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Research papers

Characterization of floods in the United States

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ABSTRACT

Floods have gained increasing global significance in the recent past due to their devastating nature and potential for causing significant economic and human losses. Until now, flood characterization studies in the United States have been limited due to the lack of a comprehensive database matching flood characteristics such as peak discharges and flood duration with geospatial and geomorphologic information. The availability of a representative and long archive of flooding events spanning 78 years over a variety of hydroclimatic regions results in a spatially and temporally comprehensive flood characterization over the continental U.S. This study, for the first time, employs a large-event database that is based on actual National Weather Service (NWS) definitions of floods instead of the frequently-adopted case study or frequentist approach, allowing us to base our findings on real definitions of floods. It examines flooding characteristics to identify how space and time scales of floods vary with climatic regimes and geomorphology. Flood events were characterized by linking flood response variables in gauged basins to spatially distributed variables describing climatology, geomorphology, and topography. The primary findings of this study are that the magnitude of flooding is highest is regions such as West Coast and southeastern U.S. which experience the most extraordinary precipitation. The seasonality of flooding varies greatly from maxima during the cool season on the West Coast, warm season in the desert Southwest, and early spring in the Southeast. The fastest responding events tend to be in steep basins of the arid Southwest caused by intense monsoon thunderstorms and steep terrain. The envelope curves of unit peak discharge are consistent with those reported for Europe and worldwide. But significant seasonal variability was observed in floods of the U.S. compared to Europe that is attributed to the diversity of causative rainfall ranging from synoptic scales with orographic enhancements in the West Coast, monsoon thunderstorms in the desert Southwest, to land-falling tropical storms and localized, intense thunderstorms in the Southeast.

1. Introduction

Floods are one of the most devastating natural disasters in the world that account for one-third of all global geophysical hazards (Smith and Ward, 1998; Adhikari et al., 2010). Floods, especially flash floods, have attracted significant attention in the recent past, both in academia and the wider world, due to their devastating nature and potential for causing substantial economic damage and loss of life. Flood hazard studies at the continental and global scales have received more attention as the destructive effects of flooding events are given more importance in public policy. According to the United States Flood Loss Report for Water Year 2014 (October 1, 2013 – September 30, 2014) compiled by the National Weather Service for the U.S. Army Corps of Engineers, the direct flood damages totaled $2.86 billion in the United States alone. Fifty-five flood-related deaths were recorded, out of which 29 were attributed to vehicle-related accidents and 39 to flash flood events (NWS, 2014). With ever increasing urbanization, casualties and damages due to flooding is expected to increase. Heavy precipitation is also seeing an upward trend at both continental (Groisman et al., 2004) and global scale (Groisman et al., 2005), which will increase the frequency and impact of flood hazards.

Floods and especially flash floods have not received the systematic and comprehensive study commensurate with their social and

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economic impacts. To understand the spatial, temporal and geographic distribution of floods, we must first have a centralized database that collates quantitative information regarding floods. However, such databases are not easily available as formal records on previous floods are scattered across disparate sources. Due to this limitation, flood characterization studies have been performed mostly based on case studies or limited databases. Costa (1987) described the hydraulic characteristics of twelve of the largest floods of small basins ever measured by the U.S. Geological Survey (USGS) in the conterminous United States (CONUS) and related them to basin morphometry of the channels. He concluded that basin physiography and geology, in addition to rain intensity and duration, are major factors in maximizing runoff. In order to devise a procedure to distinguish flash floods from other floods, Bhaskar et al. (2000) developed a Flash Flood Index. The index utilizes characteristics describing the shape of the flood hydrograph and shows weak to moderate correlation with additional hydrograph variables such as unit peak discharge and direct runoff volume. Merz and Blöschl (2003) identified the causative mechanisms of floods using 11,518 maximum annual flood peaks in 490 Austrian catchments. Gaume et al. (2009) reported the compilation of an inventory containing 550 documented flash flood events in seven hydrometeorological regimes in Europe. Marchi et al. (2010) performed a detailed study of 25 selected extreme flash floods in Europe to identify causative processes and related them to climate and basin morphology. They characterized these events in terms of basin morphology, flood-generating rainfall, peak discharges, runoff coefficient, and response time to identify implications for flash flood risk management. To approximate the basin behavior in response to rainstorms, Perucca and Angilieri (2011) evaluated the flash flood hazard of del Molle basin in Argentina by analyzing different morphometric properties. The study reported the probability of a serious flash flood hazard in the basin and suggested implementation of mitigation measures.

