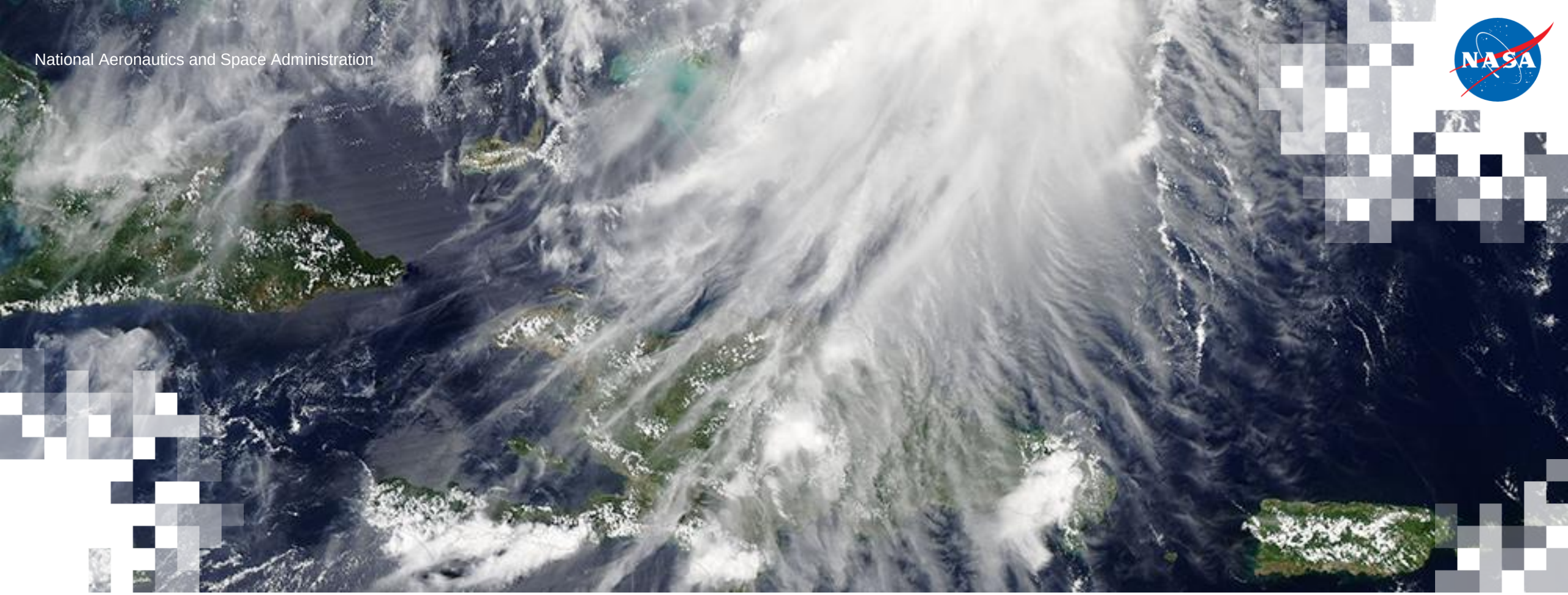
National Aeronautics and Space Administration



Assessing Landslide Hazards Before and During an Event

Thomas Stanley, Universities Space Research Association, Goddard Earth Sciences Technology and Research, NASA Goddard Space Flight Center

August 26, 2021

Training Outline

Assessing Pre- and Post-Storm Impacts

August 18, 2021

https://phys.org/news/2019-12-philippines-homes.html

Assessing Sea Level Rise at the Regional to Local Scale

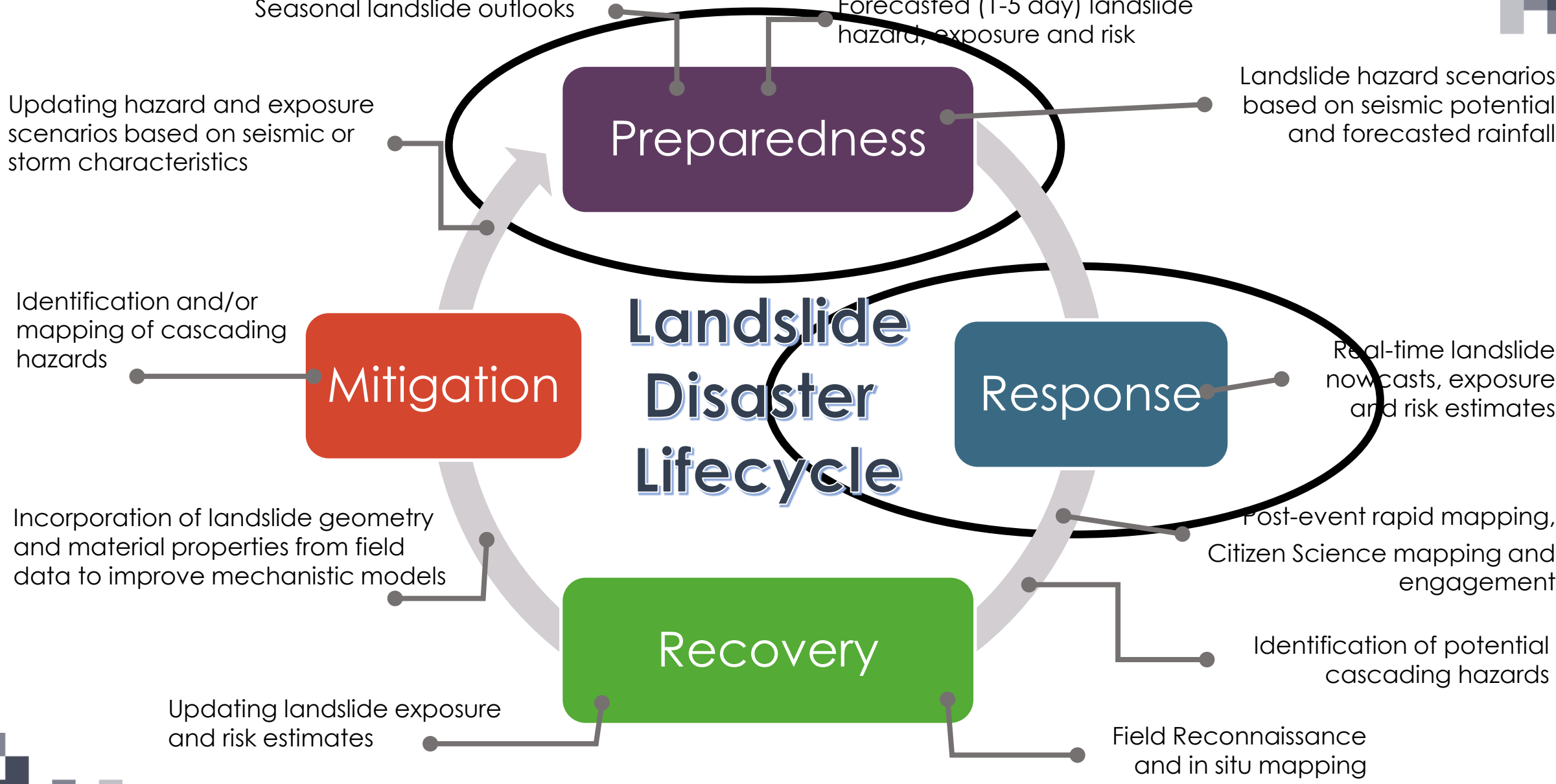
August 24, 2021

https://e360.yale.edu/features/rising_waters_how_fast_and_how_far_will_sea_levels_rise

