An Experimental Global Monitoring System for Rainfall-triggered Landslides using Satellite Remote Sensing Information

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Popular Summary

Landslides are one of the most widespread natural hazards on Earth, responsible for thousands of deaths and billions of dollars in property damage every year. In the U.S. alone landslides occur in every state, causing an estimated $2 billion in damage and 25–50 deaths each year. Annual average loss of life from landslide hazards in Japan is 170. The situation is much worse in developing countries and remote mountainous regions due to lack of financial resources and inadequate disaster management ability. Recently, a landslide buried an entire village on the Philippines Island of Leyte on Feb 17, 2006, with at least 1800 reported deaths and only 3 houses left standing of the original 300.

Landslides triggered by rainfall can possibly be foreseen in real time by jointly using rainfall intensity-duration thresholds and information related to land surface susceptibility. However, no system exists at either a national or a global scale to monitor or detect rainfall conditions that may trigger landslides due to the lack of extensive ground-based observing network in many parts of the world. Recent advances in satellite remote sensing technology and increasing availability of high-resolution geospatial products around the globe have provided an unprecedented opportunity for such a study. In this paper, a framework for developing an experimental real-time monitoring system to detect rainfall-triggered landslides is developed by combining two necessary components: surface landslide susceptibility and a real-time space-based rainfall analysis system, NASA TRMM. An operational real-time monitoring system for landslide potential (http://trmm.gsfc.nasa.gov/publications_dir/potential_landslide.html) has been displayed on the NASA websites. A major outcome of this work is the availability of a first-time global assessment of landslide risk, which is only possible because of the utilization of satellite remote sensing products. This experimental system can be updated continuously due to the availability of new satellite remote sensing products.

Given the fact that landslides usually occur after a period of heavy rainfall, this real-time landslide monitoring system can be readily transformed into an early warning system by making use of the time lag between rainfall peak and slope failure. Therefore, success of this prototype system bears promise as an early warning system for global landslide disaster preparedness and risk management. Additionally, the warning lead-time of global landslide forecasts can be also expected by using rainfall forecasts (1-10 days) from operational numerical weather forecast models. This real-time monitoring system, if pursued through wide interdisciplinary effort as recommended herein, bears the promise to grow current local landslide hazard analyses into a global decision-making support system for landslide disaster preparedness and risk mitigation activities across the world.

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Abstract

Landslides triggered by rainfall can possibly be foreseen in real time by jointly using rainfall intensity-duration thresholds and information related to land surface susceptibility. However, no system exists at either a national or a global scale to monitor or detect rainfall conditions that may trigger landslides due to the lack of extensive ground-based observing network in many parts of the world. Recent advances in satellite remote sensing technology and increasing availability of high-resolution geospatial products around the globe have provided an unprecedented opportunity for such a study. In this paper, a framework for developing an experimental real-time monitoring system to detect rainfall-triggered landslides is proposed by combining two necessary components: surface landslide susceptibility and a real-time space-based rainfall analysis system (http://trmm.gsfc.nasa.gov). First, a global landslide susceptibility map is derived from a combination of semi-static global surface characteristics (digital elevation topography, slope, soil types, soil texture, and land cover classification etc.) using a GIS weighted linear combination approach. Second, an adjusted empirical relationship between rainfall intensity-duration and landslide occurrence is used to assess landslide risks at areas with high susceptibility. A major outcome of this work is the availability of a first-time global assessment of landslide risk, which is only possible because of the utilization of global satellite remote sensing products. This experimental system can be updated continuously due to the availability of new satellite remote sensing products. This proposed system, if pursued through wide interdisciplinary efforts as recommended herein, bears the promise to grow many local landslide hazard analyses into a global decision-making support system for landslide disaster preparedness and risk mitigation activities across the world.

Index term: landslide, natural disasters, satellite remote sensing, real-time precipitation analysis, landslide susceptibility

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I. Introduction

Landslides are one of the most widespread natural hazards on Earth, responsible for thousands of deaths and billions of dollars in property damage every year. In the U.S. alone landslides occur in every state, causing an estimated $2 billion in damage and 25–50 deaths each year (FEMA, 2006). Annual average loss of life from landslide hazards in Japan is 170 (Sidle and Ochiai, 2006). The situation is much worse in developing countries and remote mountainous regions due to lack of financial resources and inadequate disaster management ability. Recently, a landslide, triggered by "La Nina" rains, buried an entire village on the Philippines Island of Leyte on Feb 17, 2006, with at least 1800 reported deaths and only 3 houses left standing of the original 300. Precipitation analysis using multiple satellites (Huffman et al., 2006), including National Aeronautics and Space Administration (NASA)'s Tropical Rainfall Measuring Mission (TRMM), reported that 500 millimeters of heavy rainfall fell on that area in a 10-day period (Lagmay et al., 2006). The need to develop more effective spatial coverage of landslide susceptibility and real-time hazard monitoring for vulnerable countries and remote areas remains apparent and urgent (Sidle and Ochiai, 2006).