In the United States, flood characterization has been done mostly through limited case studies or for a part of the country since the available information is usually sparse and non-homogeneous. Most flood databases do not catalogue sufficient information such as geospatial and geomorphologic data to be adequate for flood characterization studies. A comprehensive flood database should have certain information such as flood response variables (e.g. flooding rise time, recession time, etc.), peak discharge information, gridded rainfall rate data and as many geomorphologic parameters of the basins as possible in order to evaluate specific parameters that improve analysis of the driving geomorphologic and climatological factors, and hydrologic simulations. Some of the existing hazard databases that catalogue flooding events include the freely-accessible Emergency Disasters Database (EM-DAT) by the Center for Research on the Epidemiology of Disasters (CRED), that covers natural and man-made disasters from 1900-present (http://www.emdat.be/). The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) also maintains ReliefWeb (http://www.reliefweb.int/) which publishes disaster reports in real-time. The International Flood Network (IFNET) publishes a flood event database based on voluntary submission of events that caused 50 or more casualties between 2005 and 2007 (http://www.internationalfloodnetwork.org/). The Dartmouth Flood Observatory (DFO) maintains a Global Archive of Large Flood Events (http://floodobservatory.colorado.edu/) which is one of the most comprehensive flood databases derived from a variety of sources such as remote sensing images and government reports (Brakenridge and Karnes, 1996). However, even though the database has good global coverage, it is not exhaustive enough and its events are only geo-referenced up to 2006, which limits its usability in evaluating and improving flood models. Adhikari et al. (2010) also reported a digitized global flood inventory (1998–2008) with georeferenced flooding events.

A recent effort was undertaken to build and make publicly available a Unified Flash Flood Database described in Gourley et al. (2013), which is used in this paper. It should be noted that the database incorporates all floods, including flash floods. The database comprises USGS streamflow measurements, storm reports collected by the National Weather Service (NWS), and public survey responses during the SHAVE experiment (Gourley et al., 2010). This dataset has undergone extensive post-processing to maintain consistency in data formats across the various sources. The long USGS component of the database is suitable for characterizing floods because it contains most of the necessary attributes such as flooding rise time, peak discharge, basin area, etc. The NWS, in collaboration with local stakeholders, has defined flooding thresholds for USGS stream gauge locations, which are used to extract flooding events from the streamflow record. Michaud et al. (2001) have depicted the distribution of large floods in the U.S. using data from 130 USGS stations, but only for basins less than 200 km^2. O'Connor and Costa (2004) was the first study to systematically analyze large portions of the USGS streamflow dataset comprising largest 10% of annual peak flows from 14,815 stations. While it states that specific basins of high unit peak discharge correspond to relatively high topographic relief, it only provides a qualitative assessment of this relationship due to unavailability of geomorphological data. Other studies have uncovered flooding characteristics in a portion of the country using the same USGS data, such as Villarini and Smith (2010) in the eastern U.S. and Mallakpour and Villarini (2015) in the central U.S. Smith and Smith (2015) used this dataset to identify the "flashiest" watersheds in the contiguous United States based on the frequency of discharge peaks exceeding 1 $m^3\,s^{-1}\,km^{-2}$. They noted urban areas were frequently affected by flash flooding in the south-central U.S. (i.e., Tulsa, Oklahoma and St. Louis, Missouri) up through the mid-Atlantic (i.e., Baltimore, Maryland) as well as the Pacific Northwest. A recent study by Saharia et al. (2016) introduced a new variable called "flashiness" as a measure of flash flood severity which was extended and regionalized from gauged basins to a high resolution grid covering the CONUS. Benefiting from the representativeness and length of the Unified Flash Flood Database, the present study provides a spatially and temporally comprehensive flood characterization over the CONUS. This study, for the first time, employs a large-events database based on NWS definitions of floods instead of a frequently-adopted case study or frequentist approach, which allows us to base our analyses and conclusions on real definitions of floods. It examines flood regimes across the CONUS in order to determine how space and time scales of floods vary with climatic regimes, seasons, and geomorphology. This characterization of flood events paves the way towards improving hydrologic forecasting and risk management.

The purposes of this analysis are to (i) present an overview of the database that covers flooding events over more than 70 years from 1936 to 2013, (ii) characterize flooding events according to geomorphological basin attributes and climate classes, (iii) establish new relationships and envelope curves taking advantage of the lengthy historical record of floods, (iv) explore the results from the perspective of improving flood forecasting and risk management. The paper is organized as follows. Section 2 describes the flood and geomorphology database, the development of the archive, and an overview of the distribution of floods over the CONUS. Sections 3 and 4 characterize unit peak discharge and flooding rise time, respectively, based on geomorphologic parameters such as basin area, relief ratio, and shape factor. Finally, Section 5 provides a summary of findings and concluding remarks.