P2.6

THE HURRICANE-FLOOD-LANDSLIDE CONTINUUM FORECASTING HURRICANE EFFECTS AT LANDFALL

Andrew J.Negri [1], Joseph H. Golden [2], and Randall G. Updike [3]

[1] Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD, 20771
[2] NOAA/Forecast Systems Laboratory, Boulder, CO, 80305-3328,
[3] U.S. Geological Survey, Denver Federal Center, Denver, CO, 80225

1. INTRODUCTION

During the past several years, the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) have been called upon to respond to catastrophic floods and landslides throughout the United States triggered by intense meteorological phenomena. In the meantime, the National Aeronautics and Space Administration (NASA) has employed numerous satellite platforms to observe and monitor these Earth systems. For the most part, each of these agencies has used its own set of skills and capabilities to better understand the atmospheric processes involved in the cyclonic storms, the associated heavy precipitation, and the associated effects at landfall, loods and landslides. Cyclonic low-pressure systems reaching landfall along the Pacific Ocean states and extending inland to the east, as well as hurricane and tropical low-pressure systems from the Atlantic impinging on the southern and eastern coastal states, are the most frequent causes of these disasters. In some instances, the greatest loss of life and property is the direct result of the storm because of the high winds and heavy rains. But, in many cases, the greatest losses come from ground failures and floods.

Because the majority of our population lives in states bordering the Atlantic Ocean, Pacific Ocean, and the Gulf of Mexico, our exposure to landslide and flood disasters is of extreme concern; furthermore, unlike volcanoes and earthquakes, the hazard returns every year.

Hurricanes, typhoons, and cyclones strike Central American, Caribbean, Southeast Asian and Pacific Island nations even more frequently than the U.S. The global losses of life and property from the floods, landslides, and debris flows caused by cyclonic storms are staggering. One of the keys to reducing these losses, both in the U.S. and internationally, is to have better forecasts of what is about to happen from several hours to days before the event. Particularly in developing nations where science, technology, and communication are limited, advance-warning systems can have great impact. In developing countries, warnings of even a few hours or days can mitigate or reduce catastrophic losses of life.

*Corresponding author: Andrew J. Negri, NASA/GSFC, Code 912, Greenbelt, MD 20771; email: Andrew.J.Negri@nasa.gov

For example, during late October 1998, Hurricane Mitch formed in the southwestern Caribbean and slowly intensified as it moved west-northwestward. Mitch eventually reached Category 5 status, with maximum winds of 180 mph and the fourth-lowest central pressure ever measured in an Atlantic hurricane. This immense storm literally engulfed Central America, where it remained almost stationary for several days, drawing moisture both from the Pacific Ocean and the Caribbean Sea. The countries of Guatemala, Honduras, El Salvador, and Nicaragua, in particular, were deluged with up to 933 mm of rain (Hellin and Haigh, l999), triggering intense floods and thousands of landslides. In one instance alone, at least 2000 people from a single village were buried alive by a massive mudflow that traveled 13 miles down the slope of the Casitas volcano in northwestern Nicaragua. Hurricane Mitch eventually became the second most deadly Atlantic Hurricane in 200 years, killing over 9000 people and causing many billions of dollars in loss.

It appears that even though warnings for dangerously heavy rainfall were released by NOAA during Mitch, much of this information never reached local municipal officials in the Central American countries due to inadequate communication networks. In addition, the countries impacted the most have inadequate national weather services. It is likely that these countries were devastated far worse than otherwise would have been the case if each country had been better informed and prepared.

The United States now has the elements of science and technology that can make a profound difference in these potential disasters…

The essence of our vision is that we can develop the tools that will allow the United States to issue forecast guidance products for floods and landslides associated with the onset of major storms, and disseminate this guidance to local government entities well before the floods and slides begin.

To accomplish this vision, NOAA, USGS, and NASA are prepared to combine their respective scientific and technical talents. NOAA has the capability to provide highly reliable tracking and prediction of storm rainfall, trajectory, and landfall. USGS has the capability to evaluate beforehand the ambient stability of natural and man-made landforms, to assess landslide susceptibilities for those landforms, and to establish probabilities for initiation of landslides and debris flows. In addition, USGS is widely recognized as a leader in the study of the interrelationship of vegetation, ambient stream flow, ground water, soil moisture, and geologic conditions in assessing the potential for floods. NASA, NOAA, and USGS are all currently actively developing precipitation-flood forecasting technologies. NOAA-NWS has a successful history of developing technologies aimed at rapid dissemination of weather threat data. NASA has great capacity to monitor and evaluate various natural phenomena occurring at the Earth's surface. With its multiple satellite platforms and remote sensing devices on board these satellites, NASA provides the United States with sophisticated rainfall mapping for severe storms and hurricanes. All three agencies have a long history of work on natural hazards both domestically and overseas.