Landslides triggered by rainfall can possibly be predicted by modeling the relationship between rainfall intensity-duration and landslide occurrence (Keefer et al., 1987). Currently no system exists at either a global scale to monitor or detect rainfall conditions that may trigger landslides, largely due to lack of field-based observing networks in many parts of the world, in particular in developing countries which lack expensive ground-based monitoring networks. Thus, for many countries around the world, remote sensing information may be the only possible source of rainfall data and land surface

characteristics available for such study. Recent advances in satellite-based precipitation observation technology and increasing availability of high-resolution geospatial products at global scale are providing an unprecedented opportunity to develop a real-time monitoring system for a global view of rainfall-triggered landslides.

In this paper, a framework is proposed to develop a real-time monitoring system for rainfall-triggered landslides around the globe. Drawing on the heritage of a space-based global precipitation observation system and remotely sensed surface characteristics products, this study first derives a global susceptibility map from the geospatial data sets and then links up with the dynamic trigger, near-real-time rainfall observations, to assess landslide potential. The goal of this new system is to acquire a global view, rather than a site-specific view, of rainfall-triggered landslide disasters in a real-time fashion. Section 2 details the framework and its two major components, Section 3 describes case studies using prototype of this proposed system, and Section 4 presents concluding remarks and discusses future work and possible improvements.

II. Framework, Data, and Global Landslide Susceptibility Map

A. *Framework for monitoring rainfall-triggered landslides*

In this study, we are primarily concerned with shallow landslides that involve poorly consolidated soils or colluviums on steep hill slopes. Shallow landslides, sometimes referred to as debris flows, mudslides, mudflows, or debris avalanches, are rapidly moving flows of mixes of rocks and mud, which have the potential to kill people and destroy homes, roads, bridges, and other property. This study addresses those landslides caused primarily by prolonged, heavy rainfall on saturated hill slopes. Rainfall-triggered

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landslides may mobilize into fast-moving mudflows, which generally present a greater hazard to human life than slow-moving, deep-seated slides. Although most parts of the world have experienced major socioeconomic losses related to landslide activity (Sidle and Ochiai, 2006), currently no system exists at either a regional or a global scale to monitor rainfall conditions that may trigger landslides.

Useful assessment of landslide hazards requires, at the minimum, an understanding of both 'where' and 'when' that landslides may occur. As Figure 1 shows, landslides result from a combination of factors, which can be broadly classified into two categories: (1) semi-static variables that describe the surface characteristics, such as soil properties, elevation, slope, land cover, geology etc; and (2) dynamic variables that induce mass movement, such as heavy rainfall or earthquakes. For rainfall-triggered landslides, at least two conditions must be met: the areas must be susceptible to failure under certain saturated conditions, and the rainfall intensity and duration must be sufficient to saturate the ground to a sufficient depth. Therefore, to detect the time/space information of landslide occurrence, it is required for the proposed system to link two major components: a landslide susceptibility (LS) map and near real-time precipitation information, as shown in Figure 1. The LS map empirically shows part of the "where" and the rain intensity-duration primarily determines the "when" information. In use, the "where" LS maps are overlaid with real-time satellite-based rainfall "when" layers to detect potential landslides as a function of time and location.

In this framework, the first-order control on the spatial distribution (where) of landslides is the topographic slope of the ground surface, elevation, soil types, soil texture, vegetation, and the land cover classification, while the first-order control on the temporal

distribution (when) of shallow landslides is the space-time variation of rainfall, which changes the pore-pressure response in the soil or colluviums to infiltrating water (Iverson, 2000).

B. The Dynamic Trigger: Detection of Heavy Rainfall Using Satellite Observations

The spatial distribution, duration, and intensity of precipitation play an important role in triggering landslides. A long history of development in the estimation of precipitation from space has culminated in sophisticated satellite instruments and techniques to combine information from multiple satellites to produce long-term products useful for climate monitoring (Adler et al., 2003). A fine time resolution analysis, such as the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA; Huffman et al., 2006), is the key data set for the proposed landslide monitoring system in this study. The TMPA is a state-of-the-art, quasi-global precipitation analyses at fine time and space scales over the latitude band 50°N-S. The combined quasi-global rain map at 3-hr resolution is produced by using TRMM to calibrate, or adjust, the estimates from other satellites, and then combining all the estimates into the TMPA final analysis. The TMPA is a TRMM standard product, and is being computed for the entire TRMM period (January 1998-present). A real-time version of the TMPA merged product was introduced in February 2002 and is available on the U.S. TRMM web site (http://trmm.gsfc.nasa.gov). It is anticipated that this type of product will be continued as part of the Global Precipitation Measurement (GPM) mission (http://gpm.gsfc.nasa.gov). GPM is envisioned as an improved constellation of operational and dedicated research satellites to provide the sampling frequency necessary for global precipitation monitoring suitable for hydrology and water resources management.

Figure 2a shows a recent example of an instantaneous TMPA rain rate map downloaded from its web site. Figure 2b shows climatological percentage of daily rainfall exceeding 2 inches per day and Figure 2c is the conditional daily rainfall (i.e., the average rainfall on days when it rains) averaged from 8 years of TMPA rainfall data (1998-2005). The availability of this type of rainfall information quasi-globally provides an opportunity to derive empirical rainfall intensity-duration thresholds related to landslides and to examine antecedent precipitation accumulation continuously in time and space.

