A Regional Analysis Framework for Evaluating Satellite Rainfall Extremes in Complex Terrain for Landslide Hazards Applications

Dalia Kirschbaum(1), Daniel Wright (2), Thomas Stanley(3,1), Soni Yatheendradas (4,1)

1. NASA Goddard Space Flight Center, Hydrological Sciences Lab 2. University of Wisconsin, Madison

3. GESTAR, Universities Space Research Association 4. ESSIC, University of Maryland

Overview

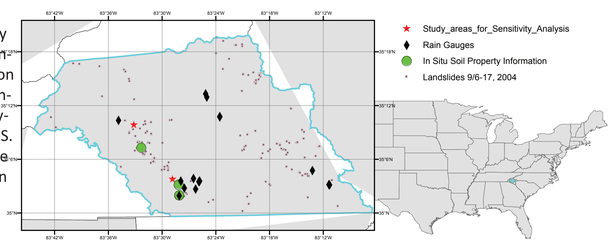
Extreme rainfall in steep, complex terrain is the primary trigger of landslides and flash floods in many parts of the world. Advances in regional hazard assessment and prediction have been limited by the challenge of quantifying the relationships between the intensity, duration, and frequency (IDF) of extreme rainfall in such terrain. The main goals of the proposed work are to better understand the characteristics of extreme rainfall in complex terrain and evaluate the limits of extreme rainfall estimates from satellites within the context of natural hazards.

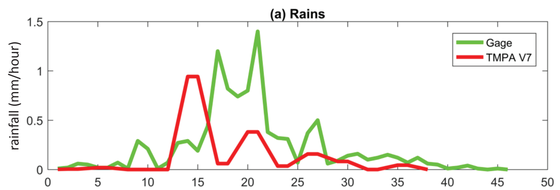
Objective 1—Develop regional-scale extreme rainfall metrics based on Extreme Value Analysis (EVA). This work uses EVA to characterize the biases and regional heterogeneities of extreme rainfall estimates from TMPA and IMERG data relative to long-term rain gages across different spatiotemporal scales.

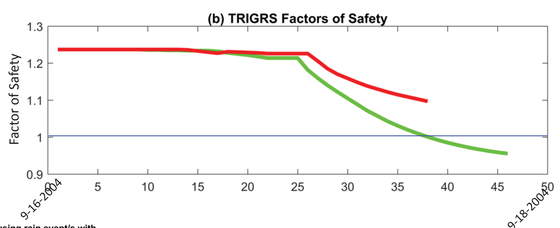
Objective 2 —Evaluate landslide events within the North Carolina Study area for three instances where we have TMPA, IMERG and dynamically-downscaled rainfall estimates from NASA Unified Weather Research and Forecasting (NU-WRF), considering both a physically-based landslide model (TRIGRS developed by the USGS) and empirical model.

Objective 3— Analyze long-term regional-scale recurrence intervals and intensity thresholds (obtained from the EVA analysis in Objective 1 and from regional empirical rainfall thresholds obtained from Objective 2) to determine the potential biases/impact of TRMM and GPM performance for landslide triggering. We will compare the extreme rainfall distributions across satellite data and model outputs to establish metrics that quantify landslide-triggering rainfall, leveraging archives of landslide events.

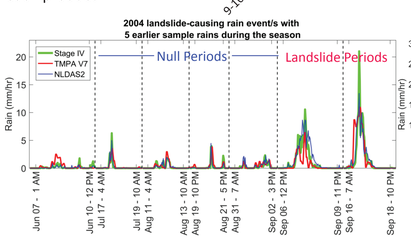
The physically-based model that has initially been tested is the Transient Rainfall Infiltration and Grid-based Regional Slope-stability analysis (TRIGRS) from USGS. The system models the timing and distribution of shallow, rainfall-induced landslides. TRIGRS requires over 12 input parameters and the forcing variable can be modified. It computes transient pore pressure and Factor of Safety (Resisting Forces / Driving Forces). Failure is assumed when Factor of Safety < 1

