Postprint: Numerical Simulation of Dynamic Disaster Induction in Ice and Snow Disaster Chains

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Abstract

Due to global climate warming, shortened return periods of extreme heavy rainfall, and rainfall-induced warming, large-scale ice and snow masses and permafrost are melting, and snow and ice disasters in alpine mountainous regions are exhibiting a trend of high frequency and incidence. High-altitude ice-rock avalanches often initiate above the snow line, entraining loose surface snow and forming ice-rock-snow avalanche-debris flows. On the one hand, during high-speed motion, the debris flow interacts violently with the surrounding air, generating a strong impact air blast disaster chain that causes damage to areas beyond the sliding mass' s flow and deposition zone. On the other hand, under shear and collision effects, the contained ice and snow materials undergo progressive melting, and the increased meltwater volume leads to flow regime transformation, ultimately forming water-rich debris flows or long-distance debris flow hazards. Therefore, in view of the unique multi-phase material composition and phase transition effects of snow and ice disaster chains, there is an urgent need to establish targeted dynamic models to investigate their evolution and hazard processes. This paper establishes a snow and ice disaster chain dynamic model RAMMS::ROCKICE that considers phase transitions, based on two-layer flow and depth-integrated theory. Grounded in mass, momentum, and energy conservation, the model can efficiently track ice/snow-water phase transitions, phase transition effects, and the generation and hazard of impact air blasts during sliding mass motion. Through analysis of the Chamoli ice-rock avalanche-debris flow and the Langtang ice-rock-snow avalanche-impact air blast disaster chain in the Himalayan region, typical dynamic hazard processes of snow and ice disaster chains are reproduced, and the research results will contribute to risk prevention of snow and ice disaster chains in the Tibet region.

Full Text

Preamble

Dynamic Modeling of Rock-Ice-Snow Avalanche Disaster Chains

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Abstract

Driven by global climate warming, shortened recurrence intervals of extreme rainfall, and rain-on-snow effects, large-scale snow and ice masses together with permafrost are undergoing accelerated melting. This has led to a marked increase in the frequency and intensity of ice-snow disasters in high-altitude mountain regions. High-altitude ice-rock avalanches typically initiate above the snowline, entraining loose surface snow and transforming into ice-rock-snow avalanches and debris flows. On one hand, during high-speed movement, these debris flows interact violently with surrounding air, generating powerful impact air blast effects that cause destruction far beyond the flow and deposition zones. On the other hand, under shear and collision forces, the contained ice and snow undergo progressive melting, with increasing meltwater content leading to flow regime transformation and ultimately resulting in water-rich debris flows that cause long-runout disasters. Therefore, given the unique multi-phase material composition and phase transition effects characteristic of ice-snow disaster chains, there is an urgent need to develop specialized dynamic models to investigate their evolution and hazard generation mechanisms.

This study presents the RAMMS::ROCKICE dynamic model for ice-snow disaster chains, developed based on two-layer flow and depth-integrated theory. Grounded in principles of mass, momentum, and energy conservation, this model efficiently tracks ice/snow-water phase transitions, phase transition effects, and impact air blast generation during avalanche motion. By analyzing the Chamoli ice-rock avalanche-debris flow event and the Langtang ice-rock-snow avalanche-impact air blast disaster chain in the Himalayan region, the model successfully reproduces the dynamic disaster processes typical of ice-snow disaster chains. These research findings will contribute to risk prevention and mitigation efforts for ice-snow disaster chains in the Tibet region.

Keywords: ice-snow disaster chain; dynamic hazard generation; numerical simulation; RAMMS::ROCKICE

Note: Figure translations are in progress. See original paper for figures.