C. Global Landslide Susceptibility Map

1) Geospatial Data Sets

Generally, scientists have thought that the soils must be saturated with water for slope failure to occur. Therefore, slope steepness has the most influence on shallow landslide likelihood, followed by soil type and the soil texture of the mass material that mantles the slope, and the mechanical and hydrological properties of the underlying rock. Additionally, vegetation on the slope is critical: slopes laid bare by fire or artificially cleared are especially vulnerable to erosion and mass wasting; slopes with lush, healthy vegetation are far more resistant. To investigate surface landslide susceptibility, this study used several global-scale geospatial data sets.

- *Digital Elevation Model data and its derivatives*

The basic digital elevation model (DEM) data sets considered in this system include NASA Shuttle Radar Topography Mission (SRTM; http://www2.jpl.nasa.gov/srtm/) and U.S. Geological Survey's GTOPO30 ((http://edcdaac.usgs.gov/gtopo30/gtopo30.html). The 30m spatial resolution provide by SRTM data is a major breakthrough in digital

mapping of the world, particularly for large portions of the developing world. DEM data are used to derive topographic factors (slope, aspect, curvature etc) and hydrological parameters (flow direction and flow path etc.). The GTOPO30 data set is also useful, with a 1-km horizontal resolution.

- *Global Soil Property Information*

Global soil property data sets are from taken Digital Soil of the World published in 2003 by the Food and Agriculture Organization of the United Nations (http://www.fao.org/AG/agl/agll/dsmw.htm) and the International Satellite Land Surface Climatology Project Initiative II (ISLSCP II) Data Collection (http://www.gewex.org/islscp.html). The ISLSCP II data set provides grided data for 18 selected soil parameters derived from data and methods developed by the Global Soil Data Task, coordinated by the Data and Information System (DIS) of the International Geosphere-Biosphere Programme (IGBP), and distributed on CD-ROM by the Oak Ridge National Laboratory Distributed Active Archive Center (http://daac.ornl.gov/). The soil parameters used in this study are soil property information (including clay mineralogy and soil depth) and 12 soil texture classes, following the U.S. Department of Agriculture soil texture classification (including sands, loam, silt, clay, and their fractions).

- *Land cover and land use data (MODIS data set)*

The global land cover data set can be used as a simple surrogate for vegetation and land use types. The data source is the MODIS land cover classification map at its highest (250-meter) resolution. The MODIS Land Cover Product describes the geographic

distribution of the 17 IGBP land cover types based on an annual time series of observations (Fridel et al., 2002).

2) Developing a prototype global-scale landslide susceptibility map

Based upon the surface geospatial data sets described above, landslide susceptibility can be constructed by a quantitative integration of susceptibility factors. Final susceptibility values are combined results of the numerical values assigned to each of the spatial data sets. For example, following Larsen and Torres-Sanchez (1998), land cover can be classified into five classes: (a) forested land; (b) shrub land; (c) grass land; (d) pasture and cropland, (e) developed land and road corridors, which describe a continuum of increasing susceptibility (e.g., from zero to one) to rainfall-triggered landslides. Likewise, other surface controlling factors are assigned numerical values between zero and one based on several empirical qualitative assessments: (1) higher slope is related to higher susceptibility; (2) higher percentage of clay to higher susceptibility; and (3) finer soil texture to higher susceptibility. The quantitative surface factors are overlaid in a GIS system and a weighted linear combination function in the GIS system is performed to derive the final susceptibility values. At the present time, all factors are considered to be equal in importance and given the same weights. The final susceptibility values are normalized from zero to one. The larger the susceptibility value, the greater the potential for landslides at that location.

Summarizing, the first-cut global LS map (Figure 3) is mapped out using USGS GTOPO30 DEM and NASA SRTM elevation data, topographic derivatives (slopes) from DEM, soil type information downscaled from Digital Soil Map of the World (Sand,

Loam, Silt, or Clay etc.), soil texture, and MODIS land cover classification data. The elemental spatial resolution is the highest resolution among the available DEMs. For example, over US SRTM 30-meter resolution is available, but only SRTM 90-meter resolution for some other regions, mostly within 60°N-60°S latitude. Over the remaining areas USGS GTOPO30 is used. The geospatial data sets are bi-linearly interpolated to the highest DEM spatial scale (30 m) in this study.

The global LS map is further classified into six categories: 0-water bodies or permanent ice and snow; 1-very low; 2-low; 3-moderate; 4-high; 5-very high susceptibility. The very high and high susceptibility categories account for 2.84% and 18.65% of land areas, as shown in Table 1. Figure 3 demonstrates the hot spots of the high landslide potential regions: the Pacific Rim, the Alps, the Himalayas and South Asia, Rocky Mountains, Appalachian Mountains, and parts of the Middle East and Africa. India, China, Nepal, Japan, the USA, and Peru are shown to be landslide-prone countries. These results are similar to those reported by Sidle and Ochiai, 2006.