Assessing Landslide Hazards

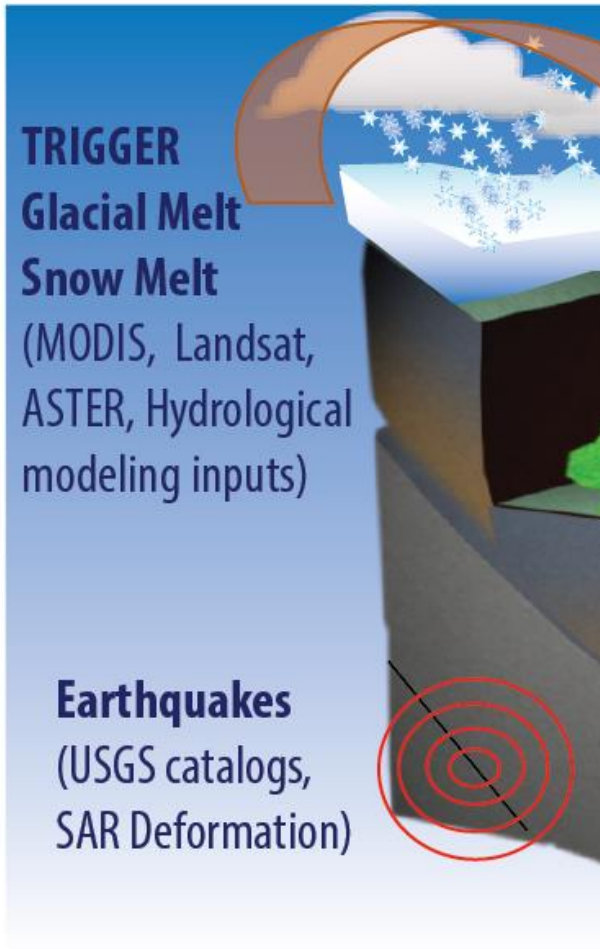
August 26, 2021

https://ttweathercenter.com/severe-weather/landslides/


Seasonal landslide outlooks
Forecasted (1-5 day) landslide hazard, exposure and risk
Preparedness
Updating hazard and exposure scenarios based on seismic or storm characteristics
Landslide hazard scenarios based on seismic potential and forecasted rainfall
Identification and/or mapping of cascading hazards
Mitigation
Landslide Disaster Lifecycle
Response
Real-time landslide nowcasts, exposure and risk estimates
Incorporation of landslide geometry and material properties from field data to improve mechanistic models
Post-event rapid mapping,
Citizen Science mapping and engagement
Recovery
Identification of potential cascading hazards
Updating landslide exposure and risk estimates
Field Reconnaissance and in situ mapping

Landslides are a major pr

And they have many causes.



earthquake.usgs.gov/earthquakes/eventpage/us6000eyfk/ground-failure/summary

Felt Report - Tell Us!
Did You Feel It?
ShakeMap
PAGER
Ground Failure
Technical
Origin
Moment Tensor
Waveforms
Download Event KML
View Nearby Seismicity
Earthquakes
Hazards
Data & Products
Learn
Monitoring
Research

Summary | About

Landslides

Estimated Area Exposed to Hazard

Little or no | Limited | Significant | Extensive

Little or no landsliding is expected, but some landslides could have occurred in highly susceptible areas.

Estimated Population Exposure

Little or no | Limited | Significant | Extensive
≤ 10 | 100 | 1,000 | 10,000 | ≥ 100,000

The number of people living near areas that could have produced landslides in this earthquake is low, but landslide damage or fatalities are still possible in highly susceptible areas. This is not a direct estimate of landslide fatalities or losses.

VIEW LANDSLIDES MAP

Liquefaction

Estimated Area Exposed t

Little or no | Limited | Significant

Little or no liquefaction i expected, but some liquefaction could have occurred in highly susce areas.

Estimated Population Exp

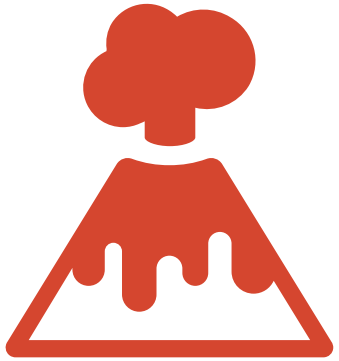
Little or no | Limited | Significant
≤ 100 | 1,000 | 10,000

The number of people li near areas that could ha produced liquefaction in earthquake is low, but liquefaction damage or fatalities are still possibl highly susceptible areas is not a direct estimate c liquefaction fatalities or l

VIEW LIQUEFACTION MAP

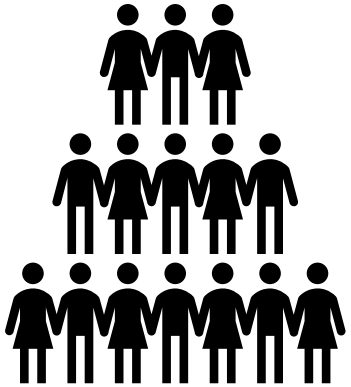
Some small island nations are highly exposed to landslides…

Due to a common combination of factors:

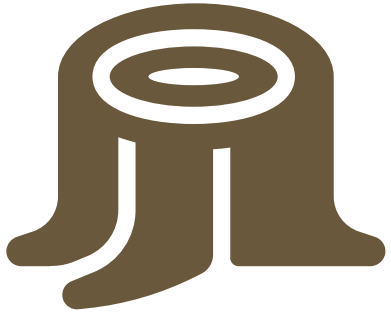


Volcanic Soils and Steep Slopes

Intense Tropical Cyclones

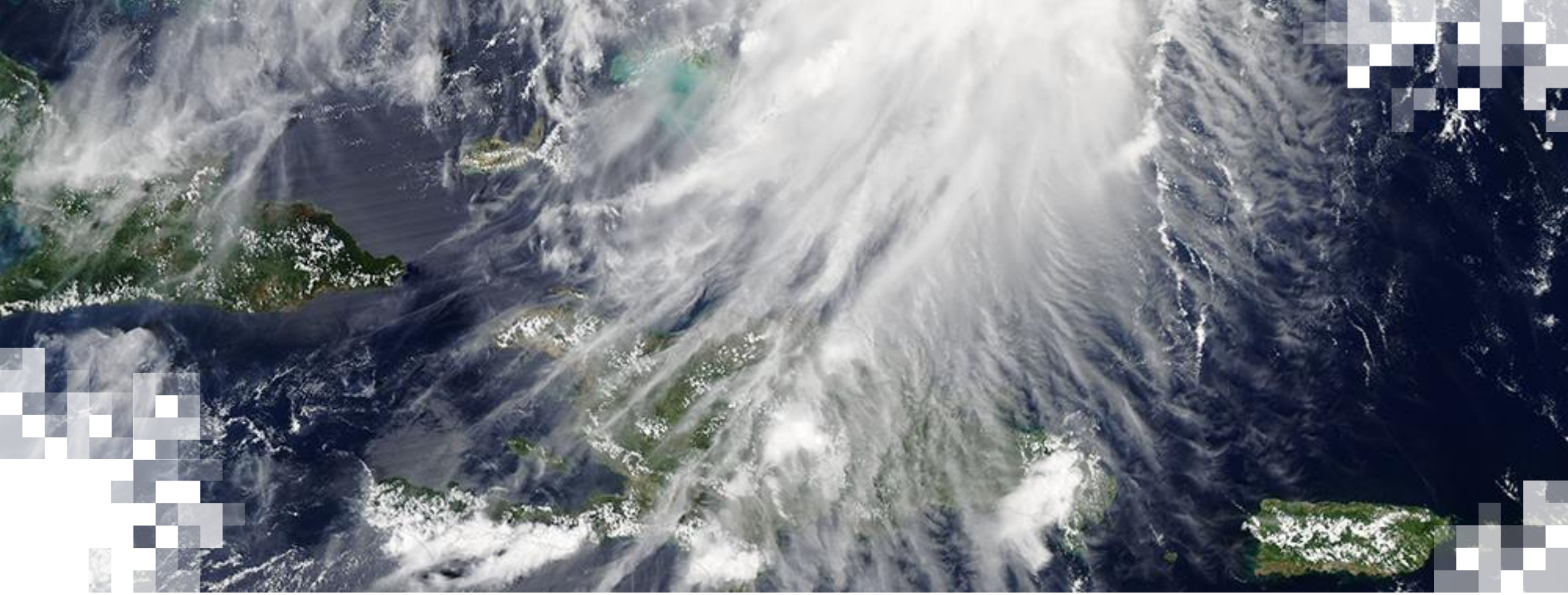


Dense Population



Deforestation

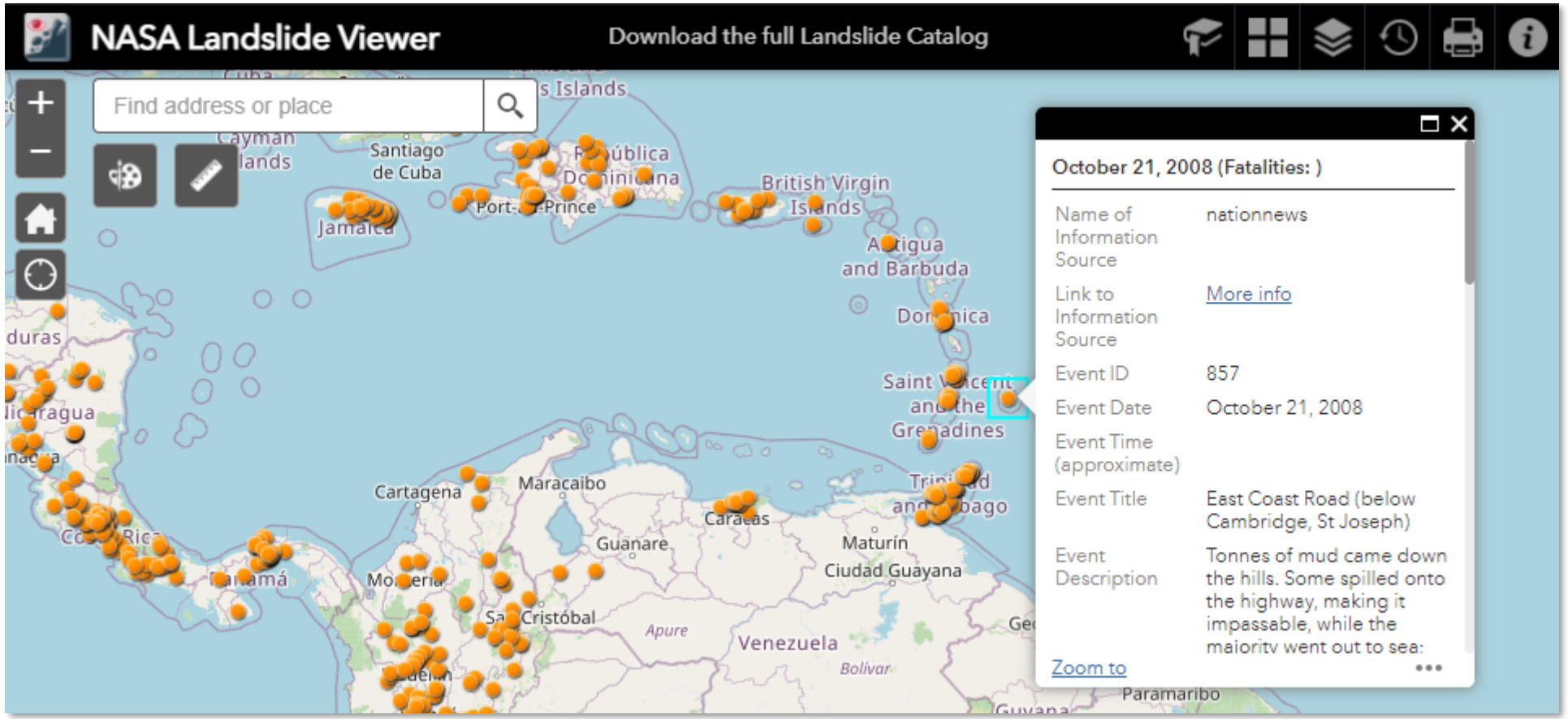
https://doi.org/10.5194/nhess-20-3413-2020



Some Resources for Assessing Landslide Hazard Before an Event

Global Landslide Catalog (GLC)

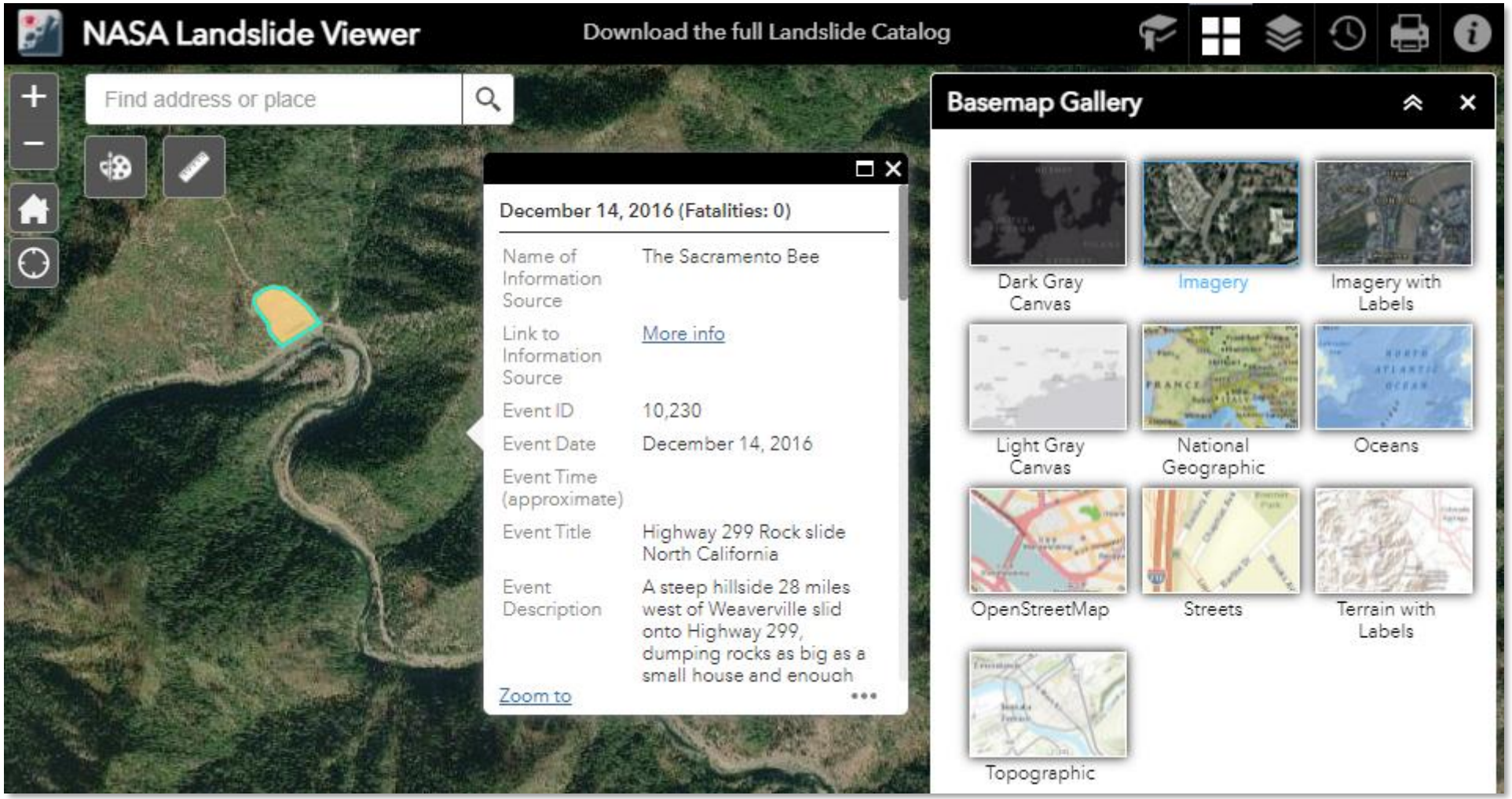
At Landslide Viewer (landslides.nasa.gov/viewer)



