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


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## Overview

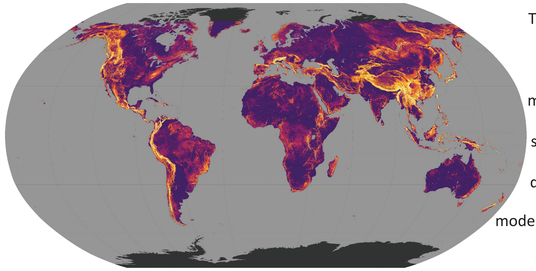
Extreme rainfall in steep, complex terrain is the primary trigger of landslides and flash floods in many parts of the world. Advances in regional hazard assessment and prediction have been limited by the challenge of quantifying and comparing biases in precipitation retrivals over complex terrain as they relate to hydrometeorologic hazards. The main goals of this work are to approach the question of how satellite data can be used to estimate landslide hazards and how biases or differences in the precipitation regime may impact how landslide hazards are approximated within complex terrain. This work approaches these research questions from three different perspectives:

**Focus 1** — Estimate potential landslide activity at the global scale using a heuristic model (LHASA) that integrates GPM IMERG with global susceptibility information

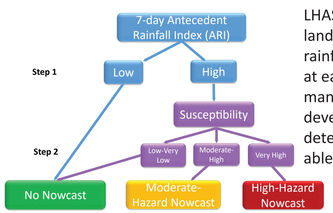
**Focus 2** — Apply LHASA to a case study in North Carolina, leveraging the Censored Shifted Gamma Distribution (CSGD) developed in a previous publication to quantify a probabilistic estimate of landslide hazard considering precipitation uncertainties.

**Focus 3** — Compare specific precipitation events over North Carolina using IMERG (early, late, final), NU-WRF and Stage IV QPE to evaluate how each product performs within complex terrain considering both micro and macrophysical precipitation processes.

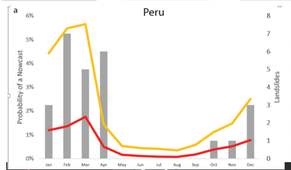
### Landslide Hazard Assessment for Situational Awareness (LHASA)



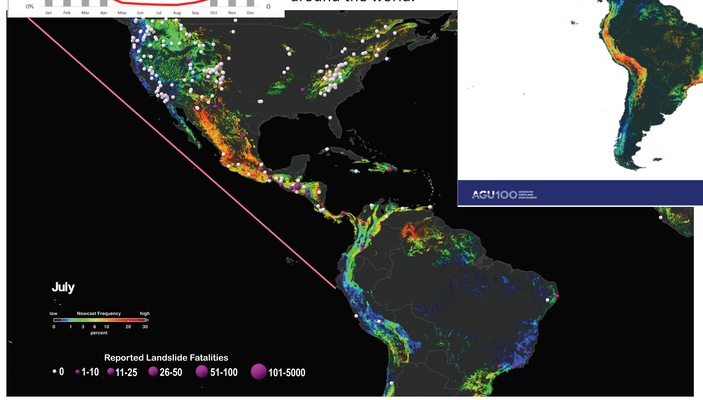
The LHASA model was developed to indicate potential landslide activity in near real-time. LHASA combines satellite-based precipitation estimates with a landslide susceptibility map derived from information on slope, geology, road networks, fault zones, and forest loss. GPM IMERG data are used to identify potentially rainfall triggering conditions . The model is run ever 3 hours at 1 km resolution and results are published at https://pmm.nasa.gov/precip-apps

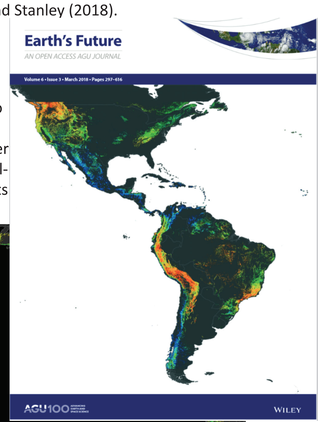



LHASA uses a decision tree framework (left) to identify potential landslide activity as a moderate or high "nowcast". An antecedent rainfall index (ARI) considers the accumulated past 7 days of rainfall at each IMERG pixel and applies a dry-down curve. The performance of LHASA is evaluated using a Global Landslide Catalog (GLC) developed by the PI and results range from 8-60% probability of detection depending on a number of factors. More details are available in Kirschbaum and Stanley (2018).



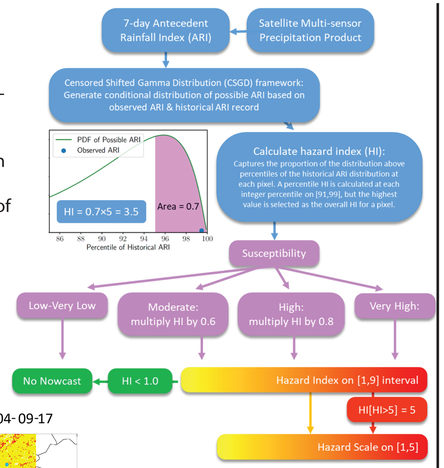

LHASA was run retrospecively with TMPA to provide a landslide climatology used to better understand the variability of landslide hotspots around the world.