Table 1 Global Distribution of Landslide Susceptibility Categories

Category	0	1	2	3	4	5
Susceptibility	Water, snow/ice	Very low	Low	Moderate	High	Very high
%(globe)	77.95	4.47	6.06	6.78	4.11	0.63
%(land)	--	20.27	27.48	30.76	18.65	2.84

III. An Experimental Monitoring System for Rainfall-triggered landslides

A. Linking rainfall data with landslide susceptibility

There is a direct relationship between rainfall levels and the occurrence of landslides (Finaly et al., 1997), which, in return, depends on the properties of the soil surface (Irigaray et al., 2000). This study links the global LS map with the frequently updated

satellite-based precipitation information to identify when areas with high landslide potential are receiving heavy rainfall. Table 2 lists selected major landslides over the NASA TRMM operational period (1998-present). The rainfall totals are accumulated from the TRMM database and the sliding susceptibility category is taken from the global LS map (Figure 3). Despite the variations, the production of shallow landslides requires intense rainfall, sustained for at least a brief period of time, in areas with susceptibility category of high or above.

Table 2 TRMM precipitation accumulation and LSM info for landslide cases

Time	Country (State/Province)	Causes/types	Susceptibility category	TRMM 3B42V6 Rainfall accumulation	Others
04/13/2006	Buenaventura, Colombia	Rain storm	High	103.04mm/day	>34 death
03/25/2006	Oahu, Hawaii	Tornado event	Very high	450mm/7day	Unknown
2/17/2006	Layte, Philippines	Rain Storm	High	400mm/5day	>1500 death
01/04/2006	Jakarta, Indonesia	Monsoon rains.	high	250mm/3day	>200 buried
10/08/2005	Solola, Guatemala	Hurricane Stan	High	300mm/3day	>1800 death
09/05/2005	Yuexi County, Anhui, China	Rain storm	High	450mm/6day Affected 210,000 people; Flattened 10,000 houses	
08/25/2005	Guwahati, India	Rain	High	310mm/3day	5 killed
04/13/2005	Santa Cruz, CA	Storm	High	147mm/day	2 death
1/10/2005	La Conchita, CA	Heavy rain season	High	390mm/14day	12 death
11/13/2003	Puerto Rico	Hurricane	High	145mm/day	Unknown
06/05/2001	Puerto Rico	Tropical storm	High	77mm/day	Unknown
05/06/2000	Puerto Rico	Tropical storm	High	258mm/2day	Unknown
08/22/1999	Puerto Rico	Hurricane Debby	High	255mm/3day	Unknown
10/30/1998	Nicaragua	hurricane Mitch	Very high	720mm/6day	>2000 death
09/22/1998	Puerto Rico	Hurricane	High	450mm/3day	Unknown

B. A Global-scale Experimental Monitoring System for Rainfall-triggered Landslides

Landslide risk assessment based on relationships with rainfall intensity-duration has been applied at both global (Caine, 1980) and regional scales (Canuti et al., 1985; Larsen and Simon, 1993; Godt, 2004). As shown in Figure 4a, empirical rainfall intensity-duration thresholds have been developed for Seattle (Godt, 2004), Puerto Rico (Larsen and Simon, 1993), and worldwide (Caine, 1980). The squares in Figure 4b indicate the rainfall intensity-duration plots of landslide cases (incomplete record) that occurred within NASA TRMM observation period (1998-current). The lower bound of rainfall intensity-duration threshold can be approximately identified if a scaling factor, 0.75, is applied to the worldwide threshold from Caine 1980. We believe that the reason for a scaling factor is the coarse resolution of global rainfall data being used, 25 km. Table 3 lists the thresholds of rainfall accumulation triggering landslides according to the worldwide threshold (Caine, 1980) and the 0.75-scaled threshold (e.g., Intensity = 11.115 Duration$^{-0.39}$). When coupled with real-time rainfall data, such rainfall intensity-duration threshold analysis can provide the basis for early warning systems for shallow landslides (Liritano et al., 1998). An experimental system for real-time monitoring landslide potential based on the adjusted rainfall intensity-duration threshold is developed from these concepts and a trial version of this operational system is displayed on the NASA TRMM website (http://trmm.gsfc.nasa.gov/publications_dir/potential_landslide.html). Accumulations of the real-time TMPA precipitation for various time intervals are computed and compared with the rainfall intensity-duration thresholds (Figure 4b and Table 3) every 3 hours. Then the area receiving rainfall exceeding the intensity-duration thresholds is marked as a potential landslide zone if the underlying susceptibility category is above "moderate" at

that location. The locations and timing of potential landslides are checked against first-hand accounts from the field or validated by later news reports.

Table 3 Antecedent Rainfall Accumulation: Landslide triggering thresholds (mm)

Duration Accumulation	12h	24h	48h	72h	96h	120h	144h	168h	192h	216h	240h
Caine 1980	67.5	102.9	157.2	201.3	239.9	274.9	307.2	337.5	366.1	393.4	419.5
0.75 scaling	50.625	77.175	117.9	150.975	179.925	206.175	230	252.9	274.58	294	314.25
Used	50	75	120	150	180	200	230	250	275	300	315

Figure 5 shows one landslide case monitored by this experimental system on 13 Apr 2006, in Colombia. The rainfall accumulation for the previous 24 hours was 103mm over central Colombia and the landslide susceptibility map indicates susceptibility category high or very high at this area, so the landslide potential is color-coded as high on the web-based graphical interface. Later news reports indicated that at least 34 people were missing and four villages were destroyed in a landslide near the Pacific port city of Buenaventura in southwestern Colombia.