http://dx.doi.org/10.1016/j.geomorph.2015.03.016

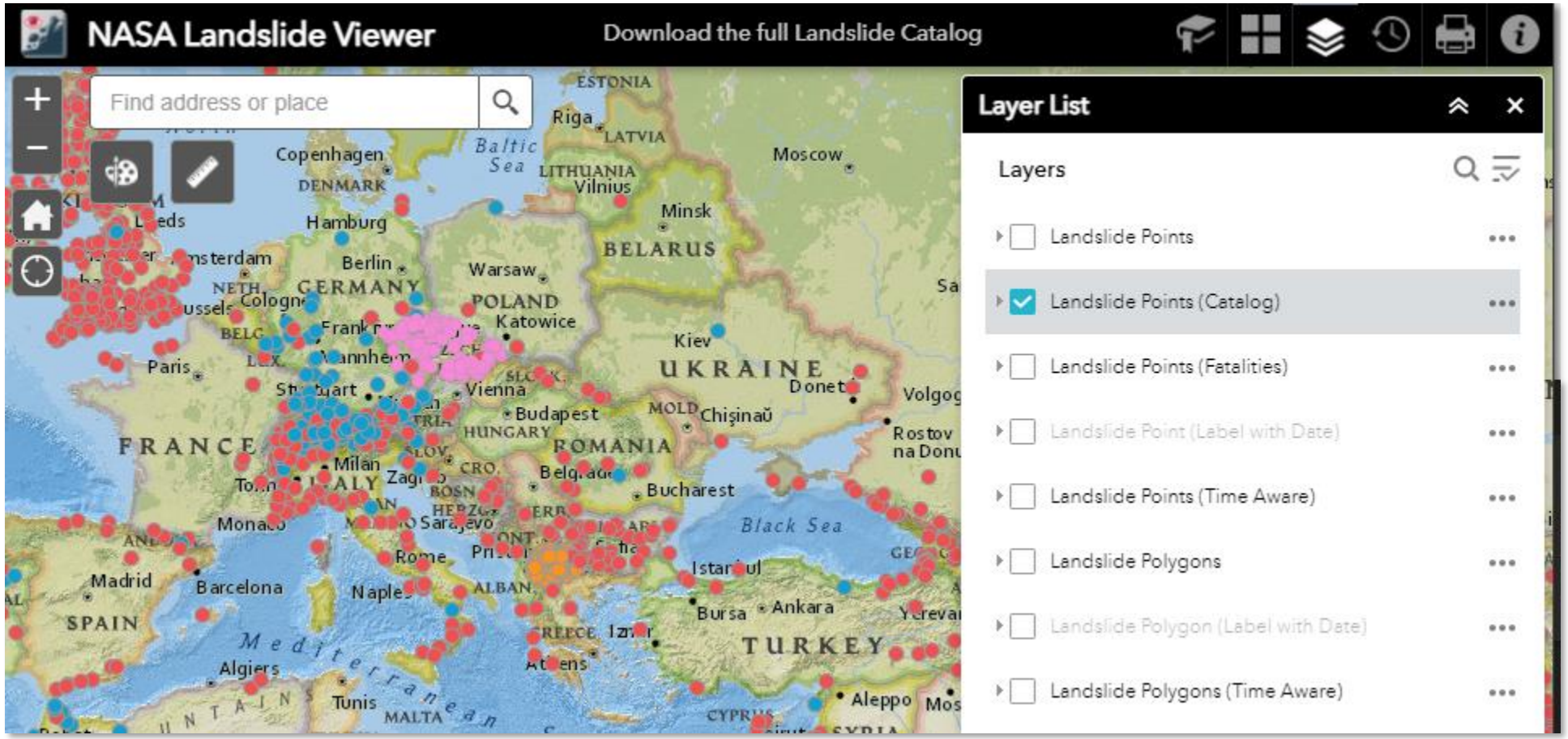
Global Landslide Catalog (GLC)

At Landslide Viewer (landslides.nasa.gov/viewer)



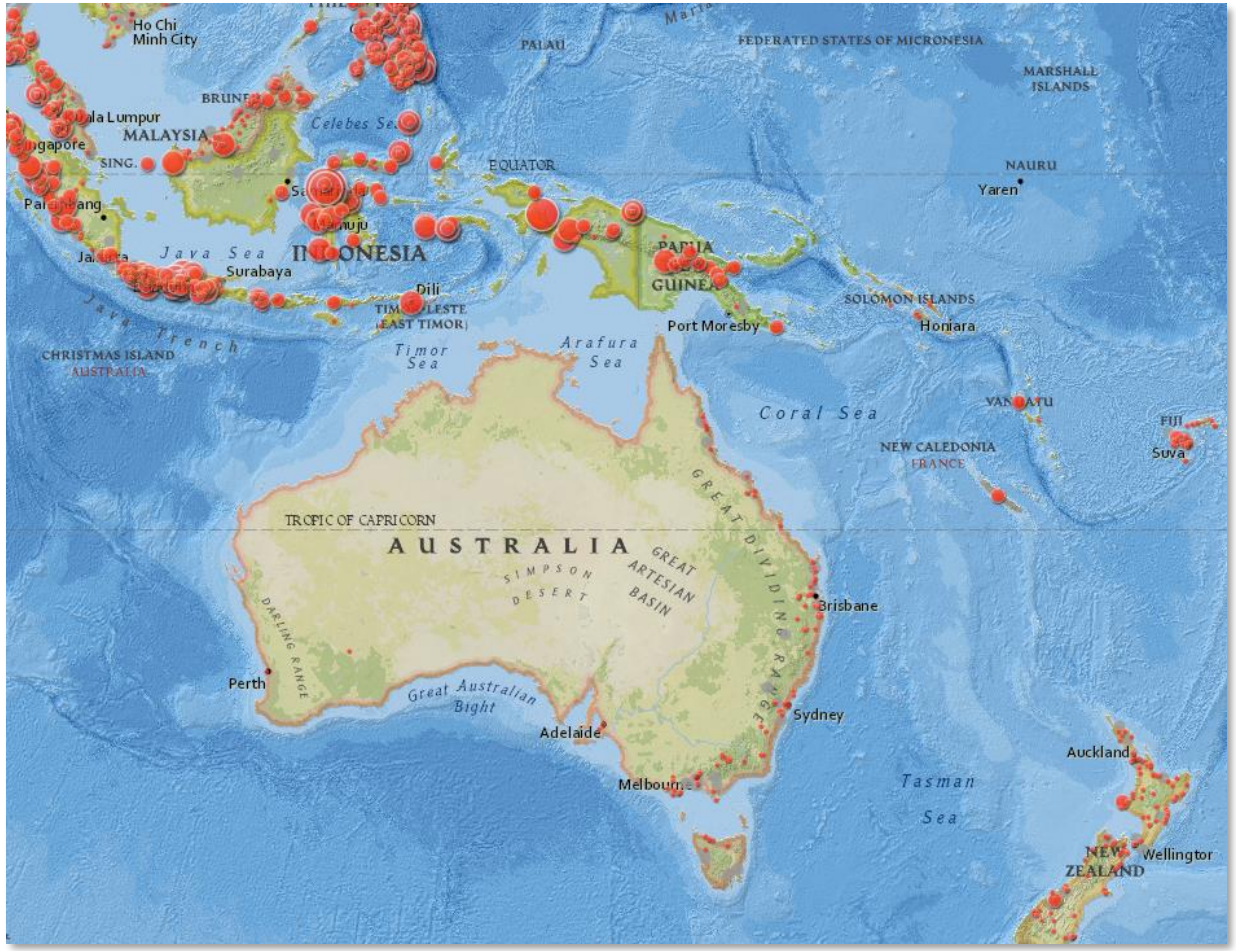
More from the Cooperative Open Online Landslide Repository (COOLR)

At Landslide Viewer (landslides.nasa.gov/viewer)



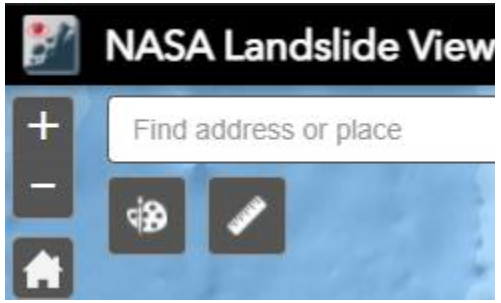
Fatalities and Time

At Landslide Viewer (landslides.nasa.gov/viewer)



Download All the Data in C

At Landslide Viewer (landslides.

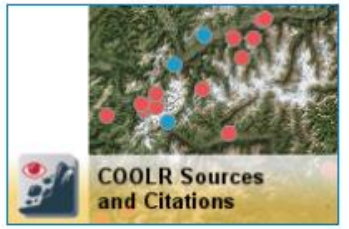


Global Landslide Catalog Downloadable Products

The Cooperative Open Online Landslide Repository (COOLR) is a worldwide database of landslide events from NASA, scientists, and citizen scientists. You can download the COOLR catalog as a file geodatabase (.gdb), shapefiles (.shp), or comma-separated values (.csv). Learn more about the data and citizen science at landslides.nasa.gov.

