Part 2 Questions & Answers Session A

Please type your questions in the Question Box. We will try our best to get to all your questions. If we don't, feel free to email Robert Emberson (robert.a.emberson@nasa.gov) or Pukar Amatya (pukar.m.amatya@nasa.gov).

Question 1: Is rainfall threshold modelling for landslide early warning effective for regions facing rainfall induced landslides?
Answer 1: Depending on the availability of the data that can constrain the thresholds, this can be very helpful. Typically, to calculate thresholds, high-fidelity (spatial and temporal) rainfall records are required, alongside specific info regarding the timing of landslides. The accuracy of the available data on landslide timing is tied to the relevant thresholds; for example, if the occurrence of landslides is only known to be on a given day, rather than at a specific hour, then the associated rainfall can only be considered for that day, and higher fidelity rainfall data may not be beneficial.

Question 2: I have tried to run the NASA model by downloading the static variable on Github. The variable git is not available, I was wondering if you know if this is an error or how I can find this variable?
Answer 2: It is working on our end. Static variables can also be downloaded from: https://gpm.nasa.gov/sites/default/files/data/landslides/static.zip.

Question 3: What are the key challenges in integrating remote sensing data with geotechnical models to assess the long-term changes in landslide susceptibility?
Answer 3: The relative scale of geotechnical data tends to be at much finer resolution than remote sensing data, and upscaling geospatial data is often inappropriate. Future estimates of rainfall patterns have significant uncertainty, meaning that specific predictions regarding landslide locations should be viewed with skepticism. For an example of work undertaken by NASA scientists exploring future changes in landslide susceptibility, this open source paper may be of interest: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023EF004325.

Question 4: Is there any other way to clean the cloud errors? Other than radiometric correction in ArcGIS or in ERDAS.

Answer 4: Some satellite imagery comes with a cloud mask that can be used for masking clouds. There are various cloud masking algorithms one can use to generate a mask as well such as Fmask, CFmask, etc. Temporal composite such as mean/median image can also be used to remove clouds.

Question 5: In Google Earth Engine, we can create a median image to minimize clouds. Is it advisable to use a median/averaged image to map landslides if, say, the image average was going to be small, around the rain event.
Answer 5: Yes it can be used. However, large differences in minimum and maximum pixel values can cause display issues. Image stretching and normalization can be utilized to map landslides in GIS software.

Question 6: How can global satellite data and remote sensing technology be applied to determine trigger threshold values for developing an early warning system for landslides in Bangladesh? Given the absence of a National Early Action Protocol (NEAP) for landslides, our team is working to develop one. Since early warning depends on accurately defining trigger thresholds, how can satellite data be integrated with historical records and community observations to establish reliable trigger threshold values?
Answer 6: It is important to note that remote sensing of rainfall produces a near-real time observation, not a forecast, and as a result we typically do not suggest using rainfall observations as part of an early warning system. Forecast rainfall data (including more local weather forecast data) may be more important. For any early warning system, thresholds for landslide occurrence (based on historically known landslide occurrence timing) should be compared with the forecast data available for that landslide time to ensure any model would be appropriately calibrated.

Question 7: Is there an opportunity to connect and collaborate with a NASA team to develop reliable trigger threshold values using satellite data and remote sensing technology?
Answer 7: Please reach out via the contact information provided to specifically discuss your case of interest.

Question 8: How can I read more about using machine learning in remote sensing? Could you please offer some resources?

Answer 8: There are a number of ARSET trainings available to explore exactly this topic! You might be interested in the following: Fundamentals of Machine Learning for Earth Science.

Question 9: Can spectral indices be used to detect landslides? What would be the recommended spectral index?
Answer 9: Yes, spectral indices can be used to detect landslides. In SALaD (Semi-Automatic Landslide Detection), two spectral (NDVI, brightness), topographical (slope) and two textural (GLCM mean and GLCM homogeneity) features were used. However, different studies use different indices and it is sometimes site dependent.