IV. Summary and Discussion

The primary criteria which influence shallow landslide potential are precipitation intensity, slope, soil type, vegetation, and land cover type. Drawing heritage from recent advances in remote sensing technology and the abundance of global geospatial products, this paper proposed a conceptual framework for a real-time monitoring system (Figure 1) for rainfall-triggered landslides across the globe. This system combines the NASA TMPA precipitation information (Figure 2; http://trmm.gsfc.nasa.gov) and land surface characteristics to assess landslide risks. First, a prototype of a global Landslide

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Susceptibility (LS) map (Figure 3 and Table 1) is produced using NASA Shuttle Radar Topography Mission and USGS GTOPO30 DEM, DEM derivatives such as slope, soil type information downscaled from the Digital Soil Map of the World (sand, loam, silt, or clay etc.), soil texture, and MODIS land cover classification. Second, this map is overlaid with satellite-based observations of rainfall intensity-duration (Figure 4b and Table 3), to identify the location and time of potential landslides when areas with significant landslide susceptibility are receiving heavy rainfall. The effectiveness of this system is compared to several recent landslide events within the TRMM operational period (Figure 5 and Table 2). A major outcome of this work is the availability of a global view of rainfall-triggered landslide disasters, only possible because of the utilization of global satellite products. Thus, this type of real-time monitoring system for disasters could provide policy planners with overview information to assess the spatial distribution of potential landslides. However, ultimate decisions regarding site-specific landslide susceptibility will continue to be made only after a site inspection.

The need of retrospective validation and improvement of this experimental system has to be stressed by continuous collection of global landslide inventory data. A global-wide evaluation of this system is underway through comparison with various inventory data bases, web sites and news reports of landslide disasters. The prototype of this system can be continuously enhanced by improved satellite remote sensing products. Several future activities are under consideration:

1) More information, such as geologic factors, could be incorporated into this global LS when they become available globally;

2) Finer resolution DEM data such as 6.1 x 6.1m LIDAR-based data can also improve the LS mapping, if only over small areas of availability;

3) Soil moisture conditions observed from NASA Aqua satellite with the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) instrument and an antecedent precipitation index accumulated from TRMM will be examined for usefulness in this experimental landslide detection/warning system; and

4) The empirical rainfall intensity-duration threshold triggering landslides may be regionalized using mean climatic variables (e.g. mean annual rainfall).

Given the fact that landslides usually occur after a period of heavy rainfall, a real-time landslide monitoring system can be readily transformed into an early warning system by making use of the time lag between rainfall peak and slope failure. Therefore, success of this prototype system bears promise as an early warning system for global landslide disaster preparedness and risk management. Additionally, the warning lead-time of global landslide forecasts can be also expected by using rainfall forecasts (1-10 days) from operational numerical weather forecast models. This real-time monitoring system, if pursued through wide interdisciplinary effort as recommended herein, bears the promise to grow current local landslide hazard analyses into a global decision-making support system for landslide disaster preparedness and risk mitigation activities across the world.

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Figure 1. The conceptual framework of real-time monitoring/warning system for rainfall-triggered landslides at global scale. Note that dash-line boxes are important components but not covered in this study.

Figure 2. NASA TRMM-based multi-satellite precipitation products: (a) real-time precipitation observations, (b), climatological percentage of daily rainfall exceeding 2 inches; and (c) conditional daily rainfall averaged from 8-year TRMM rainfall data.

Figure 3. (a) Global landslide susceptibility map derived from surface multi-geospatial data; (b) histogram of global landslide susceptibility.

Figure 4. (a) Regional or worldwide empirical rainfall intensity-duration thresholds triggering landslides; (b) the lower bound of rainfall intensity-duration threshold (dash line: Intensity = 11.115 Duration-0.39) for several landslides (squares) that occurred in the TRMM operation period (1998-2005) is approximately 0.75 of the global algorithm from Caine 1980 (dark line).

Figure 5. (a) heavy rainfall observed by NASA TMPA and (b) collocated with high landslide susceptibility from Figure 3 is correlated with a landslide event in Colombia, marked by "x".

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Research Interest:

Surface Hydrology; Remote Sensing and Spatial Analysis; Satellite-based Precipitation Retrieval Algorithm Development and Validation; Flood Forecasting and Landslide Analysis; Digital Image Processing and Analysis; Sustainable Development and Water Resources Management

Dr. Robert F. Adler

Education:

B.S.--The Pennsylvania State University, 1965

M.S.--The Pennsylvania State University, 1967

Ph.D.--Colorado State University, 1974

Honors:

Fellow of the American Meteorological Society

NASA Outstanding Leadership Medal - 2002

NASA Exceptional Scientific Achievement Medal - 1989

Goddard Laboratory for Atmospheres Scientific Leadership Award - 2002

Goddard Space Flight Center-Exceptional Performance Award - 1980

Research Focus

Dr. Adler's research focuses on the analysis of precipitation observations from space on global and regional scales using TRMM data along with data from other satellites. He studies precipitation variations in relation to phenomena such as El Nino/Southern Oscillation (ENSO), volcanoes and tropical cyclones, as well as longer, inter-decadal changes or variations. He also leads the group that produces the global monthly and daily precipitation analyses for the WCRP Global Precipitation Climatology Project (GPCP). Dr. Adler has published 80 papers in scientific journals on these topics. He is currently the Tropical Rainfall Measuring Mission (TRMM) Project Scientist.