Although all three agencies are conducting research on their respective aspects of this problem, there is currently no mechanism to integrate the potentially complementary programs. A proposed project, called the Hurricane-Flood-Landslide Continuum project, will bring together the three agencies to utilize their understanding of the range of scenarios of land surface instability (landslides and floods) as a result of specific evolving meteorological conditions. The problem is extremely complex, but scientists in USGS, NASA, and NOAA are convinced that the tools can be developed to substantially reduce the risk from hurricanes at landfall. Elsberry (2002) has recently summarized progress on predicting hurricane landfall precipitation.

2. THE RESPONSE: AN END-TO-END PREDICTION SYSTEM FOR HEAVY RAINFALL, FLOODING, AND LANDSLIDES

With the foregoing needs in mind, NOAA's Forecast Systems Laboratory (FSL) is collaborating on the Continuum project to initially develop and transfer a warning system for a prototype region in the Central Caribbean, specifically the islands of Puerto Rico and Hispaniola. The system will include satellite observations to track and nowcast dangerous levels of precipitation, hurricane tracking information from NOAA's National Hurricane Center, atmospheric and hydrological models to predict near-future runoff and streamflow changes in affected regions, and landslide models to warn when and where landslides and debris flows are imminent. See Elsberry (2002) for a recent summary of hurricane landfall precipitation forecast models. Since surface communications are likely to be interrupted during these crises, the project also includes the capability to communicate disaster information via satellite to vital government officials in Puerto Rico, Haiti, and Dominican Republic. In the initial phase of this project, studies of Mitch, Georges, and other recent hurricanes using satellite data and ground-based observations will be made to assess how the proposed forecast systems would have improved response and recovery in those devastating events.

Developed over a three-year period, this forecast system will provide important, immediate applications to short-term prediction and warning of flooding and landslides in the prototype region, and the science and technology can easily be applied in the United States and worldwide. The information deliverables for the prototype region will be tailored to the societal and economic needs of the affected countries, and will be carefully monitored and documented at the local level in order to provide feedback from forecasters and officials to the NASA-NOAA-USGS science team.

3. THE END PRODUCT: A SYSTEM APPROACH

The focus of the Continuum project is to improve our ability to predict the evolution of the Earth system in both a prognostic and retrospective sense. It is based on an approach that integrates more than one of the traditional Earth science disciplines, and encourages innovation and complementary use of models and data from multiple satellites and sensors.

The key components of the Continuum project are:

- A comprehensive, real-time data acquisition system (ground surface monitors, radar, infrared and microwave satellites, upper-air observations, etc.)
- A relocatable, multinested weather data analysis system suitable for various terrains and environments
- A high-resolution multinested weather forecast model component for ground surface precipitation prediction
- A hydrological modeling component for peak streamflow and flow duration
- Landslide and debris flow model components that are tuned to geology and ambient conditions
- An interactive, multitiered, redundant, multihazard warning communication system
- Societally relevant governmental decision-support systems
- Long-term capacity-building through training for both scientific and governmental personnel

A conceptual flow diagram showing principal tasks is shown in Figure 1. Although there is a natural linear progression whereby the output of one element forms the input to another, it is also clear that each must be closely coordinated with several others.

Careful integration of the NOAA, NASA, and USGS elements will also be necessary. For instance, terrain data necessary for landslide modeling is also a critical element in hydrological modeling, and accurate soil moisture content, a key variable for landslide modeling, is also vital as input to the hydrological and atmospheric models. NASA, NOAA and USGS will combine their technologies to allow integrated displays of the landslide, atmospheric, and hydrologic models, all of which should be available simultaneously and compatibly, via a shared Graphical Information System (GIS). Building these links will have lasting advantages for collaboration and decisionmaking beyond the scope of the initial project.

4. RETROSPECTIVE CASE STUDIES

A recent example of NASA's rainfall estimation mapping for Hurricane Isabel is shown in Figure 2.