Question 10: Can we map and identify places which have been affected by landslides with object-based image analysis, deep learning, or machine learning? I am curious if we can have an early warning system in landslide prone areas. Will we be doing any training on how we can use Landslide Susceptibility mapping using any ML method in any platform?
Answer 10: Yes, the mapping methods described in this training identifies landslides that have already been initiated. In part 3, we talk about susceptibility analysis. In terms of early warning systems, it is important to note that typically satellite data is observational, rather than predictive, and as such early warning is typically not feasible using such information. Early warning would typically rely upon predictive weather forecast data, and training a model on such information (i.e., hindcasts) would be necessary to help develop any kind of early warning.

Question 11: As a Disaster Risk Researcher interested in creating my own Landslide Risk Maps, which are the most up-to-date and accurate Landslide Inventory Datasets for the High Mountain Asia Region?
Answer 11: Global Landslide Catalog and Global Fatal Landslide Database covers HMA. However, data is only available up to 2018, for individual landslide points.

Question 12: Which is the most advanced Landslide Early Warning System that you know of? What are some of the main characteristics of that system? Where has it been successfully implemented? What scale does it work on? (slope scale/catchment scale/regional scale)?

Answer 12: We are hesitant to point to one specific system. As a general rule, the majority of systems operate very locally. Looking at fire post burn areas has also been effectively implemented at regional and local scale.

Question 13: Do you have experience using L-band SAR data, change detection or even InSAR or even Permanent Scatterers InSAR with multibaseline approach?
Answer 13: The Landslide team mostly works with optical data. We have worked with Sentinel-1 C-band data. Other teams with NASA have used SAR data as well. With NISAR launching soon, we do have plans to explore L-band data for change detection. Other NASA researchers have developed systems to use InSAR analyses; please reach out to us for further information.

Question 14: Can InSAR also work to identify steep sided gullies related to landslides and rainy events?
Answer 14: It will depend on a few factors. Landslide assessment with SAR can be challenging. If you have questions about specific areas, please reach out to the team for InSAR connections.

Question 15: Can some of the tools and methods be used for quick subsidence occurrences like sinkholes and are there some specialized approaches for sinkholes?
Answer 15: We have not looked at sinkholes specifically and have not tested these methods, and as such would not want to speculate on an answer.

Question 16: I periodically update a landslide inventory using new satellite imagery. Can automated methods to identify new slides be trained on old slides with older optical data?
Answer 16: Yes. Machine learning algorithms are trained on old landslide data.

Question 17: Could you elaborate further on amplitude-based change detection and its corresponding backscatter response? Additionally, how can the backscatter response be disentangled? Regarding the coherence-based method, does it incorporate a phase unwrapping algorithm, considering that phase unwrapping often significantly impacts sensitivity?
Answer 17: For a detailed understanding of the amplitude-based approach, we recommend reviewing the entire study in which this was first described:

https://doi.org/10.5194/nhess-2020-315. For a review of SAR use for landslides more generally, this open-access review may be informative: https://doi.org/10.1016/j.earscirev.2021.103574

Question 18: How can high-resolution drone imagery provide more accurate and detailed data for landslide risk assessment compared to satellite imagery?
Answer 18: Drone imagery, as well as being typically higher resolution than satellite data, can also provide 3D imaging of landslides, rather than 2D or 2.5-dimensional satellite data. This allows for much more comprehensive assessment of, for example, volumes. However, the spatial scale over which drone data can be acquired is typically much smaller.

Question 19: Can large cloud cover be removed using some modeling technique? Smaller clouds are easier to remove but big sized clouds create issues. In case of smaller landslides can we consider SAR? What is the max precision typically (in meters) we can obtain with SAR studies?
Answer 19: As we mentioned above, cloud masking algorithms and temporal mean/median can be used. Mapping small landslides will depend on resolution. This is a more complex answer and will depend on the SAR data used. For a detailed review of this subject area, you may find this open-access study informative: https://doi.org/10.1016/j.earscirev.2021.103574

Part 2 Questions & Answers Session B

Please type your questions in the Question Box. We will try our best to get to all your questions. If we don't, feel free to email Robert Emberson (robert.a.emberson@nasa.gov) or Pukar Amatya (pukar.m.amatya@nasa.gov).

