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Landslides in West Coast metropolitan areas: The role of extreme weather events

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ABSTRACT

Rainfall-induced landslides represent a pervasive issue in areas where extreme rainfall intersects complex terrain. A farsighted management of landslide risk requires assessing how landslide hazard will change in coming decades and thus requires, inter alia, that we understand what rainfall events are most likely to trigger landslides and how global warming will affect the frequency of such weather events. We take advantage of 9 years of landslide occurrence data compiled by collating Google news reports and of a high-resolution satellite-based daily rainfall data to investigate what weather triggers landslide along the West Coast US. We show that, while this landslide compilation cannot provide consistent and widespread monitoring everywhere, it captures enough of the events in the major urban areas that it can be used to identify the relevant relationships between landslides and rainfall events in Puget Sound, the Bay Area, and greater Los Angeles.

In all these regions, days that recorded landslides have rainfall distributions that are skewed away from dry and low-rainfall accumulations and towards heavy intensities. However, large daily accumulation is the main driver of enhanced hazard of landslides only in Puget Sound. There, landslide are often clustered in space and time and major events are primarily driven by synoptic scale variability, namely “atmospheric rivers” of high humidity air hitting anywhere along the West Coast, and the interaction of frontal system with the coastal orography. The relationship between landslide occurrences and daily rainfall is less robust in California, where antecedent precipitation (in the case of the Bay area) and the peak intensity of localized downpours at sub-daily time scales (in the case of Los Angeles) are key factors not captured by the same-day accumulations. Accordingly, we suggest that the assessment of future changes in landslide hazard for the entire the West Coast requires consideration of future changes in the occurrence and intensity of atmospheric rivers, in their duration and clustering, and in the occurrence of short-duration (sub-daily) extreme rainfall as well. Major regional landslide events, in which multiple occurrences are recorded in the catalog for the same day, are too rare to allow a statistical characterization of their triggering events, but a case study analysis indicates that a variety of synoptic-scale events can be involved, including not only atmospheric rivers but also broader cold- and warm-front precipitation.

That a news-based catalog of landslides is accurate enough to allow the identification of different landslide/rainfall relationships in the major urban areas along the US West Coast suggests that this technology can potentially be used for other English-language cities and could become an even more powerful tool if expanded to other languages and non-traditional news sources, such as social media.

1. Introduction

Intense and prolonged rainfall events are the predominant triggers of landslide worldwide (Petley et al., 2005). Thus, understanding how landslide hazard will change in the coming decades cannot leave out of consideration how anthropogenic climate change will affect the occurrence and intensity of heavy rain. Indeed, both theory (Trenberth, 1999; O'Gorman and Schneider, 2009) and observations (Donat et al., 2016) suggest that extreme rainfall becomes still more intense in a warming world, even in regions that are overall drying. Broadly, a warming world is also a more moist world. Theory indicates that the saturation humidity will adjust to the warmer surface temperatures without much changes in relative humidity and extreme rainfall events, those that are dynamically capable of strong upward motions, will become more intense. Thus, any given extreme rainfall amount is expected to become more frequent and the heaviest rainfall events are

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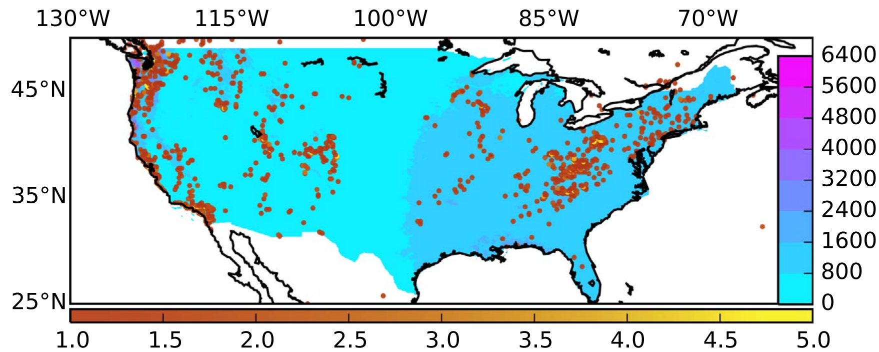

Fig. 1. Cold-colored shading: 2007–2015 mean annual total precipitation from PRISM (mm). Warm-colored dots: Number of recorded landslides over the same period in the Kirschbaum et al. (2010) dataset. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

