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NOTES AND CORRESPONDENCE

Abundant Landslides Associated with Extreme Weather Change During the 2009 Typhoon Morakot

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ABSTRACT

The abundance of landslides that occurred in Taiwan in August of 2009 is not only attributed to extremely heavy rainfall but also extreme weather change from a dry period that occurred one month before the landslides to extremely heavy rainfall within a few days when Typhoon Morakot passed through Taiwan. The dry month of July in the summer of 2009 followed several months of rainfall shortage. Numerous cracks and fissures would have developed in the ground surface. Those cracks and fissures enabled the heavy rainfall to easily infiltrate the ground, thus constituting another factor causing a huge number of landslides in southern Taiwan. Thus, warning against abundant landslides might be considered in the future as extremely heavy rainfall can occur during the hot, dry summer season.

Key words: Abundant landslides, Extreme weather change, Typhoon Morakot

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On 8 August 2009, Typhoon Morakot landed on Taiwan producing more than twenty thousand landslides triggered by extremely heavy rainfall (Lin et al. 2011). The estimated agriculture loss was more than 164 billion NT dollars. The total loss of life was 699 dead and missing people (EPA 2009). The most catastrophic of the landslides buried 474 residents in the village of Hsiaolin, southern Taiwan (Lin et al. 2010). Careful geological survey of the Hsiaolin landslide (Tsou et al. 2011) revealed that the major slide materials initially collapsed from an elevation of approximately 1280 m (Hsindoshan) and were then deposited along Chishan Creek at an elevation of approximately 450 m. The landslide immediately formed a dam. About ~40 minutes later the debris flow due to dam breach flushed away the remaining houses, except for two that were situated on the high ground in the southern part of Hsiaolin Village (Chen et al. 2011).

In addition to the extremely heavy rainfall, the huge number of landslides during Typhoon Morakot might be associated with the extreme weather change observed in the summer of 2009 (Fig. 1). It is generally agreed that the occurrence of landslides is a very complicated process, controlled by a number of factors, such as rock quality, stratification, slopes, surface friction, geological/hydrogeological conditions and so on (Szabó 2003; Wu et al. 2011; Lin 2015). The extremely heavy rainfall of 2858 mm (Typhoon Database, Central Weather Bureau, http://rdc28.cwb.gov.tw/TDB/ntdb/pageControl/ty_warning) that occurred between August 8 and 12 in the Alishan area of southern Taiwan was clearly among the major causes. It is interesting to note that the accumulated rainfall in the Alishan area in July 2009 was less than that of any other July period in the past 12 years (2002 - 2013) based on data provided by the Central Weather Bureau, Taipei, Taiwan (Fig. 1). The significant shortage of accumulated rainfall in the first half-year before August in 2009 was clearly found not only at Alishan, but also in the entire southern Taiwan area (Fig. 2). For example, the accumulated rainfall from January to July in 2009 was 1182 millimeters, less than the average accumulated rainfall for the same months between 1981 and 2010. The rainfall shortage before Typhoon Morakot was close to

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one-third of the annual accumulated rainfall at Station Alishan. As a result, such a dry month in the summer of 2009 with a long rainfall shortage over several previous months in the southern Taiwan area, the ground surface would have developed numerous cracks and fissures. Although the crack and fissure openings are associated with induced movement at depth and pre-existing structures by the *in situ* stress field, the differential movement generates tensile zones at depth

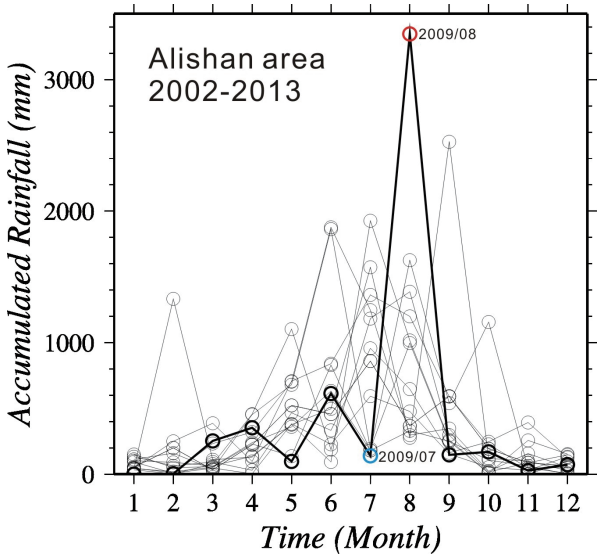

Fig. 1. Accumulated rainfall in the Alishan area of southern Taiwan in every month between 2002 and 2013 (provided by Central Weather Bureau in Taiwan). The thick line marks the monthly rainfall in 2009, indicating that numerous landslides triggered by the extremely heavy rainfall in August, but the extremely low rainfall in July.

