Part 1 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 Sean McCartney (sean.mccartney@nasa.gov) or Robert Emberson (robert.a.emberson@nasa.gov).

Question 1: Do soil properties influence the determination of failure planes in landslides? If so, would soils with the same properties have the same failure plane, assuming other factors are not considered?
Answer 1: Soil property does influence the likelihood of landsliding, but this is typically most important in smaller, shallow landslides. Failure planes are often found at the intersection of bedrock and soil, and the relative types of these materials will be important for such landslides. Very large landslides may fail on fractures or faults within the deeper bedrock. In summary, soil properties are important but determining their relative role is typically determined using field analysis.

Question 2: How can geological material data be integrated with optical remote sensing data? Do you recommend using local geology or regional geology?
Answer 2: Most studies of landslide hazard typically use local or regional analysis of geological structure and lithology; although some satellite data has been used to help determine the surface characteristics of geology (including hyperspectral data), understanding what is happening underneath the surface is also critical, and this requires local or regional datasets.

Question 3: Are the effects of landslides the same across different countries? Are the examples you have provided also applicable to Bangladesh, particularly in the Chittagong Hill Tracts (CHT)?
Answer 3: There are many factors that influence landslide triggering, which may vary depending on the location around the world - for example, local lithology, vegetation, or land management practices. The effects of landslides may also depend on what emergency management and mitigation practices are carried out in an individual location. Specifically regarding the Chittagong Hill Tracts, satellite observations have been used to assess the impact of landslides in this area previously, although the authors note that field studies are important here as they are elsewhere.

Question 4: Is piping considered a type of landslide, or is it a distinct erosion process? How do the mechanisms of piping and landslides differ, and are there cases where both processes interact?
Answer 4: I believe in this case you are referring to piping which is typically described as an erosion process of earthen dams that takes place when water that seeps through the dam carries soil particles away from the embankment, filters, drains, foundation or abutments of the dam. This is not typically considered a landslide, but theoretically destabilisation of slopes due to internal erosion may influence overall slope stability and lead to landslides.

Question 5: Is radar useful for looking at the stability of rubble piles?
Answer 5: Radar can be used to assess slow movement of cm to mm per year, and this has helped determine stability of slow moving landslides. This technique is called Interferometric SAR analysis. Although I am not aware of specific analysis focused on rubble piles, there may be applicability of InSAR to this type of application.

Question 6: Are drones (with multispectral sensors) better at detecting landslides at a small scale instead of using Landsat and Sentinel data, the course resolution data?
Answer 6: Unmanned Aerial Systems (UAS) have been extensively used to assess landslides at local scale. Typically these can produce higher resolution analysis and can even use methods like 3-dimensional structure-from-motion to build 3D pictures of landslides. However, to combine this data with other inputs, it is important to note that this type of information must be geo-referenced.

Question 7: Typically for a risk assessment, the most difficult part to get is the post-event estimate of damage. It seems like we can derive hazard and exposure layers from NASA's satellite products or options like Open Street Map (OSM). Does NASA have an event reports database publicly available for landslides? How do NASA folks estimate social/infrastructure vulnerability?
Answer 7: NASA collected a large amount of information regarding landslide locations and events; you can find this data on NASA Landslides' website:
https://gpm.nasa.gov/landslides/data.html
In terms of social/infrastructure and vulnerability, this remains a major challenge. Several research projects supported by the Disasters Program have begun to explore

some of these issues:
https://appliedsciences.nasa.gov/our-impact/news/nasa-selects-seven-new-projects-advance-disaster-science

Question 8: Cloud cover is a constraint. Can we use precipitation datasets to map landslide susceptibility?
Answer 8: We will discuss more in Part 2 and Part 3 of this training. Clouds can be a constraint, but SAR can view through clouds. Precipitation data is important for landslide assessment, and NASA researchers have developed models that use rainfall data to estimate the likely locations of landsliding as a result of rainfall:
https://gpm.nasa.gov/landslides/projects.html

