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## A study on an extensively applicable method for determining snowmelt-induced landslides warning periods based on a hydrological index

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In snow-covered regions, a large number of landslides are induced by infiltration of snowmelt water. Although it is very important to early find signs of increase in landslide activity such as cracks or bulges for preventing or mitigating snowmelt-induced landslide disasters, thick snow cover often makes it difficult to find them. In such cases, frequent patrols of slopes prone to landslides during periods with high risk can be effective. In Japan, snowmelt advisories are issued by the Japan Meteorological Agency while snowmelt-induced disasters (e.g., flood and landslides) are predicted based on meteorological conditions. Although it seems that snowmelt advisories can be used for judging whether patrols are required, it has been reported that snowmelt advisories are not issued for some days with high risk of snowmelt-induced landslides (Irasawa et al, 2011). Focused exclusively on landslides, Nakaya et al (2008) and Touhei et al (2016) proposed methods for capturing 70% of landslides by setting a critical level using reservoir inflow and river water level and flow rate as hydrological indices. These methods, however, are difficult to apply for areas affected by human impacts including irrigation and water intake and drainage of power stations. In this study, based on the antecedent precipitation index, reported as a hydrological index showing a good correlation with slow-moving landslide velocity (e.g., Enokida et al, 2002), we propose an extensively applicable method for setting snowmelt-induced landslides warning periods. The target areas are three 5-km meshes in Joetsu and Myoko Cities, Niigata Prefecture, central Japan, where heavy snowfall in winter and the underlying Tertiary sedimentary rocks cause many snowmelt-induced landslides every year. We used for analyses 285 landslide cases that occurred from December to May in 1979 to 2020 reported in data set on landslides compiled by the Niigata Prefectural government. We used (meltwater and/or rainwater), which is the total amount of water reaching the ground surface, instead of precipitation, for calculating the antecedent precipitation index. The amount of snowmelt was estimated based on the heat balance method using the Japan Meteorological Agency observation data alone (Matsunaga, 2019) for the center of each mesh with an average elevation within the mesh. and the antecedent index with a various half-life were calculated hourly. Using the standard score, calculated by normalizing the antecedent index, we determined the critical standard score capturing 70% of the target landslides in each mesh and the half-life minimizing the landslides warning periods (i.e., periods during which the standard score exceeds the critical standard score). These procedures resulted in

the average landslides warning periods per year of 36 to 50 days with 36 to 318 hours of the half-life for all meshes. On the other hand, snowmelt advisories were issued for 30 days per year in average from 2013 to 2020, capturing only 36% of the target landslides. Thus, the method proposed in this study shows more than 30% higher landslide capture ratio and therefore is better than snowmelt advisories for setting snowmelt-induced landslides warning periods.