Question 1: Is there any way to use satellite data to predict landslides? Or any satellite data that can help?
Answer 1: Prediction can mean a couple of things. In terms of predicting the location of a landslide, we will discuss susceptibility analysis in Part 3 of this training. In terms of predicting timing of a landslide, this typically requires forecast information regarding rainfall. Forecast rainfall data is typically coarser resolution and/or accuracy than observational data of rainfall, which means development of thresholds or other predictive models must be trained using forecast rainfall data, and cannot be extrapolated from observational rainfall data.

Question 2: Sorry if I am jumping ahead, but I am wondering we'll discuss: predicting vs. assessing the potential threat of landslide areas (in advance of an actual event, versus post-facto). Realizing obviously the need for additional data (e.g., soils, geology, DEMs etc.).
Answer 2: We will certainly explore this element in Part 3 of the training.

Question 3: Which state of the art Convolutional Neural Network (CNN) and Artificial Intelligence (AI) models are being used to map landslides with optical satellite imagery?
Answer 3: Our team is using different versions of U-Nets. Recent literature has shown transformer based models to be better compared to CNNs. One example of it is the IBM and NASA's Prithivi-EO-2.0 foundation model. This model has been fine tuned for downstream landslide mapping tasks.

Question 4: Are there any papers or frameworks to train a Convolutional Neural Network (CNN) to automatically map landslides while also writing all the metadata a landslide inventory ought to have?
Answer 4: Yes there are open source public reference training datasets to train a deep learning model (https://arxiv.org/abs/2206.00515). Model shapefile outputs and general

metadata may be produced by such models although we would recommend manual evaluation of any automatically produced metadata to ensure reliability.

Question 5: Do different satellites have different measurements and resolutions for landslides? What are some good satellites for measuring landslides in your opinion? I keep hearing Landsat, Sentinel-1, etc., but not sure of the differences. Are there any recommended reading resources to know the differences?
Answer 5: You might be interested in reviewing Fundamentals of Remote Sensing for explanations of the capabilities of different satellites.

Question 6: Could you use a single algorithm combining Object-Based Image Analysis (OBIA) and a pixel-based method simultaneously to enhance the end result?
Answer 6: We are using pixel-based features to get to objects. They interlinked at some level. OBIA plus deep learning has been shown to enhance results. See https://link.springer.com/article/10.1007/S10346-021-01843-X.

Question 7: What is a reasonable training ratio (manually mapped slide area vs overall Area of Interest [AOI]) for SALaD approach?
Answer 7: Depends, large training data is preferred. Single ratio cannot be suggested.

Question 8: Pukar, not sure why over segmentation would not be a bad result from the model. Can you please explain further?
Answer 8: Landslides vary in shapes and sizes. A perfect set of segmentation parameters that can perfectly segment all landslides present in an image might not be possible. It is always easier to combine small landslide objects to form a single landslide polygon than breaking big objects.

Question 9: Is there a correlation study for repeat SALaD vs. change detection investigations for the same AOI?
Answer 9: We have not done a specific study.

Question 10: How can someone who isn't familiar with machine learning get started on using SALaD? Do I need any special software? Do I use Google Earth for satellite imagery?

Answer 10: We would recommend exploring the information available on the NASA Landslides project page for SALaD: https://gpm.nasa.gov/landslides/projects.html. There you can find the papers that describe the model, as well as the link to the code. Google Earth unfortunately is not a good solution for satellite imagery since it is not possible to pull data from that source for use in a Python coding process. Several satellite sources including Landsat and Sentinel are freely available and effectively georeferenced, and allow for use in coding processes.

Question 11: How often and at what point are "ground truthing" and\or any onsite observation or calibration data or evidence: obtained, considered useful or necessary? At what relative cost?
Answer 11: Ground truth data is certainly relevant and important. In many cases, very small landslides (below the resolution of available satellite data) may still be important, and ground-based analyses will be the only approach to capture these events. In addition, ground-based analysis will be important to determine stability of newly formed landslide dams and deposits, as well as to characterize any impacts on roads. In general, the value of satellite data is to provide a first pass to determine where landslides have occurred in the greatest numbers, which can then help guide the deployment of field resources in a cost-beneficial manner.