Question 9: Could you speak more to the use of the failure slope:landscape slope probability ratio as shown on slide 24? Could you provide a reference for the frequency graphs shown?
Answer 9: This is from a recent NASA Disasters supported research study; you can find the open-access article here: https://doi.org/10.5194/nhess-22-1129-2022

Question 10: How can we use earthquakes to map landslide susceptibility? Is there any data for earthquakes, apart from earthquake zones? When we work on a city scale, the whole city might fall in one earthquake zone. How can we show an earthquake's spatiality on a city scale?
Answer 10: The USGS produces an excellent global landslide model that is triggered based on earthquake shaking. This can be found here;
https://earthquake.usgs.gov/data/ground-failure/
In terms of assessing city-wide shaking, NASA Disasters has supported a range of research studying earthquake impacts; you can find examples from the 2023 Turkiye earthquake here:
https://appliedsciences.nasa.gov/what-we-do/disasters/disasters-activations/turkiye-syria-earthquakes-2023

Question 11: In humid subtropical climates like Zimbabwe, there are pronounced wet and dry seasons. NDVI values decline drastically in the dry season depicting similar patterns as landslides (vegetation loss). How can we differentiate between both in the NDVI time series?

Answer 11: Typically we use changes in vegetation extensively for landslide assessment, but in areas where it has died off during seasons it can be more difficult. If a landslide is larger and excavates bedrock material, NDVI mapping can still show differences since subsurface bedrock typically remains spectrally differentiable from even dead vegetation. The human eye is not always perfect and automated methods can be helpful. We will discuss more about this in Part 2.

Question 12: I'm curious if there is an onus on international governments to mitigate risks if they are given risk data from another country?
Answer 12: Unfortunately I do not have specific expertise to answer this question.

Question 13: I heard about NASA's disaster response efforts related to landslides in Rio de Janeiro before. Is there any repository where I can learn more about the methodology and how to assess the LHASA model at a more local or regional scale?
Answer 13: The LHASA model can be found here: https://gpm.nasa.gov/landslides/projects.html, which includes links to the Github repository where the reproducible code is hosted. The work with Rio de Janeiro is not published at this time but please reach out via my contact information to connect.

Question 14: We can assess which street can be affected by the landslide, and from what I understand to assess it we also need the elevation or the slope gradient. Since DEM data that is freely available (especially in my country) is about 8 meters and streets could have a higher spatial resolution than that (have a smaller width than the slope gradient), how can we minimize the bias?
Answer 14: At local scale, it may be more appropriate to assess very small landslides (below the scale of associated data) using field analyses.

Question 15: What's the progress made by NASA in terms of understanding landslide mechanics and prediction using physics-informed machine learning?
Answer 15: Physics-informed machine learning has been limited so far using satellite data. Incorporating drone data and satellite-based data has been the most helpful here; teams previously supported by NASA Disasters have begun to estimate some of these factors: https://doi.org/10.1029/2023JF007471

Question 16: Is paddy cultivation on the mountain slope considered a cause of landslides? This was considered a chance in the Landslide at Malin, Pune.
Answer 16: I am not familiar with this specific event and do not want to speculate on the land use involvement. Paddy cultivation is widespread and we are unsure.

Question 17: How can hyperspectral data help landslide monitoring and what active hyperspectral data are being used for the purpose?
Answer 17: Hyperspectral data can help assess surface characteristics. A good recent example can be found from USGS monitoring of landslides on the California Coast: https://www.usgs.gov/news/hyperspectral-data-analysis-mapping-coastal-landslide-hazards-along-big-sur-coast

Question 18:Can geological features like folds, faults etc. influence landslides?
Answer 18: Certainly. If these folds and faults influence the shear strength of the subsurface environment then it can affect the susceptibility to landsliding.