Tags

617 catalog coolr csv file geodatabase glc global landslide landslide inventory nasa point polygon shapefile



COOLR Sources and Citations (CSV)
CSV

Important citation information about the landslide catalogs within the Cooperative Open Online Landslide Repository.

Global Gridded Landslide Inventory
CSV

Count of landslides mapped within each 1-km grid cell. This file contains most of the landslide inventories used for training version 2.0 of the global landslide nowcast, now under review at Frontiers in Earth Science.

NASA Global Landslide Catalog Points (CSV)
CSV

The NASA Cooperative Open Online Landslide Repository (COOLR) points, downloadable as a .csv file.

NASA Global Landslide Catalog Points (Shapefile)
Shapefile

The NASA Cooperative Open Online Landslide Repository (COOLR) points, downloadable as a .shp file.

NASA Global Landslide Catalog Polygons (CSV)
CSV

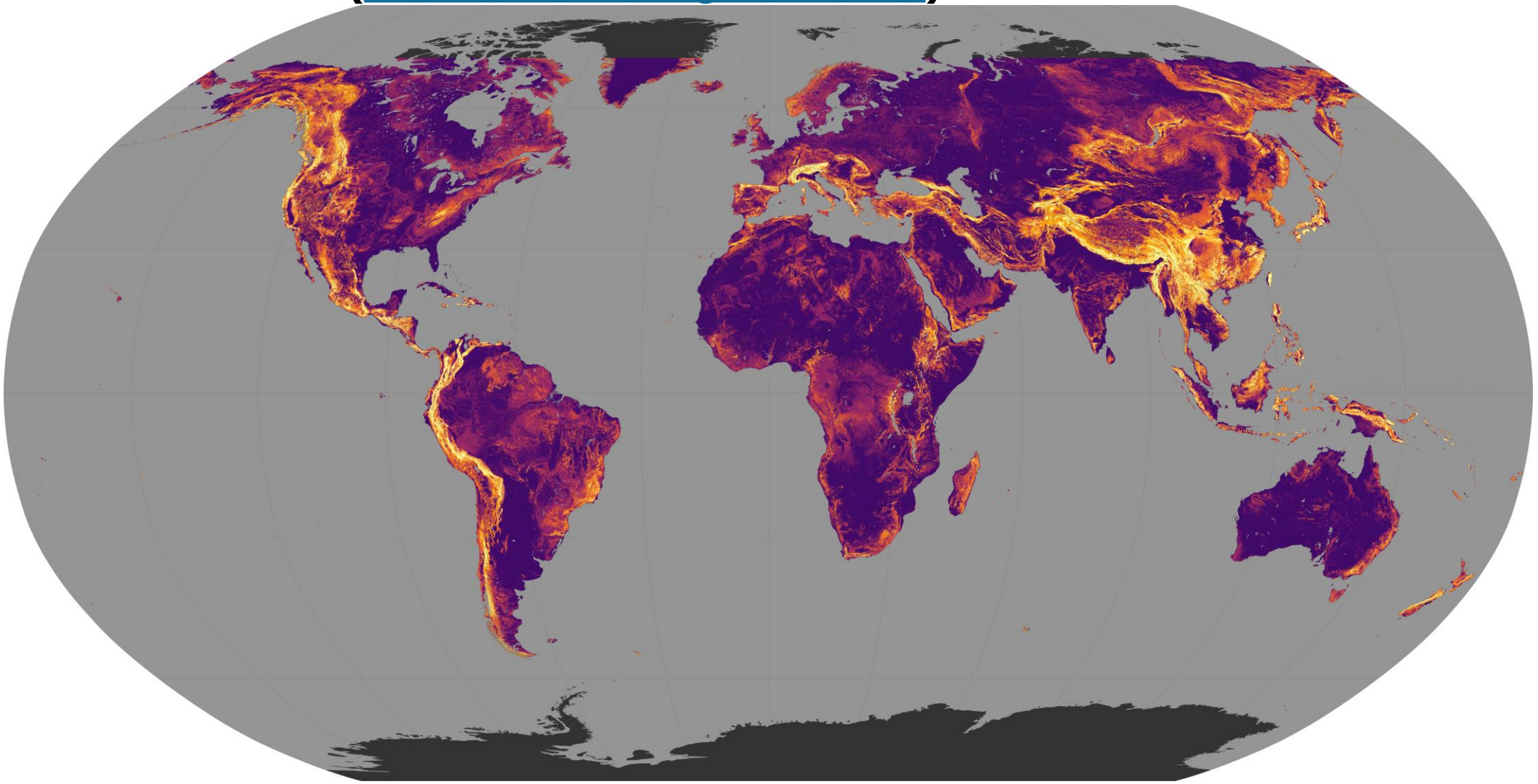
The NASA Cooperative Open Online Landslide Repository (COOLR) polygons, downloadable as a .csv file.

NASA Global Landslide Catalog Polygons (Shapefile)
Shapefile

The NASA Cooperative Open Online Landslide Repository (COOLR) polygons, downloadable as a .shp file.

Global Landslide Susceptibility Map

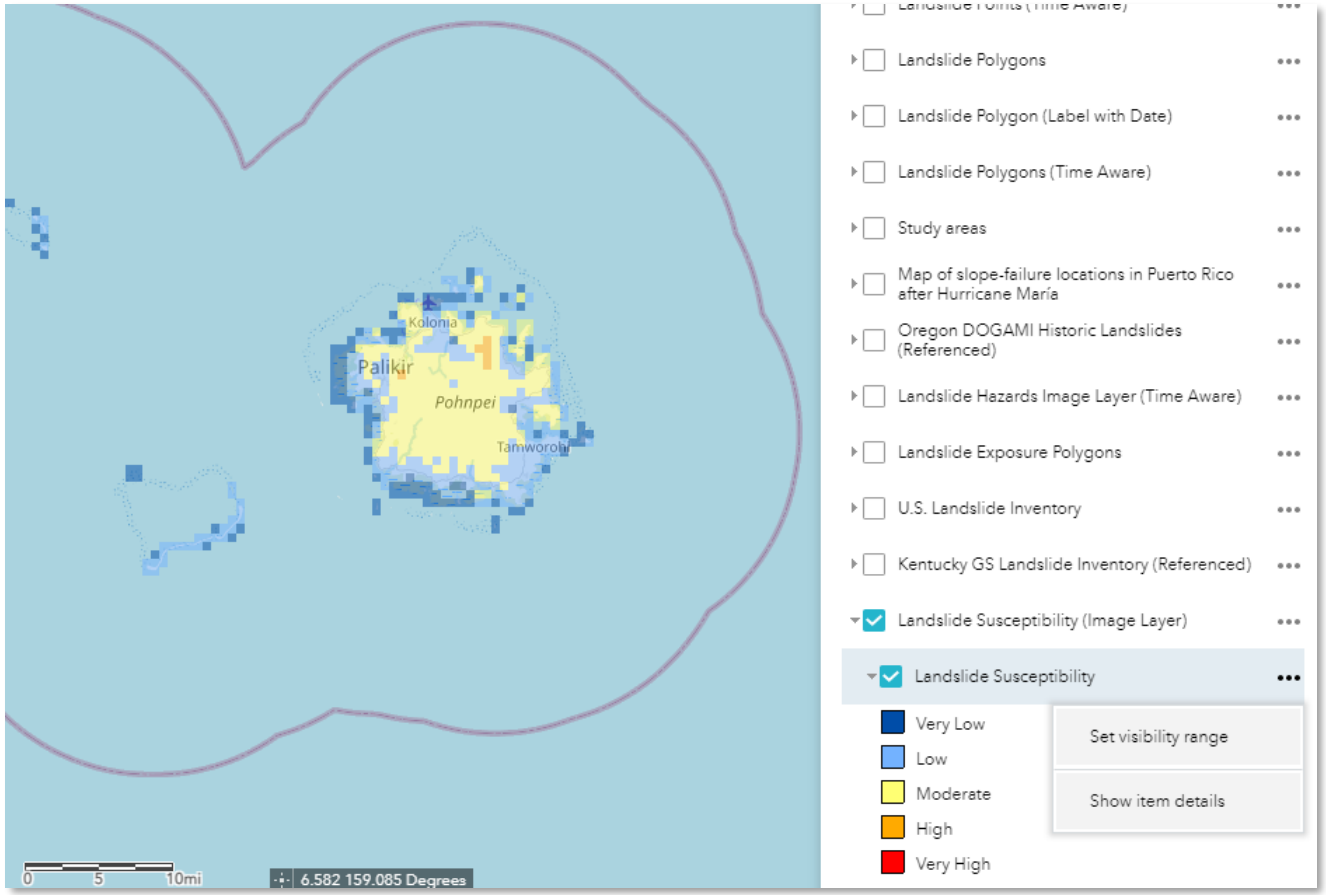
At Landslide Viewer (landslides.nasa.gov/viewer)

