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Heat flux measurement from vertical temperature profile and thermal infrared imagery in low-flux fumarolic zones

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Hydrothermal systems are associated to most of the dormant volcanoes. Heat is transported by steam from the hot magma body in the connected porosity and the fissures of the rock to the surface. If the flux is low enough (<500 W/m^2), the steam mainly condensates in the soil close to surface, and a significant proportion of the heat is transported to the surface by conduction, producing a gradient of temperature and a thermal anomaly detectable at the surface.
Detecting and monitoring these fluxes is crucial for hazard management, since it reflects the state of the magma body in depth. In order to quantify this flux two methods are considered. First, a vertical profile of temperature is measured by a series of thermocouples, and the conducted flux is estimated thanks to the Fourier law. Secondly, a more recent method uses the thermal infrared imagery to monitor the surface temperature anomaly (STA) between the studied zone and an equivalent zone not affected by the geothermal flux. The heat flux from the soil to the atmosphere is computed as the sum of (1) the radiative flux, (2) the sensible flux and (3) the residual steam flux. These two methods are complementary and have an equivalent uncertainty of approximately 20%, which would allow to track the major changes in the hydrothermal system.
However, the surface and sub-surface temperatures are strongly influenced by the climate. For instance, it has been widely demonstrated that the surface temperature dramatically decreases after a rainfall. In order to estimate the reliability of the measurements, a numerical model simulating the evolution of the subsurface temperature in low flux fumarolic zone has been built. In depth, the heat can be transported either by conduction, or by the rising steam, or by condensed water. In surface, both the radiative flux and the sensible flux (convection of the atmosphere) are taken into account. This model allows to estimate the changes of temperature due to a variation of solar illumination, wind, or rainfalls. It has been successfully tested during 5 months with a permanent station built on the Ty fault on La Soufrière volcano (Guadeloupe, Lesser Antilles).
Results show that the diurnal cycle has a significant influence on the temperature up to ca. 30 cm depth, hindering the use of the thermal gradient in this zone, while the STA has a negligible variation. Rain has a more dramatic influence: the surface temperature and the STA are significantly affected, even for small rains. The model shows that the drop of temperature and the affected thickness are mainly controlled by the amount of rain, while the relaxation time is primarily a function of the heat flux.
These results have strong implications in the interpretation and the reliability of the temperature surveys, and could be used to correct them from the climate fluctuations.