The control of source processes and topography on the dynamics of devastating pyroclastic density currents generated during the Merapi 2010 eruption

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The Merapi 2010 eruption, the most intense at Merapi since 1872, provided a unique detailed empirical dataset on the generation, emplacement, and devastating impact of a diversity of pyroclastic density currents (PDCs) during an escalating rapid-onset, multi-stage eruption that threatened a large population. An 11-minute sequence of laterally-directed explosions and retrogressive collapses on 5 November 2010 at Merapi destroyed a rapidly-growing dome and generated high-energy PDCs (stage 4) spreading over 22 km2 with a runout of 8.4 km, while co-genetic valley-confined PDCs reached 15.5 km. The deposits and the widespread devastating impact of associated high-energy PDCs on trees and buildings show striking similarities with those from historical volcanic blasts (Montagne Pelee, Bezymianny, Mount St. Helens, Soufriere Hills). We provide data from extensive stratigraphic and sedimentologic field studies of the first unequivocal blast-like deposits in the recent history of Merapi. We used high resolution satellite imagery to map eruptive units and flow direction from the pattern of extensive tree blowdown. The stratigraphy of Stage 4 PDCs consists of three depositional units (U0, U1, U2) that we correlate with the second, third and fourth explosions of the seismic record. Both U1 and U2 show a bi-partite layer stratigraphy each with a lower L1 layer and an upper L2 layer. The lower L1 layer is typically very coarse-grained, fines-poor, poorly-sorted and massive, and was deposited by the erosive waxing flow head. The overlying L2 layer is much finer grained, fines-rich, moderately to well-sorted, with laminar to wavy stratification. L2 was deposited from the waning upper part and wake of the PDC. Field observations indicate that PDC height reached 330 m with an internal velocity of 100 m.s-1 within 3 km from the source. The geometry of the summit and terrain morphology formed by a major transversal ridge and a funneling deep canyon significantly limited the loss of kinetic energy of the PDC hence focussing their mass into a major canyon constriction. The resulting elevated PDC velocities and high particle concentration promoted overspilling of high ridges into tributary valleys, while generating elevated dynamic pressures offset from the crater that caused major destruction of buildings and forest to 6 km from the summit. The Merapi 2010 eruption highlights that source and path effects can significantly control the dynamics of high-energy PDCs generated as a result of explosive and gravitational disintegration of a rapidly growing dome. This constitutes a challenge for current efforts in mathematical modelling of PDCs and quantitative risk assessment of potential impact areas at Merapi and at other volcanoes, particularly during multi-stage eruptions that can generate a diversity of PDCs in a short time-period during which the properties of the substratum over which succesive PDCs are emplaced can evolve significantly with time.