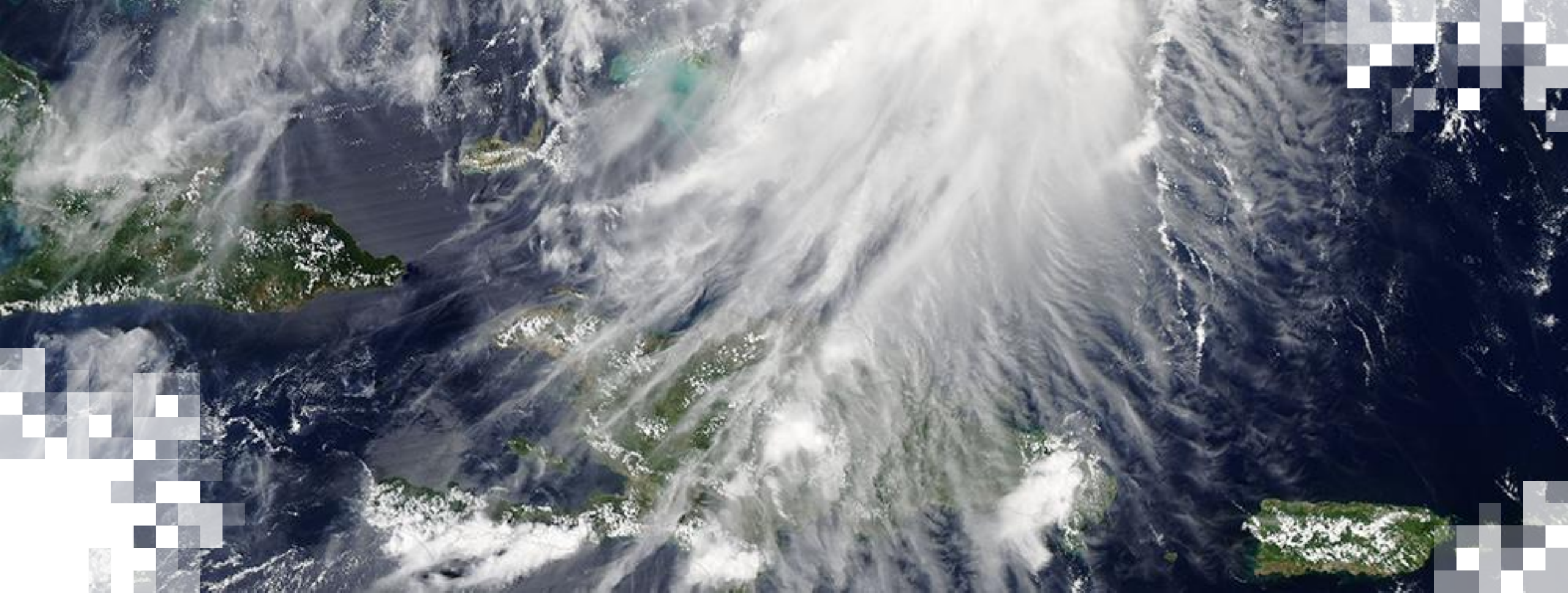


http://dx.doi.org/10.1007/s11069-017-2757-y

Global Landslide Susceptibility Map

At Landslide Viewer (landslides.nasa.gov/viewer)