Question 19: Detecting landslides over large and diverse terrains presents challenges due to cloud cover, vegetation, and data resolution limitations. What innovative approaches or sensor fusion techniques are being explored to enhance large-scale landslide detection and real-time monitoring?
Answer 19: NASA has supported a range of research to assess landslides using high resolution and multi-sensor approaches, including using AI methods. We will discuss these elements in more detail in parts 2 and 3 of the training.

Question 20: How can satellite imagery and remote sensing techniques be used to assess the relationship between landslides and floods, particularly in regions with heavy rainfall and steep terrain?
Answer 20: Many studies have focused on either landslides *or* flooding, and rarely focused on both in combination. This is in part because flash floods, rather than riverine floods, are more common in mountainous regions, and prediction of flash flooding is challenging with satellite data. This is a fruitful area for future research!

Question 21: What is the best approach for mapping rockfall source areas and detached blocks? Satellites such as Sentinel 2 have too coarse a resolution and the images provided by very high resolution satellites are often expensive.

Orthophotos are also usually published every few years. Do you think it is possible to detect the deposits using LiDAR?
Answer 21: Several studies have used LiDAR to assess landslide deposits. A widely used methodology has been developed by scientists at USGS:
https://www.dnr.wa.gov/publications/ger_presentations_gsa_2017_mickelson.pdf

Question 22: In Mali, we are facing several types of landslides, notably in mining sites (2024 and 2025) and urban peripheries (Bamako). How, with our limited access to real-time data, can we prevent such events?
Answer 22: Mine-related landslides and landslides impacting urban areas are critically important and significantly impact communities around the world. For those local assessments, satellite data may still be beneficial (see part 3 of the training for more info on local-regional susceptibility analysis) but geo-engineering approaches to determine slope stability may be more important for critical individual hillslopes.

Question 23: What's the progress made at NASA for Landslide Early Warning Systems? What are the challenges involved and what is the future roadmap for landslide prediction and early warning?
Answer 23: Because early warning typically requires a prediction based on forecast estimates of landslide triggers, it has been challenging to effectively implement early warning estimates due to lower accuracy of global rainfall forecasts. In part 3, we will talk a bit more about these efforts.

Question 24: We usually have Landslide inventories, landslide susceptibility and landslide hazard maps, but the next level is Landslide Risk Maps. What is NASA's progress and approach on Landslide Risk Maps?
Answer 24: Risk is certainly a challenge! We are developing estimates of exposure to landslides using population and infrastructure data, but estimating vulnerability and therefore risk remains a challenge. NASA Disasters has supported collaborative work between NASA scientists and the Pacific Disaster Center (PDC) to produce exactly that - which can be found operationally in their free-to-use DisasterAware system
https://www.pdc.org/disasteraware/

Question 25: Related to question 11, what about deriving the Typic Meteorological Year curve for NDVI for specific locations? We are thinking about this method to deploy in Europe.

Answer 25: That's an interesting approach, and although I'm not aware of specific research focusing on that kind of assessment, determining the longer term trends in NDVI or other surface spectral characteristics and then detecting anomalies as a way to explore landslides would be relevant.

Part 1 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 Sean McCartney (sean.mccartney@nasa.gov) or Robert Emberson (robert.a.emberson@nasa.gov).

Question 1: I can imagine that as depth increases, the compression of the material due to the weight of the material above also increases. Depending on the type of soil and its porosity, does this decrease the chance of that material moving? Is there a typical depth at which material is likely to move in a landslide?
Answer 1: Depth of landslides is typically closely associated with the size of the landslide (DOI: 10.1038/ngeo776) and the distribution of landslide sizes varies depending on a number of factors in a landscape. In some settings, preferential landslide failure depth may be associated with certain soil layers or at the soil-rock interface. Larger (and thus deeper) landslides are rarer (distributions typically follow a power-law distribution). If compression has led to a shift in the balance of shear stress vs shear strength within the subsurface, it may alter landslide likelihood.