Question 12: Question to Pukar: Is the multi-temporal landslide inventory data of Nepal mentioned in the presentation open source? What is its accuracy compared to manually extracted data? Also, just want to double-check, are both the training and prediction based on the entire landslide polygons rather than just the source area?
Answer 12: Yes, they are available in the NSIDC High Mountain Asia DAAC. Please see https://nsidc.org/data/hma_mtli/versions/1 and https://nsidc.org/data/hma2_mtli/versions/1. These inventories have gone through manual corrections. Training is done using complete landslide polygons.

Question 13: When training an AI model, as you said, the model is only as good as its training data. I can imagine that finding a good landslide dataset for training, especially due to issues like cloud cover, is not easy. Could you find a high-quality dataset that would be a strong candidate for training and then generate 1,000 synthetic datasets based on it—modifying the images, altering the landslide

geometry, etc.—to reduce the time needed to find training data and speed up the entire process?
Answer 13: An exciting question, given that it is the subject of ongoing research. We have asked the same question, and are currently exploring exactly this.
Data augmentation techniques can be used to increase the number of training samples. Augmentation includes image flipping, rotation, adding noise etc. See, https://albumentations.ai/.

Question 14: Is the GeoAI segmentation method effective for monitoring active and recorded landslides?
Answer 14: This method is usually used for mapping. Monitoring involves use of SAR to measure movement. However, segmentation methods can monitor growth and reactivation of landslides.

Question 15: You mentioned InSAR is good for slow moving landslides. What is a good method to detect a fast moving landslide? What about a fast moving landslide but at a smaller scale?
Answer 15: Fast moving landslides can be monitored using Pixel Offset tracking. Scale is satellite resolution dependent.

Question 16: According to the rules of perspective, what parameters are allowed for foreshortening images taken with SAR?
Answer 16: Could you ask this question with more details? NASA ARSET has several SAR trainings, see below for links to trainings:

1. An Introduction to Synthetic Aperture Radar (SAR) and its Applications
2. Disaster Assessment Using Synthetic Aperture Radar
3. SAR for Detecting and Monitoring Floods, Sea Ice, and Subsidence from Groundwater Extraction

Question 17: Will you be presenting more insights on fusing optical and SAR-based analyses?
Answer 17: We will speak a little about this in Part 3. A recent NASA study using such methods for flood detection can be found here:
https://ntrs.nasa.gov/api/citations/20210016467/downloads/Generating%20Flood%20Probability%20Map%20Based%20on%20Combined%20Use%20of%20Synthetic%20Aperture%20Radar%20and%20Optical%20Imagery.pdf

Question 18: InSAR requires large satellite baselines to achieve high fringe sensitivity. Usually, Sentinel-1 has a relatively small orbital tube of just 150 m. As far as I know, the optimal baseline size for good fringe sensitivity is around 2 km. Are there any satellite systems that have this baseline? Would you have some literature that you could share regarding this use case?
Answer 18: The upcoming NISAR mission will fulfill these requirements; you can review the science users guide here:
https://nisar.jpl.nasa.gov/system/documents/files/26_NISAR_FINAL_9-6-19.pdf

Question 19: Is it possible to predict a landslide from Non-Optical Detection (InSAR) from Interferogram?
Answer 19: Predicting landslides based on InSAR is outside of our scope of expertise; in general, InSAR has been used to track changes but the variety of potential factors that can lead to rapid catastrophic failure of landslides may not be well predicted by historical InSAR tracking.

Question 20: Have you used LiDAR data for looking at post landslide forest structural changes? Is it possible to incorporate point-cloud information into the automated approach?
Answer 20: We have not experimented with LiDAR. Typically, ground-based studies have been at the forefront of using LiDAR DEMs for landslide detection and volume estimation.

Question 21: What automatic techniques are recommended for fast slides, given that the frequency of daily or longer resolution images is low, for the required response times (no more than 48 hours)?
Answer 21: Pixel Offset tracking can be used. For rapid response only commercial platforms are ideal.

Question 22: Is SALaD only for mapping landslide areas, like feature extraction?
Answer 22: SALaD is a mapping framework at its essence. It can be used for mapping other things if task specific features can be provided such as for flood and landcover mapping.