Dr. George Huffman

Education:

Ph.D. (Meteorology) Massachusetts Institute of Technology, 1982

B.S. (Physics) The Ohio State University, 1976

Present Position:

Chief Support Scientist, Science Systems and Applications, Inc. (Lanham, MD)

Professional Interests:

Observational and theoretical mesoscale and synoptic meteorology, including precipitation retrievals from satellite and other sensors, retrieval errors, cumulus convection, and forecasting
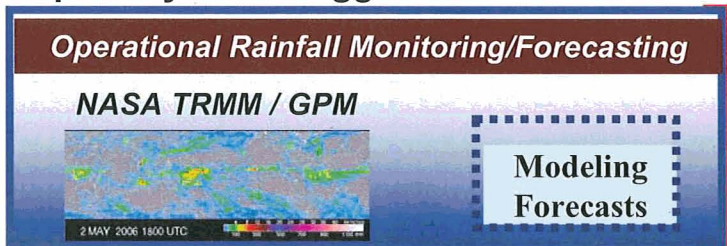
Recent Professional Activities:

Design/implement/extend Satellite-Gauge-Model global rainfall estimation, combining SSM/I, geosynch. IR, gauge, and TOVS data; estimate RMS error in such data sets; produce GPCP and Pathfinder data sets using SGM for 1979 to (delayed) present; design/implement One-Degree Daily combination for GPCP; develop TRMM algorithms 3B-42 and 3B-43, develop/implement TRMM Multi-satellite Precipitation Analysis for TRMM in both real time and post-real time. Dr. Huffman has 46 refereed publications, as well as numerous conference and seminar presentations.
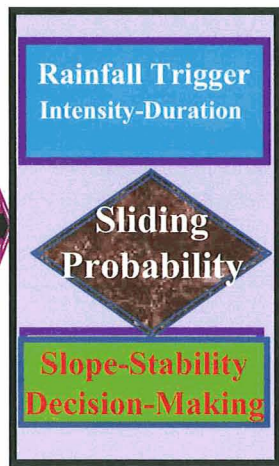
Recent Awards:

ASA/GSFC Mesoscale Atmos. Processes Branch Exceptional Technical Support Award, 2004.

NASA/GSFC Lab. for Atmos. Contractor Award for Outstanding Performance in Science, 2002
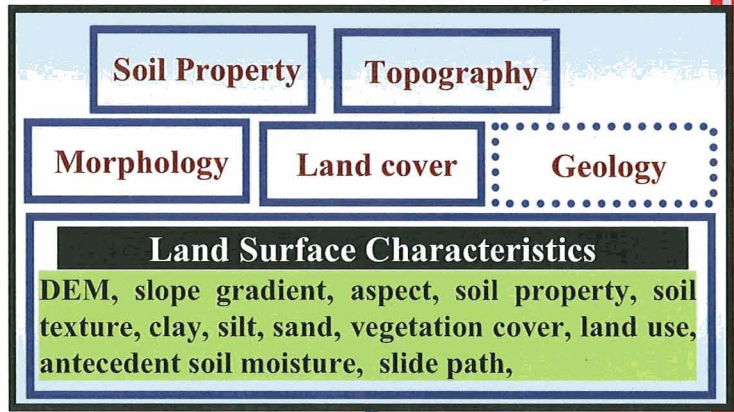
Comp. 1: Dynamic trigger: Rainfall

Detection/Warning

Operational Rainfall Monitoring/Forecasting

NASA TRMM / GPM

2 MAY 2006 1800 UTC

Modeling Forecasts

Rainfall Trigger Intensity-Duration

When

Where

Sliding Probability

Risk

Slope-Stability Decision-Making

How big

Damage

Comp. 2: Landslide Susceptibility Map

Soil Property   **Topography**

Morphology   **Land cover**   **Geology**

Land Surface Characteristics

DEM, slope gradient, aspect, soil property, soil texture, clay, silt, sand, vegetation cover, land use, antecedent soil moisture, slide path,

Enhance, | Correct, and Validate

Local Inventory Database

Figure 1. The conceptual framework of real-time monitoring/warning system for rainfall-triggered landslides at global scale. Note that dash-line boxes are important components but not covered in this study.