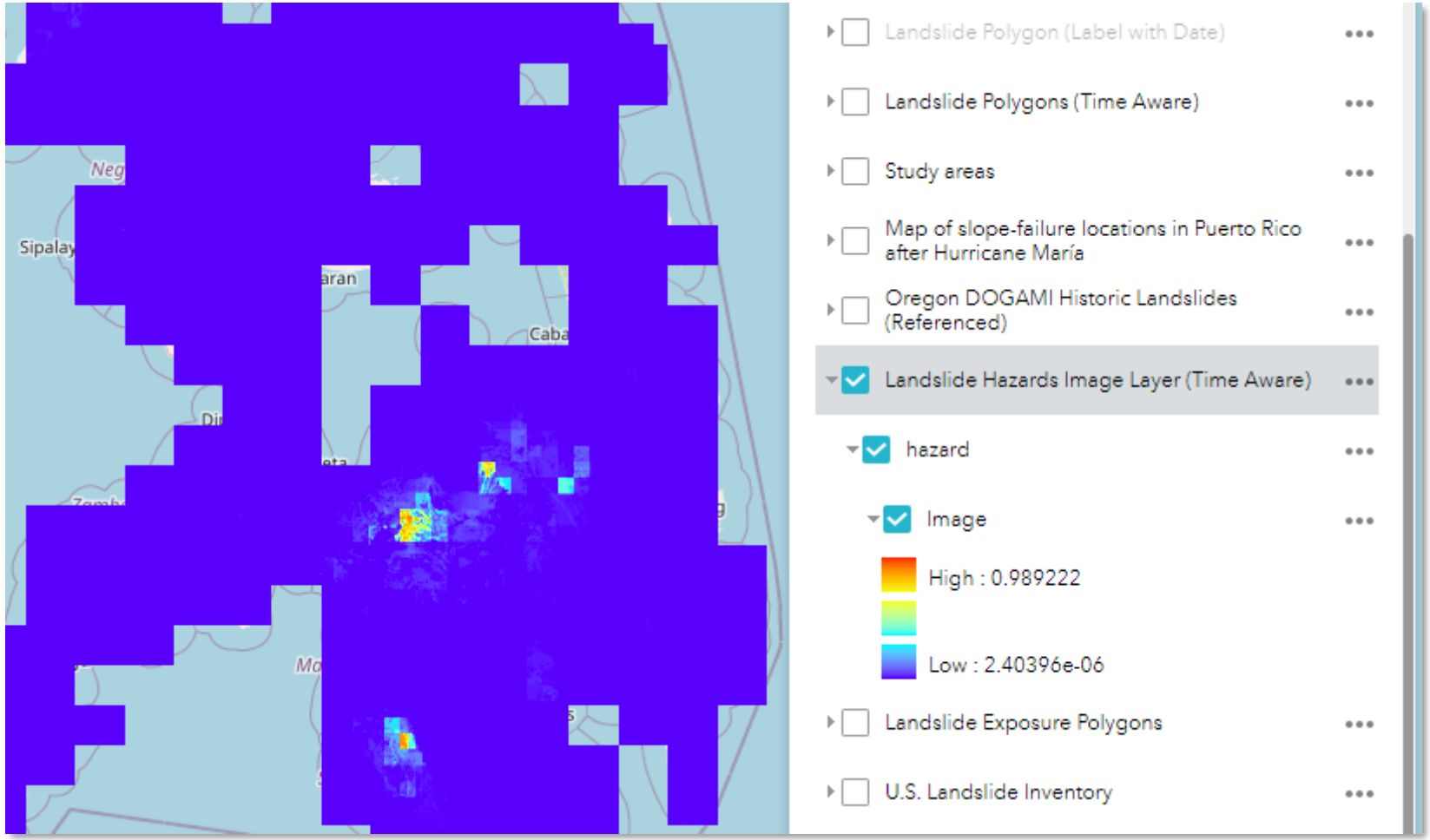




Some Resources for Assessing Landslide Hazard During an Event

Global Landslide Nowcast

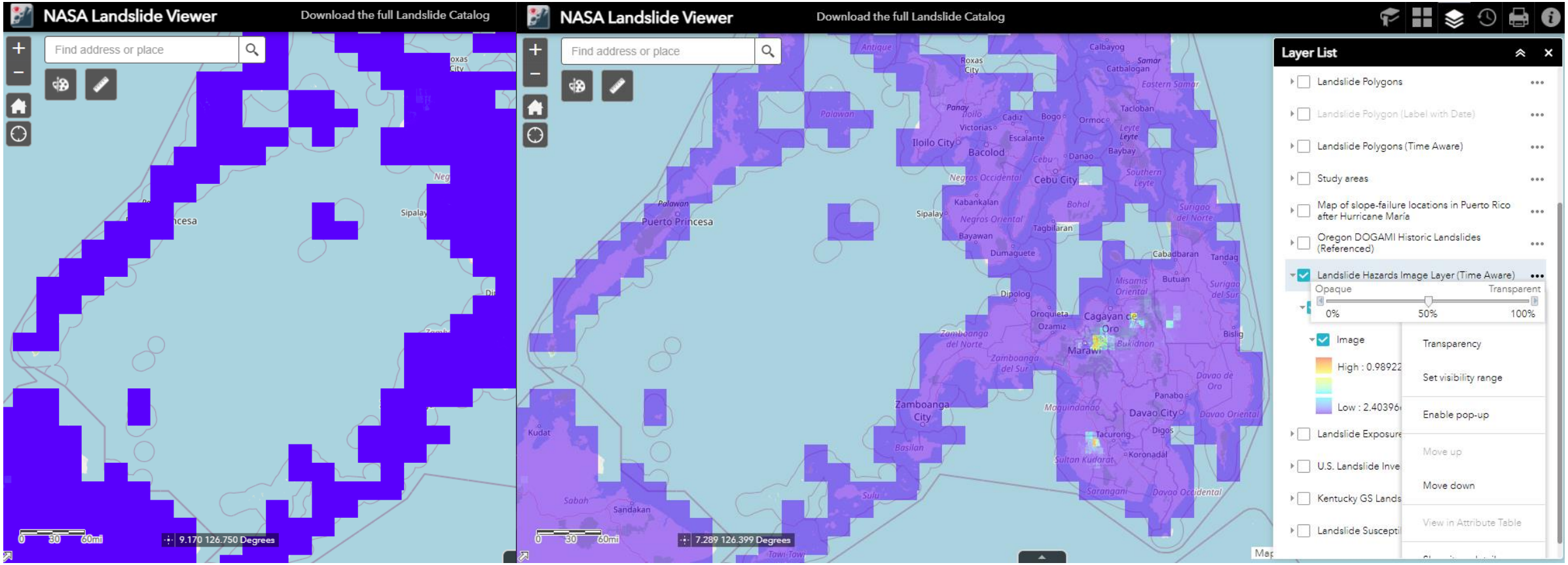
At Landslide Viewer (landslides.nasa.gov/viewer)



https://doi.org/10.3389/feart.2021.640043

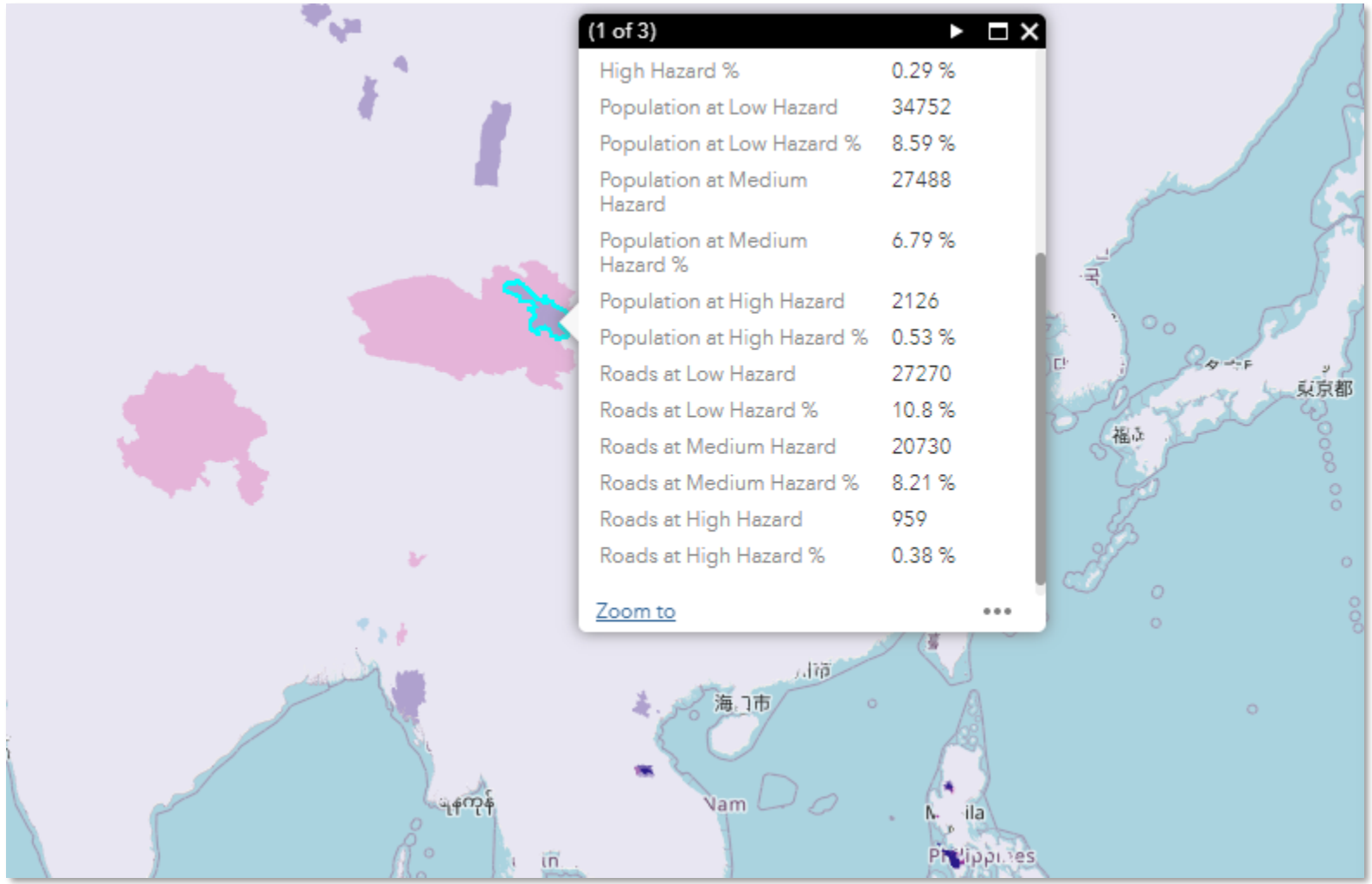
Global Landslide Nowcast

At Landslide Viewer (landslides.nasa.gov/viewer)



Exposed Population and Roads from the Global Landslide Nowcast

At Landslide Viewer (landslides.nasa.gov/viewer)



Exposed Population and Roc
Global Landslide Nowcast

At Landslide Viewer (landslides.na

maps.nccs.nasa.gov/download/landslides/nowcast/exposure/

Index of /download/landslides/nowcas

Name	Last modified	Size	Description
Parent Directory		-	
admin2.zip	26-May-2021 10:06	325M	
csv/	23-Jul-2021 10:30	-	

maps.nccs.nasa.gov/download/landslides/nowcast/exposure/csv/

Index of /download/landslides/nowcast/exposure/csv

Name	Last modified	Size	Description
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2021-04-14_0000.csv	05-May-2021 13:31	4.4M	
2021-04-26_1900.csv	05-May-2021 13:31	4.4M	
2021-04-27_0900.csv	05-May-2021 13:31	4.4M	
2021-05-03_0900.csv	05-May-2021 13:31	4.5M	
2021-05-03_1500.csv	05-May-2021 13:47	4.5M	
2021-05-04_0900.csv	14-May-2021 11:27	4.5M	
2021-05-12_0900.csv	14-May-2021 11:27	4.4M	
2021-05-12_1500.csv	14-May-2021 11:27	4.4M	
2021-05-13_1500.csv	14-May-2021 16:31	4.4M	
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2021-05-14_0300.csv	15-May-2021 04:30	4.4M	
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2021-05-14_2100.csv	15-May-2021 22:30	4.4M	
2021-05-15_0300.csv	16-May-2021 04:30	4.4M	
2021-05-15_0900.csv	16-May-2021 10:30	4.4M	
2021-05-15_1500.csv	16-May-2021 16:30	4.4M	
2021-05-15_2100.csv	16-May-2021 22:30	4.5M	
2021-05-16_0300.csv	17-May-2021 04:30	4.5M	
2021-05-16_0900.csv	17-May-2021 10:30	4.5M	