Isabel, which was once a powerful Category 5 hurricane in the central Atlantic with winds estimated at 160 mph, finally came ashore on September 18, 2003 as a much weaker Category 2 storm with winds of near 100 mph just south of Cape Hatteras along the outter banks of North Carolina. Isabel quickly tracked off to the northwest leaving heavy rains, downed trees and widespread power outages thoughout the mid-Atlantic region. The TRMM-based, near-real time Multi-satellite Precipitation Analysis (MPA), Figure 3, shows rainfall totals along the path of Isabel for the period 17-19 September 2003. The heaviest amounts (darker reds), on the order of 6 inches, appear offshore. Inland the highest totals occur over central and southeast Virginia with widespread areas receiving 4 to 5 inches of rain (red areas). Most of central and eastern North Carolina had between 1.5 and 3 inches (green areas) with locally heavier amounts in areas of the outter banks (red areas). Rainfall totals in western North Carolina, the Delmarva peninsula and eastern Maryland were relatively light (blue areas). In the general the MPA estimates agree well with radar observations with the exception of far northern North Carolina near the border with Virginia where radar estimates tend to be somewhat higher. Overall the rainfall totals from Isabel were relatively low due to the rapid forward motion of the storm. Isabel moved quickly to the northwest after coming ashore at between 18 and 24 mph around the backside of a high pressure system to the east and ahead of an approaching trough from the west. The hurricane and tropical storm symbols mark the positions of Isabel every 6 hours beginning at 5 am EDT on September 18 as reported by the National Hurricane Center.

As another retrospective case study, we propose to apply existing datasets for Hurricane Georges as it passed over the islands of Puerto Rico and Hispaniola, as well as another extreme precipitation event, the Venezuelan flooding/landslides of December 1999. Up to 760 mm rainfall was estimated over Puerto Rico in 24 h, during the passage of Hurricane Georges. We plan to use these relatively well-observed cases to develop and test a modeling/analysis system that utilizes satellite-based rainfall estimates and rainfall forecasts to forecast flooding and landslides associated with hurricanes and other heavy rain events. This would include determining the utility of existing multisatellite precipitation analyses (e.g., Grose et al., 2002) in flood and landslide analysis through the use of hydrological and landslide models. Larsen and Simon (1993) have developed an empirical rainfall threshold for landslides on Puerto Rico (Figure 4). The Puerto Rico threshold compares well to data from other areas of the humid tropics, indicating that the rainfall accumulation and duration values derived from this threshold can serve as the basis for temporal landslide forecasting on Hispanola.

5. THE INTERAGENCY TEAM: NOAA, NASA, AND USGS

The leadership team for the Continuum project consists of a few key personnel in NOAA-Boulder, NASA-Greenbelt, and USGS-Denver. Project scientists and engineers will be drawn from numerous research facilities in these three agencies. This is a bold experiment in sharing expertise toward a common goal that none of the three agencies could do alone. NASA scientists at the Goddard Space Flight Center, in Greenbelt, Maryland, will have the lead in satellite monitoring, rainfall estimation, processing and analysis. NOAA scientists at FSL, in Boulder, Colorado, will have the lead in assimilating the satellite observations to the estimation of rainfall in near real time and in storm tracking. The USGS Geologic Discipline, based in Denver, Colorado, will have the lead responsibility for landslide and flood modeling. In addition, various combinations of NASA, USGS, and NOAA personnel from a variety of science centers across the country will be involved in the project, including the development of the central GIS, the deployment of worldwide weather workstations, the onsight scientific leads in the prototype area, the vegetation variability influence, the socio-economic factors, aircraft-borne monitoring, antecedent archives, system verification, and training.

6. CONCLUSIONS

We believe that by careful integration of remote-sensing and in-situ observations, and assimilation of these observations into high-resolution mesoscale models with topographic forcing, prediction of tropical precipitation is possible at small spatial and temporal scales. The goal of the Continuum project is to link such analyses and forecasts with hydrological and landslide/debris flow models to produce useful probabilistic maps of landslides for local emergency management and other officials in a timely manner. We plan to demonstrate such a capability using the comprehensive datasets already available for Hurricane Georges (1998) over Puerto Rico and the Dominican Republic, and other case studies.

REFERENCES

Elsberry, R., 2002: Predicting Hurricane Landfall Precipitation: Optimistic and Pessimistic Views from the Symposium on Precipitation Extremes, *Bull. Amer. Meteor. Soc.*, **83**, 1333–1339.

Grose, A.M.E., E.A. Smith, H.-S. Chung, M.-L. Ou, B.-J. Sohn, and F.J. Turk, 2002: Possibilities and Limitations for Quantitative Precipitation Forecasts using Nowcasting Methods and Geosynchronous Satellite Imagery, *J. Appl. Meteor.*, **41**, 763–785.

