The development of compound lava flow fields: insights from the 2008-9 eruption of Mt. Etna, Sicily

1. Introduction
Lava flow models can predict areas that will be threatened during short-lived effusive volcanic eruptions, but long-lived activity (>3 weeks) results in complex flow fields. Multiple ephemeral vents may develop, feeding small flows that undergo processes including breaching and tubing, which are not fully understood. During the 13/05/2008 – 06/07/2009 eruption of Mt. Etna (Sicily), which emplaced lava flows into the Valle del Bove (VdB), we collected images and topographic data to enable analysis of the role of such processes in flow field evolution.

2. Data collection
By June 2009, effusive activity was limited to the VdB headwall (Fig. 1). A number of ephemeral vents (lifetimes of up to a few days) fed flows reaching up to 1 km in length, with lifetimes of hours to days. At this time we collected topographic data of the active flows using a terrestrial laser scanner, and deployed 4 Canon EOS 450D cameras on the VdB rim that captured images at 5-30 minute intervals until the end of the eruption (Fig. 2).

3. Flow field development
More than one ephemeral vent could be active at any time, each feeding more than one flow. Flows experienced breakouts, due to cooling induced stagnation, pulses in effusion rate (Fig. 3), or accidental breaches resulting from transient channel blockages. Pulses were observed to reactivate ephemeral vents and flows, initiate breakouts from stalled fronts, and cause flow fronts to accelerate (Fig. 3).

4. Flow front tracking
The fronts of some larger flows (and associated breakouts) have been tracked through the image sequence. Using knowledge of the camera imaging geometry, the pixel tracks can be reprojected onto the topographic surface to determine flow advance in 3-D geographical coordinates (Fig. 4). Integration of the imagery and topography allows flow lengths, hence velocities, to be extracted (Fig. 5).

5. Analogues in larger (km-scale) flows
Repeated levée breaching events were observed during the 2001 and 2004 Etna eruptions. In 2001, breaching led to two major new flows, one of which advanced at 40 to the original flow direction (Fig. 6). In 2004, breakage flows advanced slightly further than the original flow front. Such processes may potentially increase or renew the hazard posed by a flow.

6. Conclusions and Future Work
The combination of time-lapse imagery and topographic data allows short-term changes in lava flow field configurations to be tracked, and flow velocities to be estimated. Short-term changes in effusion rate can be observed in the form of pulses that result in new flow units, which may or may not be sustained, but care must be taken in distinguishing pulses that result from true changes in supply from those arising due to transient blockages. The calculation of flow advance velocities is the first step towards extracting quantitative estimates of rheological properties from the images. Processes similar to those observed here have been documented in larger (km-scale) flows during several eruptions on Etna (Fig. 6) though with poorer time resolution. Smaller-scale flows, which can serve as analogues for larger flows, are easier to monitor using remote imaging, and can be used to validate existing lava flow models.