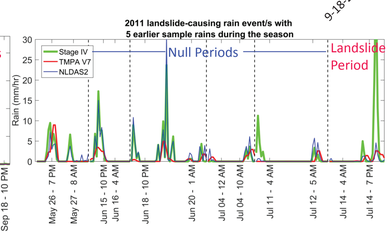




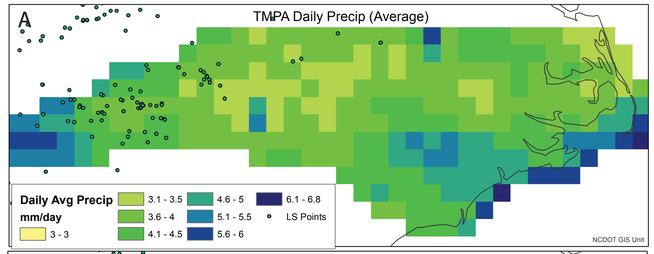


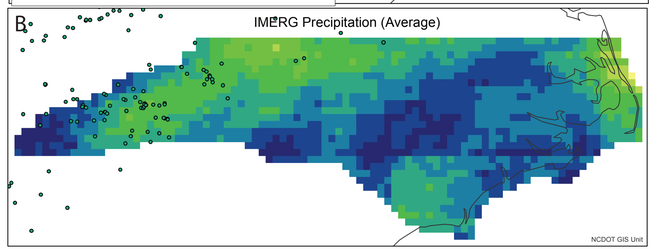
Example showing Gauge and TMPA V7 rainfall (top) with corresponding FS (bottom) for a study site in Western North Carolina for a 2004 rain event. Factor of Safety for this study site shows the failure and corresponding landslide event for each product.



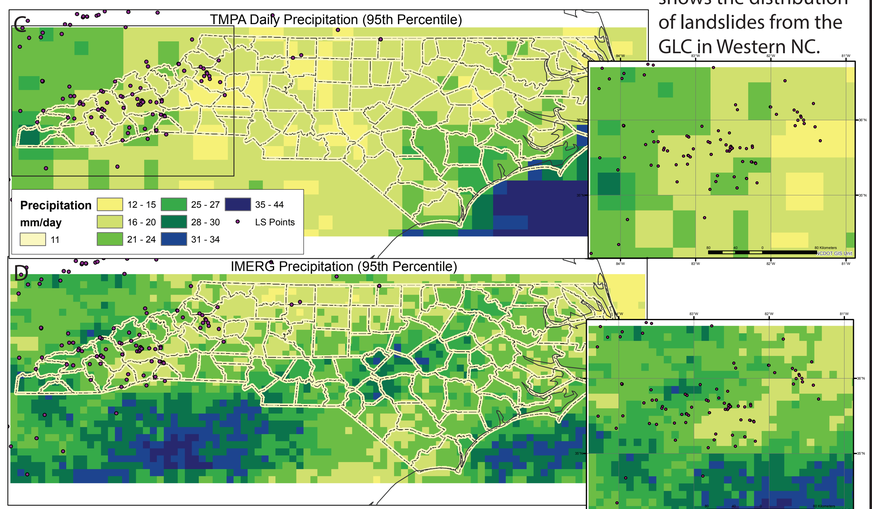


TMPA vs. IMERG over North Carolina

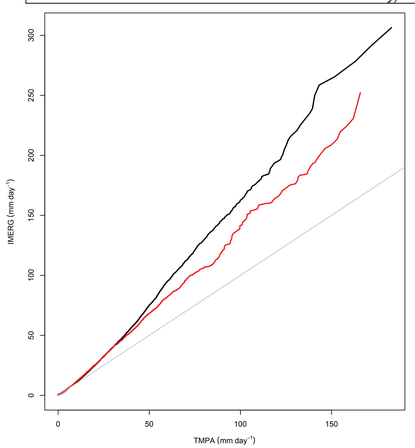




TMPA V7 (A) and IMERG (B) mean daily average rainfall (mm/day) for May 2015-2016. Landslide are shown from 2007 - 2016 from NASA's Global Landslide Catalog, which is comprised of media reports and other disaster databases.



TMPA V7 (C) and IMERG (D) rainfall for the 95th percentile computed for May 2015-2016. Inset box shows the distribution of landslides from the GLC in Western NC.



Characterizing the distributions and differences of extreme precipitation from TRMM and GPM is fundamental to better understanding how these data may impact hazard models such as landslide and floods. The question is how to take advantage of the longevity of TRMM and the high spatial and temporal resolution of IMERG. The left plot shows the quantiles comparing the same May 2015 - May 2016 time period for TMPA and IMERG for North Carolina (black) and the inset area where the most landslides are occurring (red). Quantile mapping offers a simple, established means to approximate such long-term statistics, but only within appropriately defined domains. The Q-Q plot for this region shows clear biases towards higher IMERG values, which increase with higher mm/day values.