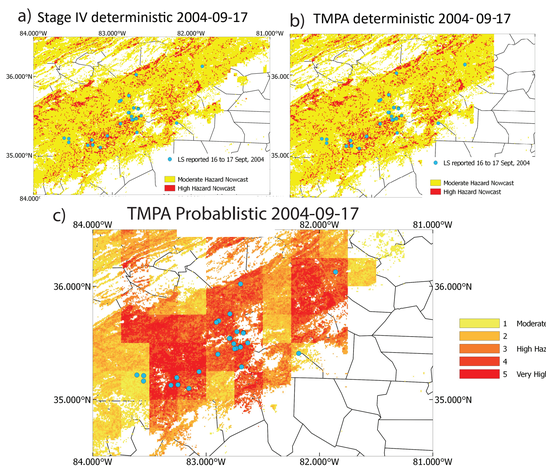



## Probablistic Hazard Modeling

In order to move from a heuristic threshold-based hazard approach to one that better accounted for uncertainty in rainfall probabilistically, a new schema has been developed that utilizes the CSGD framework to generate a conditional distribution of possible ARI values based on observed ARIs from TMPA and Stage IV gauge analysis. The flowchart at the right highlights the new approach, which we are testing for several cases over North Carolina. The resulting Hazard Index (HI) provides a probabilistic scale of potential landslide activity rather than a binomial one.



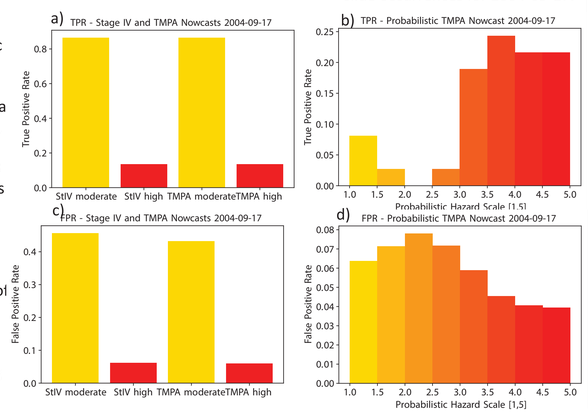




The figure on the left shows the LHASA model results for Hurricanes Ivan and Frances that occurred in September, 2004. The Stage IV (a) and TMPA (b) results highlight the distribution of Nowcasts using the current LHASA method. The table below shows the results in terms of the true positive rate (TPR) and False Positive Rate (FPR) for these two precipitation sources. There is not a large difference (if any) between the results because the precipitation for the event was so high that it exceeded the 95th percentile threshold for both datasets. In the new hazard model (c) nowcasts capture all of the reported landslides on 2004-09-17.

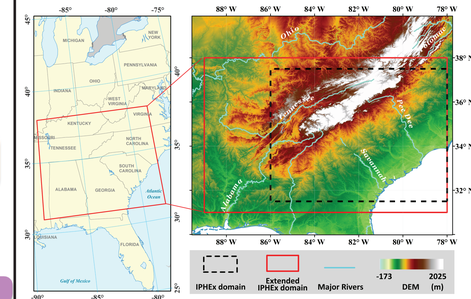
The probabilistic nowcast is able to categorize the larger area around landslide occurrences as higher hazard. While one looking at the deterministic nowcasts might think that the whole area covered by yellow/red is equally hazardous, the probabilistic nowcast clearly shows that there are some areas within the entire nowcast that are more hazardous than others. This area matches up nicely with the reported landslide occurrences for 2004-09-17.

| Precip Input | Nowcast category | TPR | FPR |
|---|---|---|---|
| Stage IV | Moderate Hazard | 0.865 | 0.457 |
| | High Hazard | 0.135 | 0.061 |
| TMPA | Moderate Hazard | 0.865 | 0.432 |
| | High Hazard | 0.135 | 0.060 |

Though it is difficult to compare the TPR for deterministic and probabilistic methods directly, the initial results show that the higher hazard ratings using the probabilistic method have a higher TPR relative to the deterministic methods. This is in part because higher hazard ratings cover more area in the probabilistic nowcast on 2004-09-17, but also because the probabilistic methodology allows pixels with susceptibilities of 3 or 4 to be rated as higher hazard if rainfall is sufficiently extreme. In contrast, landslides in pixels with a susceptibility of 3 or 4 can only be captured by moderate hazard nowcasts in the deterministic model. The figures on the right show the TPR and FPR of the Stage IV and TMPA nowcasts using the LHASA method (a, c) and the probablistic method (b,d). The higher nowcast ratings (from 3.0 to 5.0) do a good job of capturing landslide occurrence without overestimating the area of high hazard on 2004-09-17.