(a)

12 JUN 2006 0600 UTC

.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 Inches/hr

5   10   15   20   25   mm/hr

Percentage Daily Rainfall Exceeding 2 Inch/day (out of 8-Year TRMM Data)

(b)

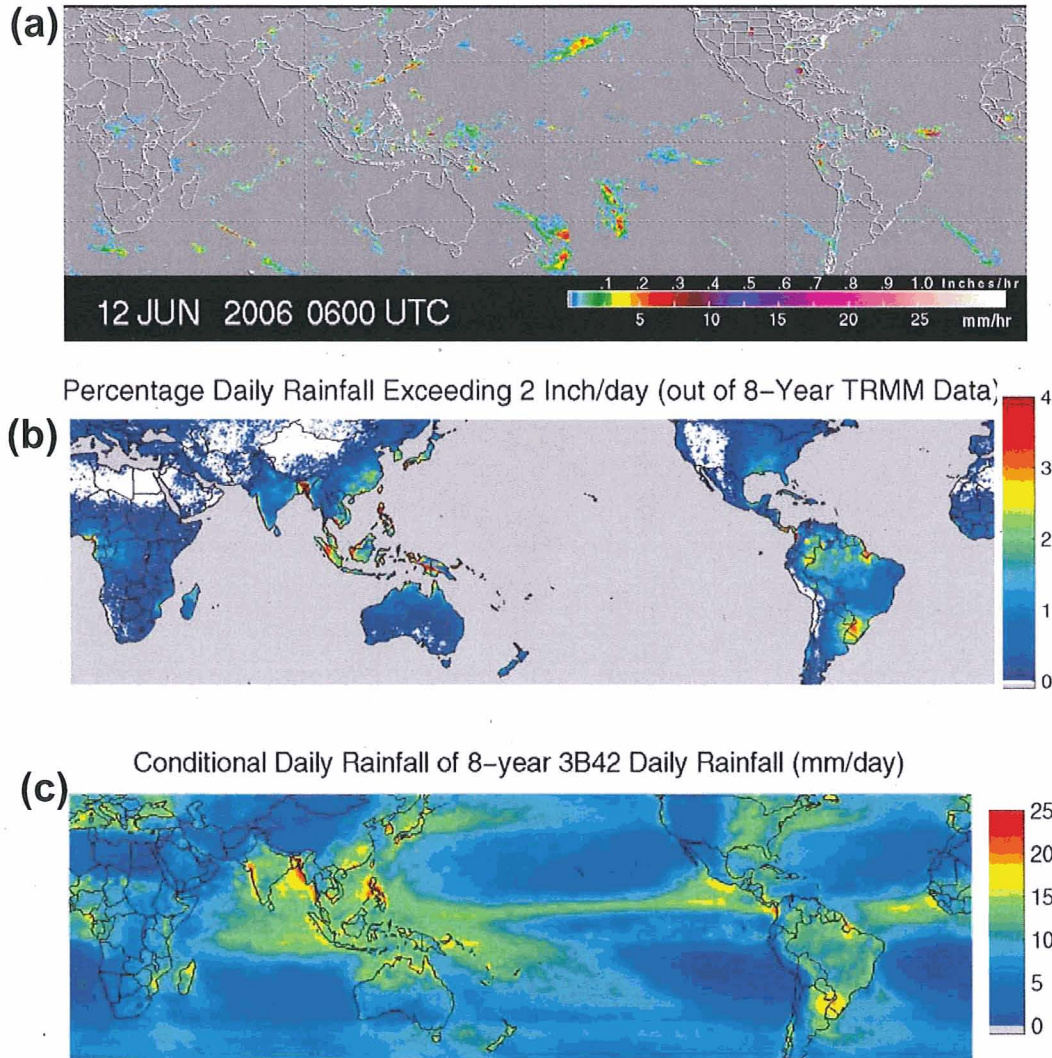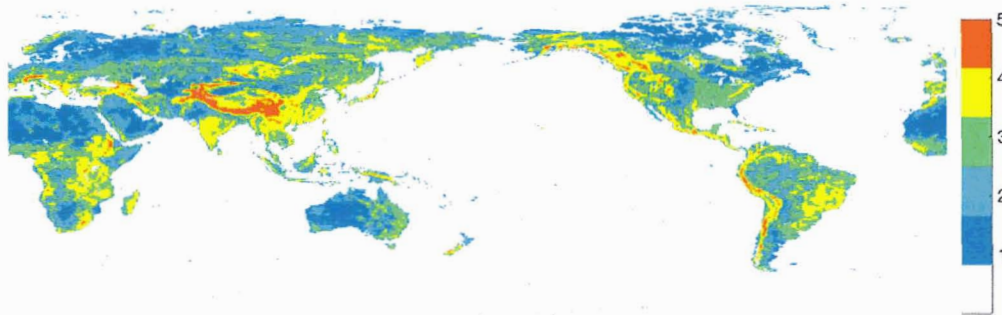Conditional Daily Rainfall of 8-year 3B42 Daily Rainfall (mm/day)

(c)

Figure 2. NASA TRMM-based multi-satellite precipitation products: (a) real-time precipitation observations, (b), climatological percentage of daily rainfall exceeding 2 inches; and (c) conditional daily rainfall averaged from 8-year TRMM rainfall data.