Hellin, J. and M.J. Haigh, 1999: Rainfall in Honduras during Hurricane Mitch, *Weather*, **54**, 350–359.

Larsen, M.C., and Simon, A., 1993: A rainfall intensity-duration threshold for landslides in a humid-tropical environment, Puerto Rico: *Geografiska Annaler*, **75A**, 13-23.

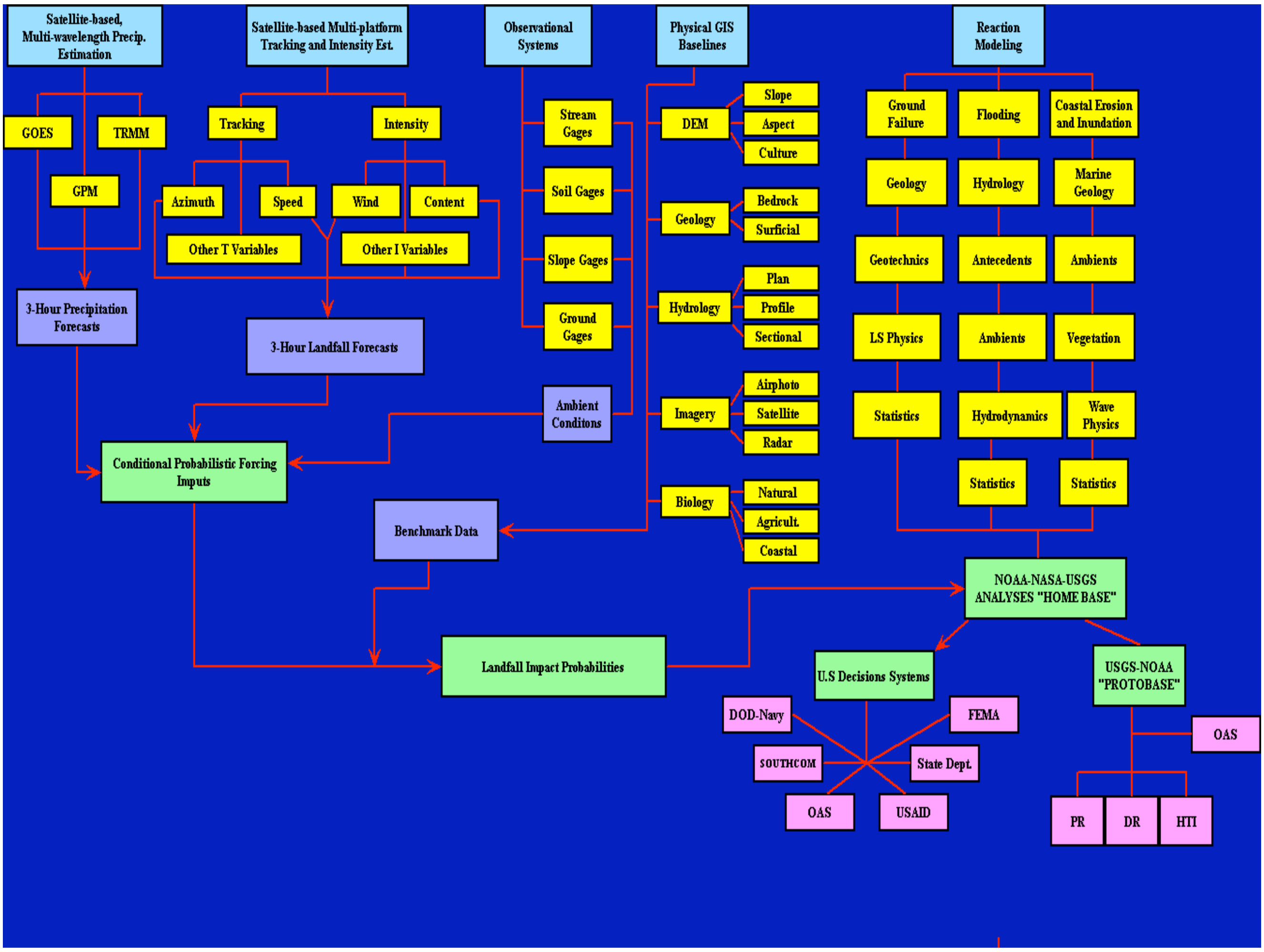

Figure 1 Conceptual flow-chart of major tasks required to fulfill major outputs of Continuum project.