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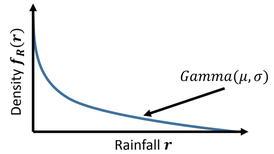
Characterization of Extreme Precipitation and Distributions

1. The Gamma Distribution:

2-step way of characterizing rainfall:

1: $p(r > 0)$: probability of nonzero rainfall

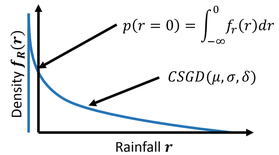
2: if $r > 0$; $f_R(r)$: Gamma distribution with parameters μ, σ



2. The Censored Shifted Gamma Distribution (CSGD):

1-step alternative:

1: Left-censor "negative" precipitation to 0 using "shift" parameter δ: CSGD with parameters μ, σ, δ



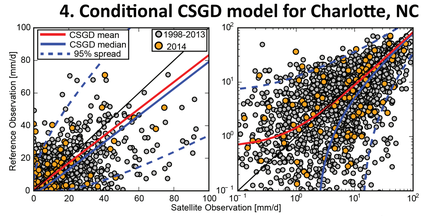
3. Uncertainty and Conditional CSGDs:

Uncertainty grows with observation magnitude. We have developed a regression framework whereby CSGD parameters can be conditioned on the observation $R_s(t)$:

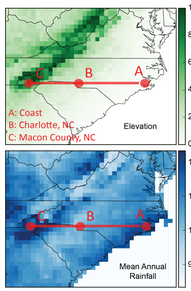
$$\mu(t) = \mu\left(\alpha_1 + \alpha_2 \frac{R_s(t)}{\overline{R_s}}\right)$$

$$\sigma(t) = \alpha_3 \sigma \sqrt{\frac{\mu(t)}{\mu}}$$

4. Conditional CSGD model for Charlotte, NC

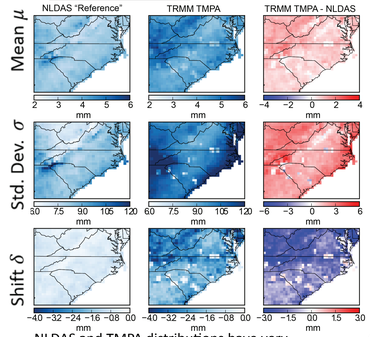


Study Area



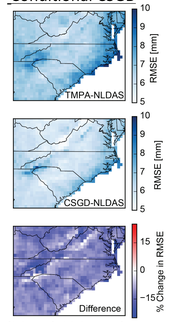
High rainfall near the coast and over the eastern edge of Blue Ridge mountains, lower in the Piedmont

CSGD Parameters



NLDAS and TMPA distributions have very different "shapes," particularly due to the light rain detection in TMPA (which affects the shift parameter δ, i.e. probability of precipitation)

Error correction with Conditional CSGD

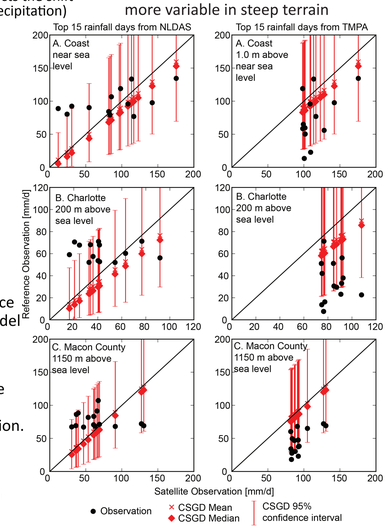


Conditional CSGD reduces error by ~10%, but this improvement is more variable in steep terrain

Extreme Rainfall Error Modeling

The heaviest rainfall days from NLDAS exhibit a wide range of corresponding TMPA estimates. In all 3 grid cells, but particularly B and C, there is a tendency for TMPA to produce erroneously heavy rainfall days, relative to NLDAS. Such days are difficult for the CSGD error model to rectify.

Most of the 15 heaviest rainfall days reported by NLDAS from 1998-2013 fall within the confidence interval of the conditional CSGD model that has been fit to TMPA data. The CSGD model appears to perform best in the coastal and mountainous areas (A and C), though examination of additional grid cells is needed.



Conclusions

The CSGD is a convenient way for modeling precipitation occurrence and intensity. The conditional CSGD framework can be used to model the error in satellite rainfall estimates, though erroneously high estimates are difficult to rectify.

Future work includes comparing with other more complex satellite error models (such as PUSH) and evaluating the impact of other atmospheric covariates such as precipitable water in error estimation.

References:

Stanley, T., D. B. Kirschbaum, G. J. Huffman, and R. F. Adler, 2016: Approximating long-term statistics early in the Global Precipitation Measurement era. Earth Interact., *submitted*.

Wright, D., D. Kirschbaum, 2016: Satellite Precipitation Characterization and Error Modeling Using Censored Shifted Gamma Distributions. Journal of Hydrometeorology, *in preparation*.