Landslide Susceptibility Category
0: Water Bodies, Permanent Snow/Ice;
1: Very Low Susceptibility;
2: Low Susceptibility;
3: Moderate Susceptibility;
4: High Susceptibility;
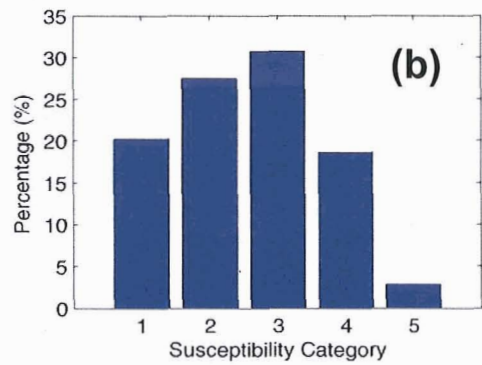**5: Very High Susceptibility.**

Figure 3. (a) Global landslide susceptibility map derived from surface multi-geospatial data; (b) histogram of global landslide susceptibility.
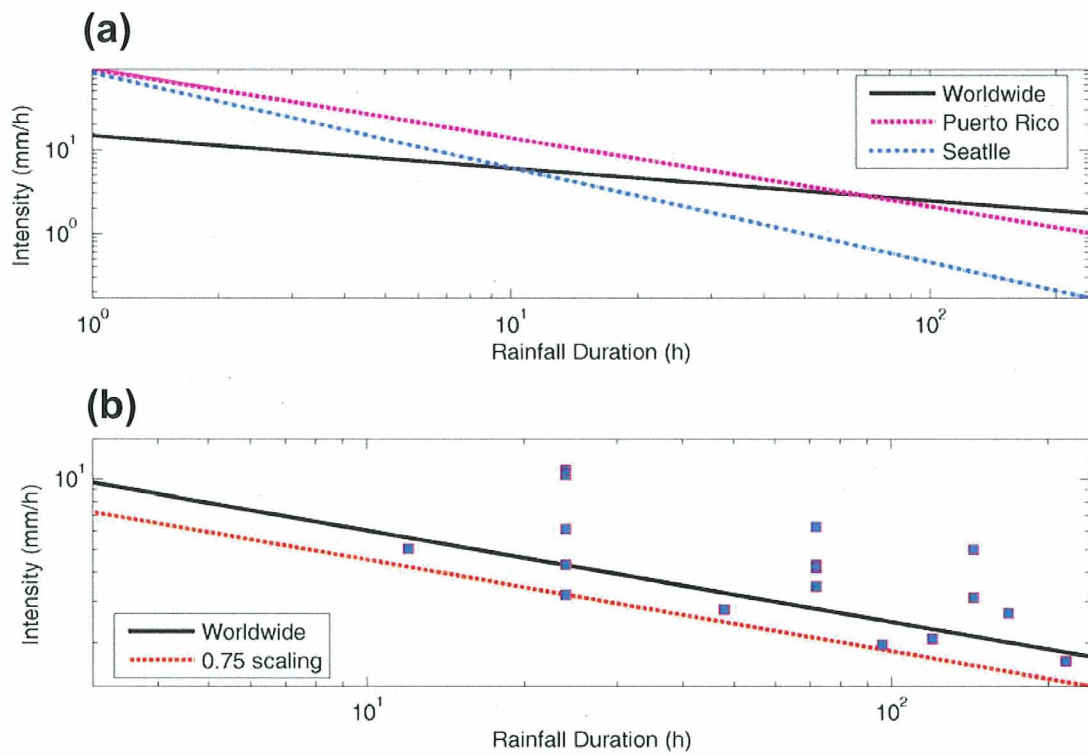
Figure 4. (a) Regional or worldwide empirical rainfall intensity-duration thresholds triggering landslides; (b) the lower bound of rainfall intensity-duration threshold (dash line: Intensity = 11.115 Duration$^{-0.39}$) for several landslides (squares) that occurred in the TRMM operation period (1998-2005) is approximately 0.75 of the global algorithm from Caine 1980 (dark line).
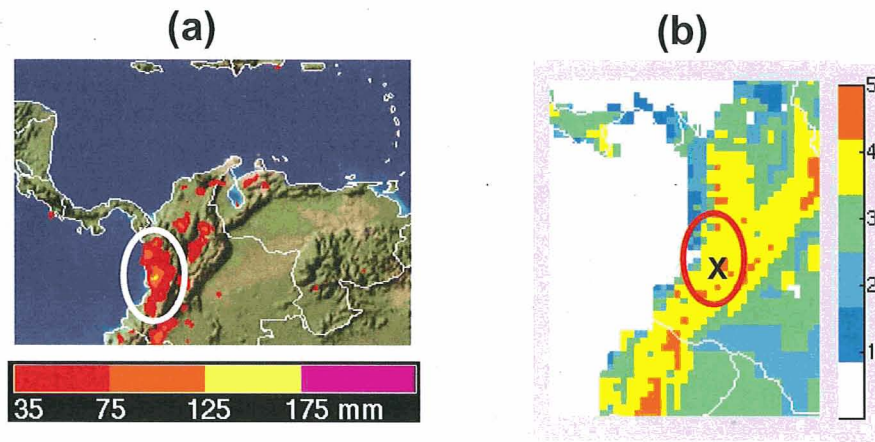
Figure 5. (a) heavy rainfall observed by NASA TMPA and (b) collocated with high landslide susceptibility from Figure 3 is correlated with a landslide event in Colombia, marked by "x".