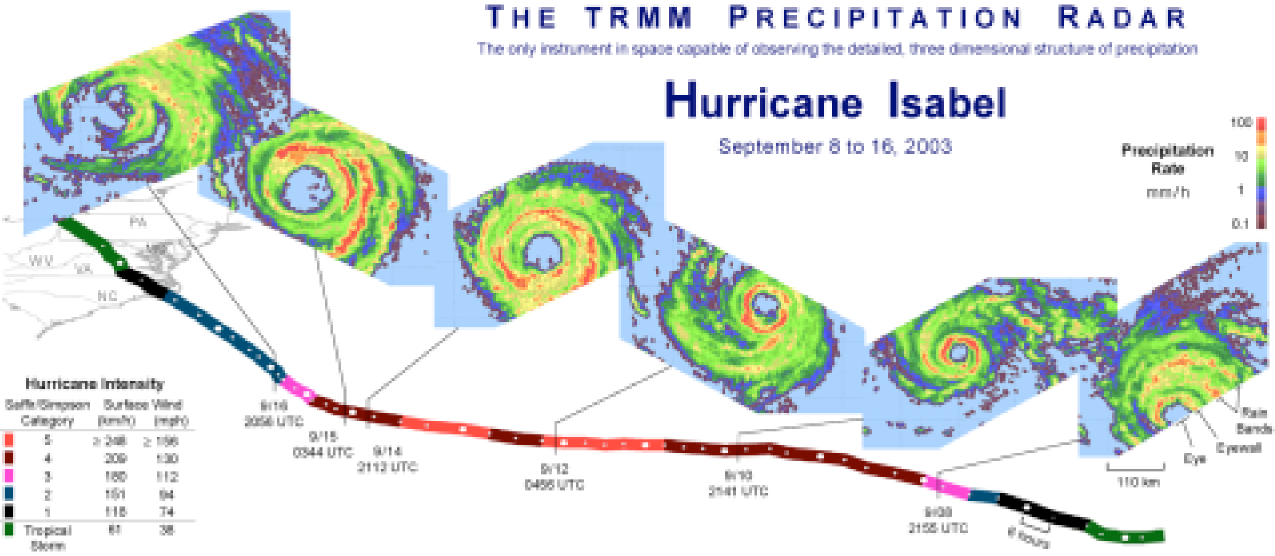

Figure 2 Montage of TRMM Precipitation Radar Images of Hurricane Isabel 8-16 Sept. 2003

