate
μ: dynamic viscosity

Cooling at the surface of the flow

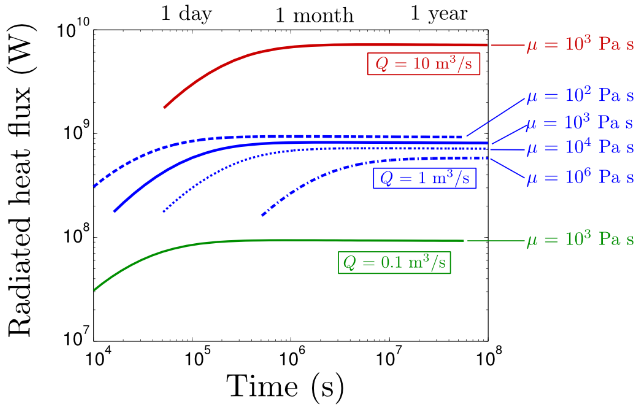
$$-k\left.\frac{\partial T}{\partial z}\right|_{z=h} = \varepsilon\sigma(T_{top}^4 - T_a^4) + \lambda(T_{top} - T_a)$$

c - Experimental set-up



e - Model results

Model lava flow
T_0=1200 °C
T_a=20 °C
$T_g = T_0$
ρ=2300 kg.m^{-3}
k=3 W.K^{-1}.m^{-1}
C_p=1000 J.K^{-1}.kg^{-1}
ε=0.95



b - Scaling

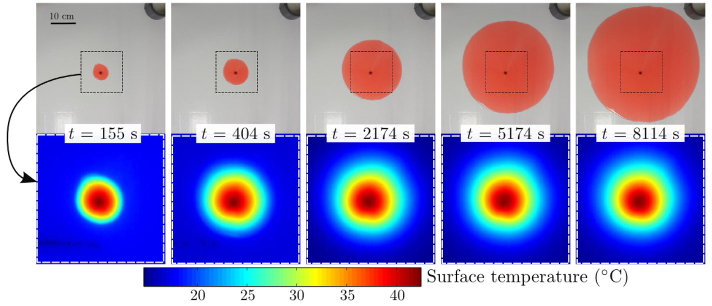
$$N_T = \text{Relative energy content}$$

$$N_{surf} = \frac{\text{Total heat flux at the surface}}{\text{Vertical heat diffusion in the current}}$$

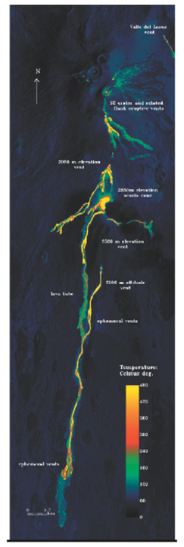
$$N_\lambda = \frac{\text{Convective heat flux at the surface}}{\text{Total heat flux at the surface}}$$

d - Experiments with silicone oil

Surface thermal steady state !



f - Comparison with natural lava flows



Etna, 29 July 2001
Airborne sensor MIVIS

Flow F4 (since 18 July)
Radiant heat flux = 4 GW

$$\Big\downarrow$$

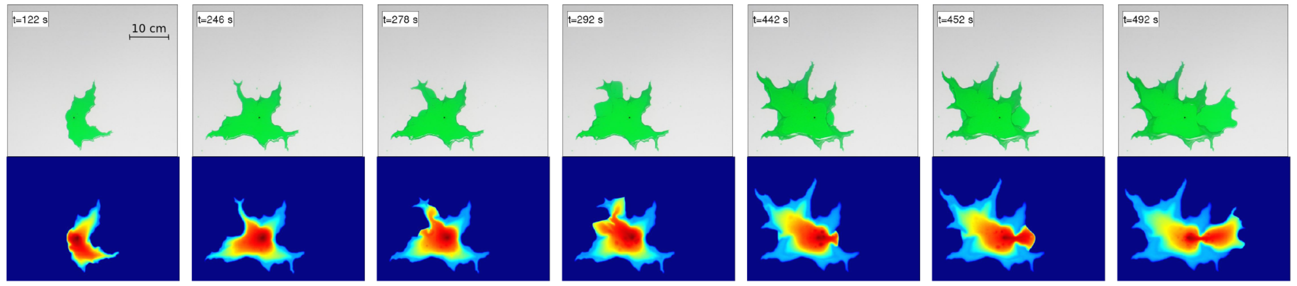
MODEL
(plateau heat flux)