## Comparison of NU-WRF and latest IMERG rainfall estimates over the extended IPHEx domain: Initial results




Building off of the CSGD work, this analysis considers NU-WRF, IMERG and Stage IV data over the IPHEx domain to compare and contrast the performance of the retrievals in complex environments based on different precipitation regimes. The numerical weather model provides an alternative, physically-based approach to dynamically simulate precipitation, and it holds advantages in situations of complex micro/macrophysical precipitation processes. We posit that the two approaches are complementary, and investigate it by comparing GPM-era IMERG and NU-WRF model. Future work will focus on developing evaluation metrics to incorporate both rainstorm pattern and intensity. This will be used to estimate where, when and why each technique reaches its limit or performs poorly in specific terrain.

### Four major warm-season rainfall regimes (from IPHEx Sci. Plan, 2014)

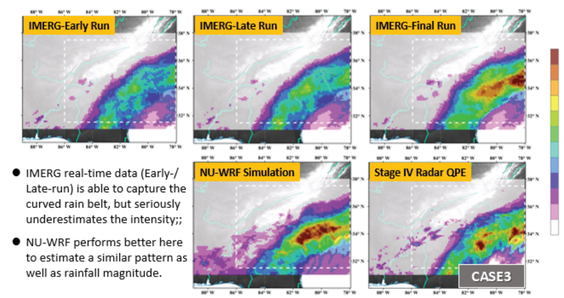
R1: Light/moderate rain (<5 mm/hour): orographic enhancement of incoming moist air

R2: Heavy short-duration rainfall with isolated thunderstorms

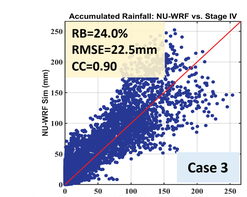
R3: Heavy rainfall by westerly and southerly convective systems modulated by orography

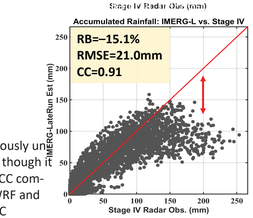
**R4: Very heavy rainfall induced by tropical and extratropical systems**

| Events No. | Time Start | Year/RR* |
|---|---|---|
| Case1 | May 21-25 | 2017/R2 |
| Case2 | Apr 23-25 | 2017/R2 |
| Case3 | Sep 02-04 | 2016/R4 |
| Case4 | Oct 07-09 | 2016/R4 |

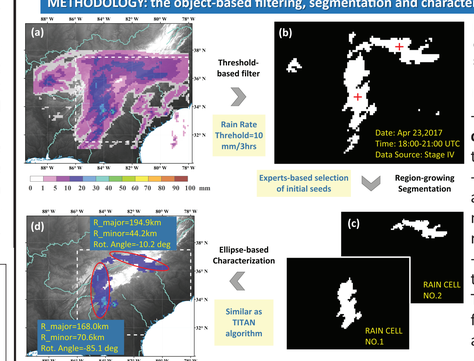



- IMERG real-time data (Early-/Late-run) is able to capture the curved rain belt, but seriously underestimates the intensity;;
- NU-WRF performs better here to estimate a similar pattern as well as rainfall magnitude.



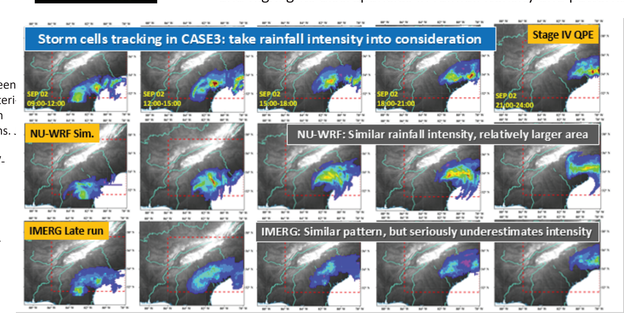

### METHODOLOGY: the object-based filtering, segmentation and characterization algorithm




Right: IMERG tends to seriously underestimate heavy rainfall, though it shows a similar RMSE and CC compared to NU-WRFfor NU-WRF and IMERG for RB, RMSE and CC

- We develop an **object-based filtering, segmentation and characterization algorithm** for storm cells identification, tracking and evaluation;
- This algorithm approximates rainstorm cells by ellipses, and characterize their shape by calculating center location, major and minor radii, rotation angle, area, max/averaged rain intensity of the identified rain cells;
- Compare the characteristics identified by different precipitation sources.

The below figure shows the example of storm cell tracking for Stage IV, NU-WRF and IMERG Late using the algorithm and highlights discrepancies in rainfall itensity and patterns.





**References:**

Wright, D. B., D. B. Kirschbaum, and S. Yatheendradas, 2017: Satellite Precipitation Characterization, Error Modeling, and Error Correction Using Censored Shifted Gamma Distributions. . Hydrometeorol., doi:10.1175/-JHM-D-17-0060.1. https://doi.org/10.1175/-JHM-D-17-0060.1.

Kirschbaum, D., and T. Stanley, 2018: Satellite-Based Assessment of Rainfall-Triggered Landslide Hazard for Situational Awareness. Earth's Futur., 1–29, doi:10.1002/2017EF000715. https://-doi.org/10.1002/2017EF000715.