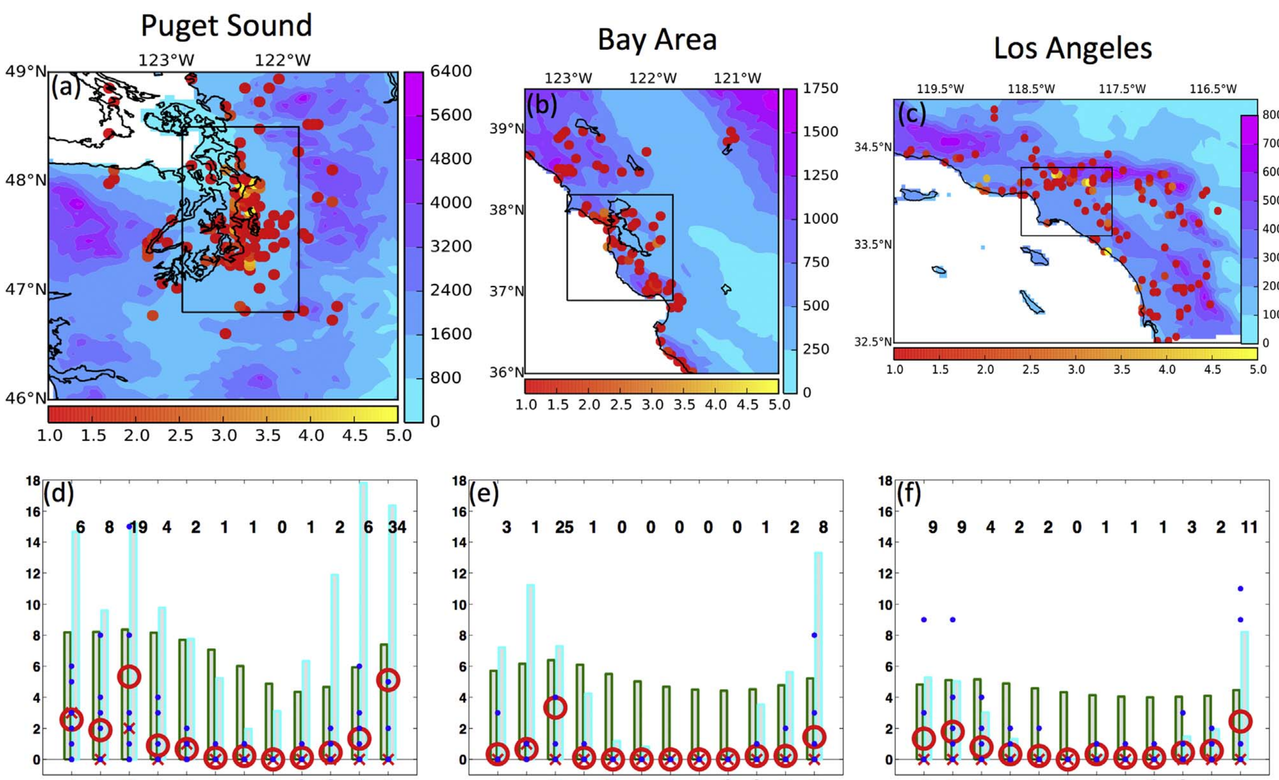

Fig. 2. Top Row: 2007–2015 mean annual total precipitation from PRISM (mm, cold-colored shading, vertical color bars) and number of recorded landslides (warm-colored dots, horizontal color bars) but for areas of the West Coast centered around Seattle (Puget Sound, left), San Francisco (Bay Area, center) and Los Angeles (LA Area, right). The black boxes indicate the domains of the urban areas included in this study. Bottom Row: Bars are the monthly climatology of 1-meter soil moisture (green bars, units of hundred of kg/m^2) and rainfall accumulation (cyan bars, units of tens of mm). Blue dots are the total number of landslides in the study areas in individual years (extreme years might fall outside the graph), the median is given by the cross and the mean by the open circle. The numbers on top indicate the maximum monthly occurrences of landslides. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

expected to have even heavier rainfall. Climate models agree with the theoretical scalings (O'Gorman and Schneider, 2009) and, at least for the mid-latitudes, provide a robust estimate of an expected increase in the intensity of the 99.9th percentile of daily rainfall of 6% per degree of global warming (O'Gorman, 2015).

While robust for very broad regions, these projections are more uncertain at any specific location. Regional changes in both mean rainfall accumulation and rainfall characteristics are more complex, as they result from the combination of temperature-induced changes in atmospheric humidity and changes in the atmospheric circulation. The expected annual mean rainfall change for coming decades in the US West Coast, for example, are of wetter rainfall totals in the northern region (the Pacific Northwest) and dryer totals in the Southern region (Southern California, Collins et al., 2013; Seager et al., 2014). The separation line, where rainfall anomalies will be small, is uncertain, as different models project slightly different changes, but is typically somewhere around central to northern California. Moreover, the annual changes are the combination of widespread wetting anomalies in winter and widespread dry anomalies in the summer. However, Simpson et al. (2015) argue that climate models likely overestimate the mid-winter wetting of the West Coast.

An increase in intense daily events for regions that are expected to get wetter is, at least qualitatively, beyond serious doubt. But in regions where the mean rainfall is projected to decrease we expect that the distribution of rainfall will include more dry and low-rainfall events, and that only the most extreme events will intensify. If landslides tend to occur when rainfall exceeds a certain threshold that lies somewhere in between, changes in the occurrence of triggering events become more uncertain and in need of more detailed investigation. Other aspects of the changing climate (from the likelihood of thawing to the