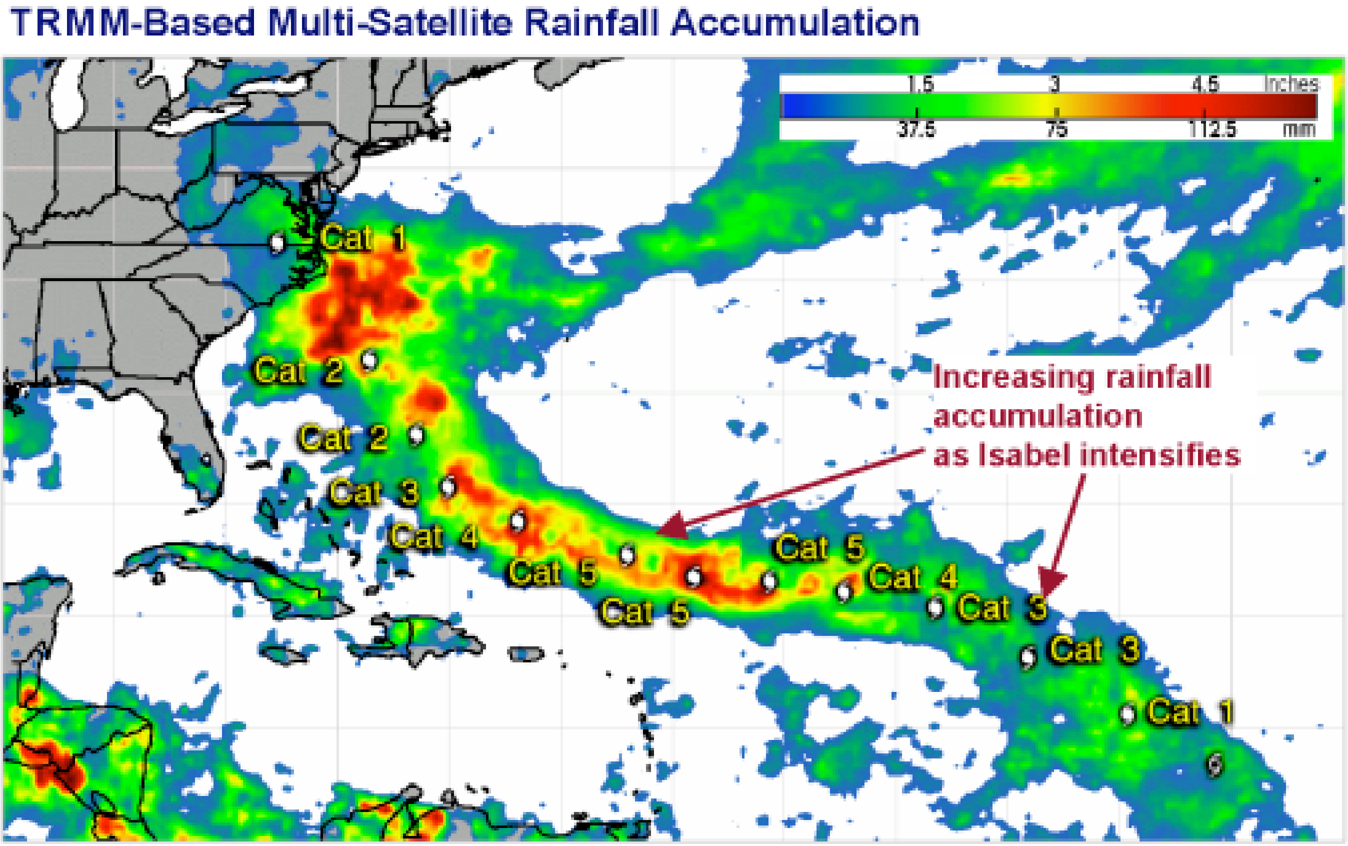

Figure 3 Accumulated Precipitation from the TRMM Multi-Satelliet Algorithm for Hurricane Isabel

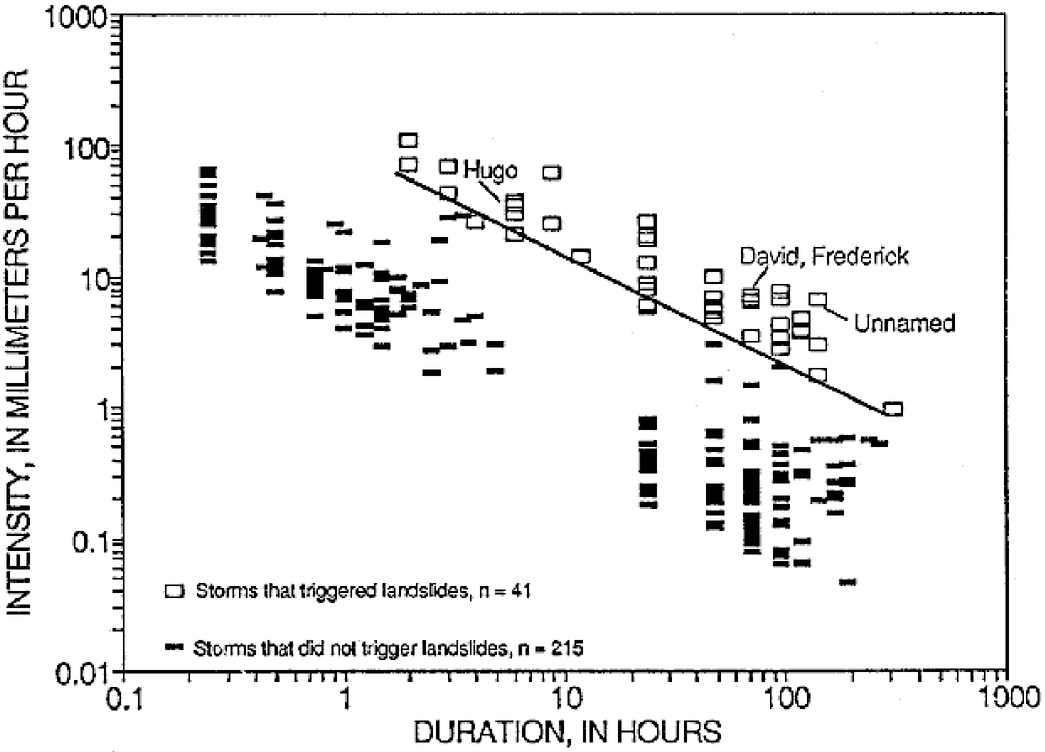

Figure 4 Rainfall threshold for landslides in Puerto Rico (Larsen and Simon, 1993)