Question 2: Is there a way to identify risk areas before a landslide occurs using SAR with longer wavelengths, such as P- and L-band, which can penetrate deeper into the soil?
Answer 2: To our knowledge, ground-penetrating SAR has not been employed to explore landslide risk, but this is an excellent question, and potentially an interesting research direction.

Question 3: Will you be going into detail about SMAP during this training?
Answer 3: We will not be briefing in depth about SMAP data for landslide analysis, although if this is of interest please reach out to us via the contact information provided.

Question 4: How do I access the SMAP data? Checked the website but it's not clear where exactly the link to access the data is.
Answer 4: Level 3 (derived soil moisture data) SMAP data can be downloaded from the National Snow and Ice Data Center (NSIDC):
https://nsidc.org/data/spl3smap/versions/3

Question 5: I've been developing a GNSS-enhanced machine learning model for detecting land deformation related to geohazards, specifically earthquakes and landslides. I've encountered challenges establishing reliable deformation thresholds. These thresholds are highly sensitive to various factors, as you mentioned, including rainfall, NDVI, and slope. Do you have any recommendations or references that delve deeper into the methodologies for defining these critical thresholds?
Answer 5: Robert is open to receiving an email following up on this.

Question 6: What are the common satellite products used for monitoring forest loss? What are their spatial resolutions?
Answer 6: The most widely used dataset is the 30m Landsat-derived data provided by NASA-supported researchers at the University of Maryland:
https://earthenginepartners.appspot.com/science-2013-global-forest
Sentinel-2as well.

Question 7: Is it possible to detect rainfall-induced shallow landslides using Sentinel 2 or Landsat imagery? Especially in the area where soil erosion is prominent. Re-vegetation issue is also there.
Answer 7: Yes, we use Sentinel-2 and Landsat. Resolution is not as fine as commercial–it would have to be larger landslides. Parts 2 and 3 will cover multiple smaller landslides in an area.

Question 8: Is rainfall a triggering factor or a risk variable for a forecasting model?
Answer 8: Rainfall, short term, may be a specific trigger. Annual or season scales, rainfall rates are something that will affect the susceptibility or risk.

Question 9: After a fire, especially in areas with slopes > 15%, with intense rainfall and lack of vegetation, slow ground movements can be triggered. I use Sentinel-1 SAR images for DinSAR calculation, which is sensitive to small movements. I have found that even with just two inSAR images and a coherence greater than 0.8, good results can be achieved. So, can these movements be detected with just two satellite images?
Answer 9: Some locations the vegetation structure or lack of data.

Question 10: You mentioned you may need to monitor *long term* low intensity rainfall, how long is long term? Do you include more than 15 days of rainfall for this?
Answer 10: We focus on rainfall in a 7 day period before the event. We found dates going back further did not correlate as much. Long term will include climatology.

Question 11: In the Emergency Management realm, is there a way to request a study like the one shown in Brazil to be done for our area specifically?
Answer 11: The work in Rio took ~ 6 years. But we are looking into ways to make this more transferable to other locations. Local data will be needed, ideally but the methodology remains the same.

Question 12: In this webinar, land disturbances were used as ancillary data. How about using streamlines to identify landslide areas for further assessment of sediment erosion in areas such as the badlands?
Answer 12: We will discuss this in Part 3.The location of distance from streamlines is widely used. River systems can be a strong control.

Question 13: Antecedent rainfall has been shown to be important when modeling landslide induced rainfall. Likely to assist in establishing initial moisture conditions in the ground. How is this accounted for in your analyses? Do you perform any geotechnical analyses to support and/or validate your work?
Answer 13: In part 3 we will cover this as well. The antecedent index
Validation crowdsourcing is encouraged via:
https://gpm.nasa.gov/landslides/data.html

Question 14: Which data products about extreme weather are available through NASA missions?
Answer 14: Near real-time data about extreme weather can be found from NASA's Land, Atmosphere Near real-time Capability for Earth observation (LANCE):
https://www.earthdata.nasa.gov/topics/human-dimensions/severe-storms/near-real-time-data