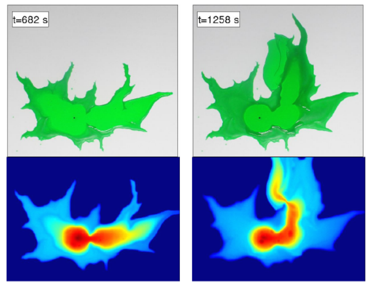
$$\boxed{\text{Effusion rate } Q \approx 6 - 8 \text{ m}^3.\text{s}^{-1}}$$

$$\left(\begin{array}{c}\text{Ground-based effusion rate}\\ Q \approx 6 - 11 \text{ m}^3.\text{s}^{-1}\end{array}\right)$$

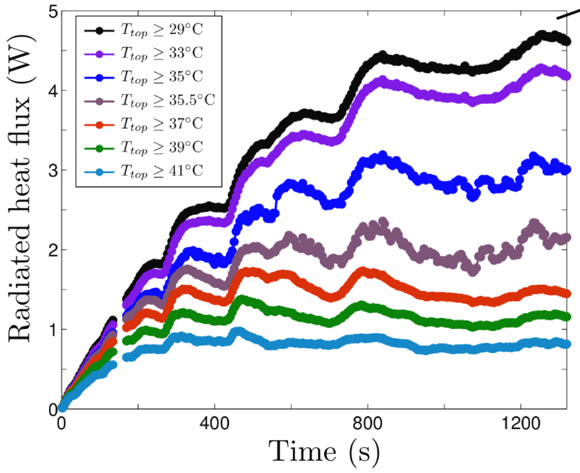
(Lombardo and Buongiono, 2003)

(3) Solidifying material





PEG wax,
constant supply rate

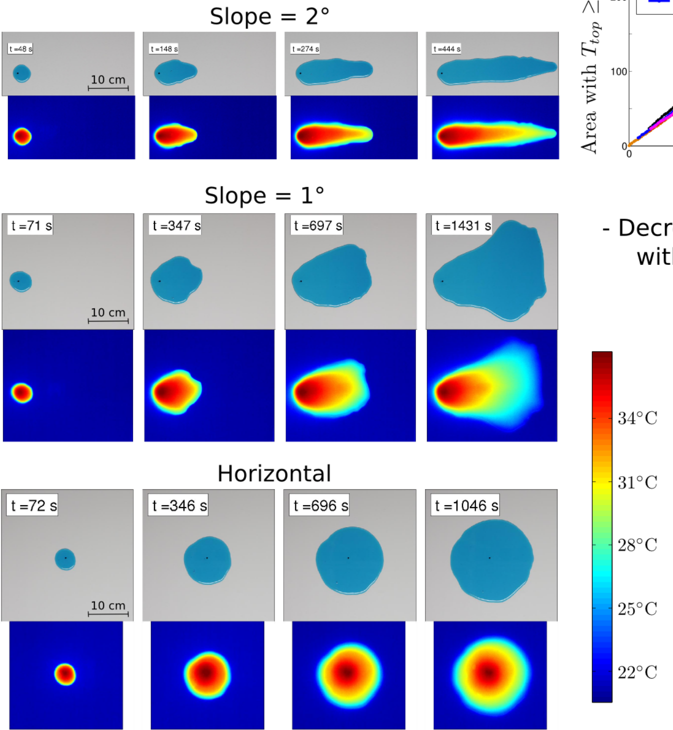


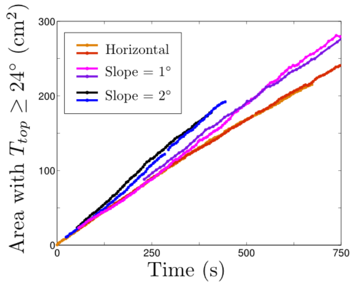
Theoretical isoviscous steady heat flux = 6 W

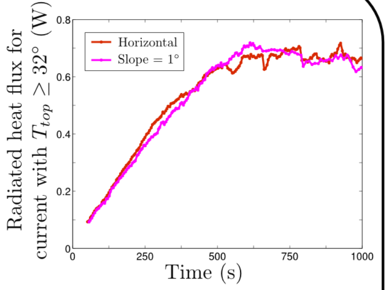
- Step-like evolution of the total radiant heat flux (non-periodic overflow of liquid material)
- Apparition of a steady regime with increasing temperature threshold (= "active area")

(4) Topography

Glucose syrup, same input rate







- Decrease of transient time with increasing slope?
- Similar radiated heat flux in the steady regime

Harris, *Bulletin of Volcanology*, 70, 2007.
Lombardo & Buongiono, *Ann. Geoph.*, 46, 2003.
Hirn et al., *IEEE Trans. on Geosc. & Rem. Sens.*, 47, 2009.

(5) Take-home message

- For a constant effusion rate, the radiated heat flux of the "active" part of the flow reaches a plateau after a transient time
- Assessing the effusion rate of lava flows
  - → correct order of magnitude of the effusion rate calculated with the simple model
  - → difficulty to interpret an instantaneous thermal information
  - → is there a threshold temperature defining the active part of a lava flow?