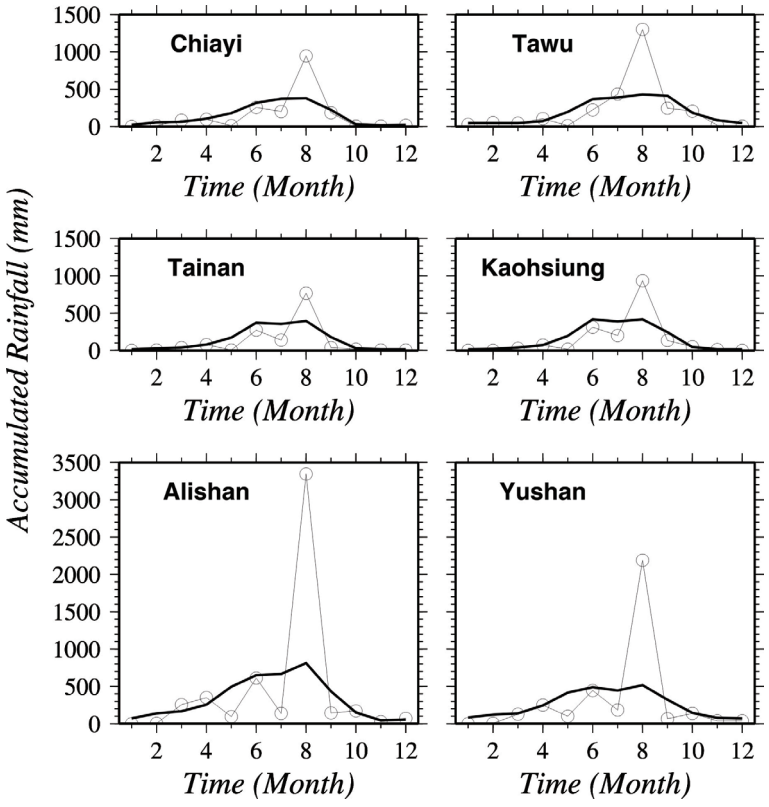

Fig. 2 Monthly accumulated rainfalls (thin lines with circles) recorded at 6 sites in southern Taiwan in 2009. The thick lines show the monthly average rainfall between 1981 and 2010 (provided by Central Weather Bureau).

and then forms cracks or fissures at the land surface (Sheng et al. 2003). Those cracks and fissures enabled the heavy rainfall to easily infiltrate the ground (e.g., Van Asch et al. 1999; Tsaparas et al. 2002; Aleotti 2004; Zhan and Ng 2004; Guzzetti et al. 2008), and, thus, constituted another factor causing numerous landslides. Other typhoons such as Sinlaku and Kalmaegi in 2008 also brought heavy rainfall to the Alishan area (Typhoon Database, Central Weather Bureau, http://rdc28.cwb.gov.tw/TDB/ntdb/pageControl/ty_warning), but they did not trigger as many landslides because of the absence of deep fissures and cracks in the ground surface prior to the heavy rainfall. The landslide abundance in August 2009 might therefore have resulted from both extremely heavy rainfall occurring within a period of days and the extreme dry weather that occurred in the preceding month. Similar results have been reported by Szabó (2003), who found the impact of irregular rainfall events triggering landslides in the regional context of landslides in Hungary.

In summary, a study of a possible relationship between abundant landslides and extreme weather change observed during the 2009 Typhoon Morakot provides potential future warning for a large number of landslides as extremely heavy rainfall, often brought by typhoons or monsoon, occurs in the dry and hot summer season. It is worth noting that a rainfall shortage warning was given for central and southern Taiwan areas in early 2015. Such dry weather is similar to that in 2009 if not enough rain falls in the spring of 2015. As a result, abundant landslides may be produced during the 2015 typhoon season.

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