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Assessing effusion rate of lava flows from thermal structure: theoretical analysis and lab-scale experiments

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Management of effusive volcanic crises has to be based on the quantitative interpretation of flow monitoring. An important issue is the ability to predict where the flow will go, and when it will stop. Geophysical fluid dynamics shows that the spreading of lava flows is mainly controlled by its rheology and the eruptive mass flux. Hence the key question is how to evaluate them during the eruption (rather than afterwards). A relationship between the surface structure temperature and the eruption rate is likely to exist, based on the first-order argument that higher eruption rates should correspond to larger energy radiated by a lava flow. A theoretical formula combining some empirical parameters was developed by Harris and co-workers (review in Harris et al., 2007) and is used to estimate lava flow rate from satellite. However, the theoretical grounds of this technique, as well as its domain of validity, remain questioned. Here we propose a systematic theoretical study to help to define the validity domain of this approach and to investigate whether or not it can be refined and/or modify to better assess flow rates. We chose in our approach to study at lab-scale a flow with a rheology simpler than that of the natural lava, but taking into account all the complexity of the cooling process at the surface of the flow, by radiation and convection. We used fully controlled experimental parameters, especially the cooling conditions, the flux rate and geometry of the flow. The spreading geometry is the one of an axisymmetric viscous gravity current of newtonian viscosity (Huppert, 1982). For a given enthalpy content, the coupled cooling/spreading processes are characterized by two dimensionless numbers. A first one quantifies the efficiency of the surface cooling compared to the heat advected in the flow. The second one quantifies the relative efficiency of radiative and convective surface cooling. We identify different stages of cooling as a function of these numbers and we define the conditions required to confidently infer the eruptive mass flux of a flow based on its surface temperature.