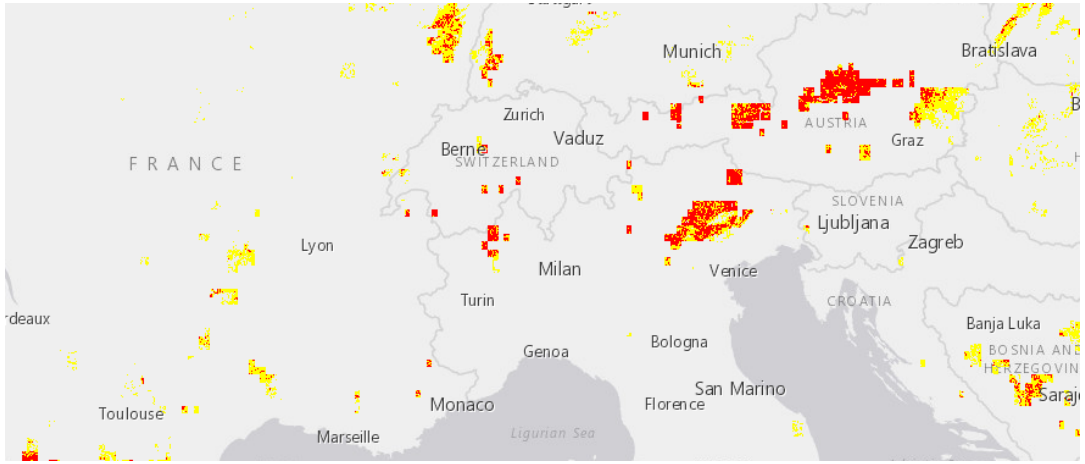
New Features in the Global Landslide Nowcast (LHASA 2.0)

- Probabilistic, rather than categorical outputs
  - Due to the use of machine learning
  - Incorporates soil moisture and snow mass
- Increased accuracy
- Exposure analysis

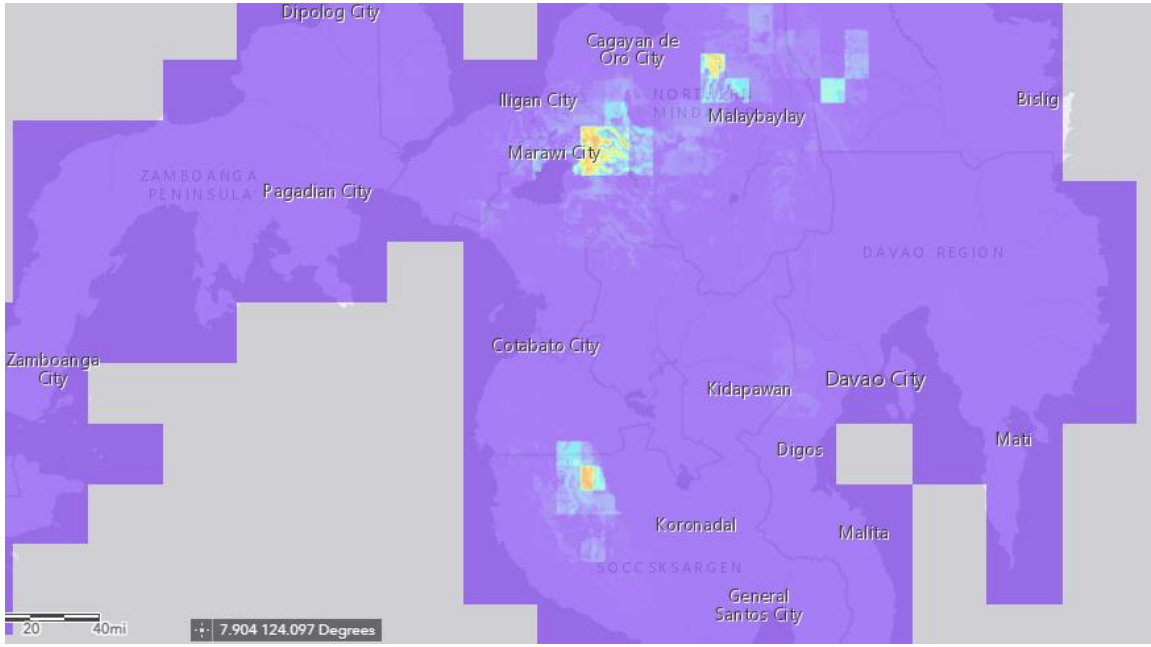
- However, version 1.1 is still published at https://pmmpublisher.pps.eosdis.nasa.gov/ and https://gpm.nasa.gov/data/visualizations/precip-apps.
- Both sites allow you to view the "classic" model output:

The Landslide Hazard Assessment for Situational Awareness (LHASA) Model

Version 1.1

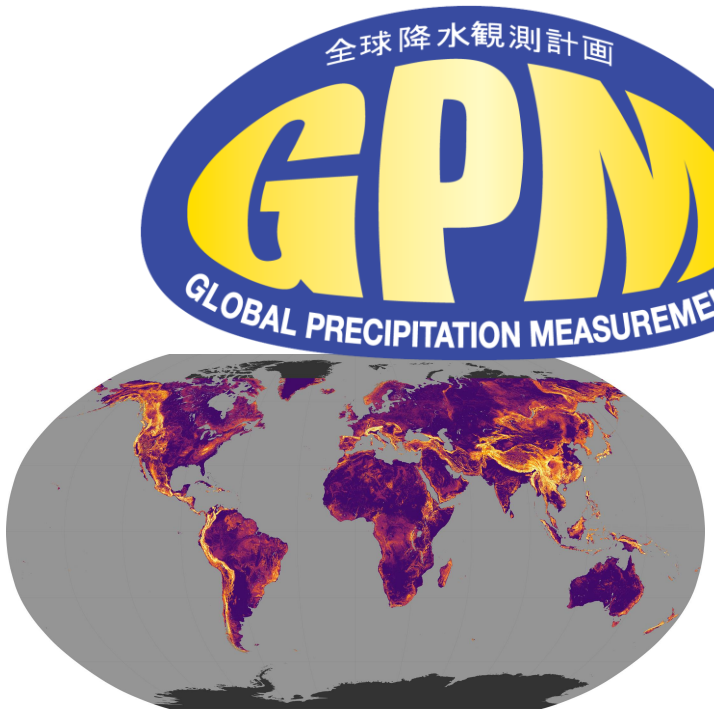


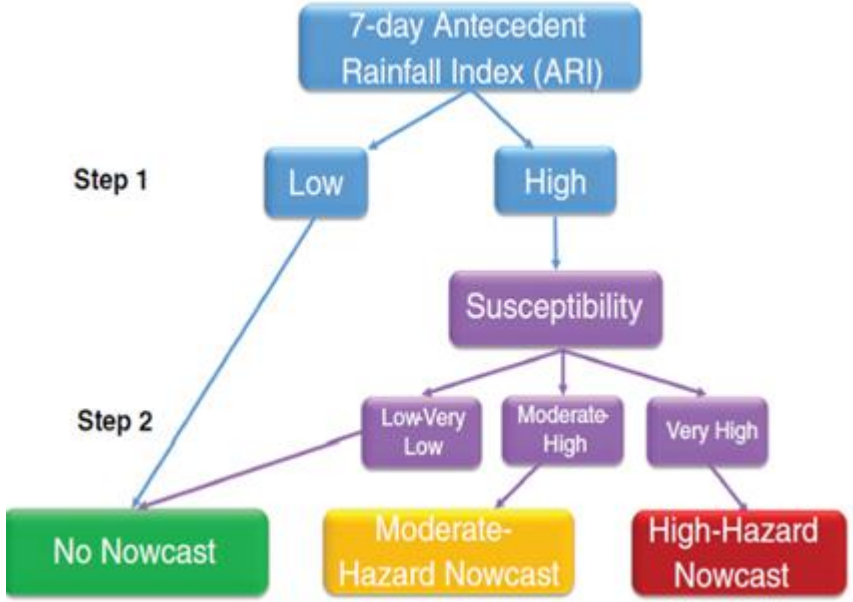
Version 2.0

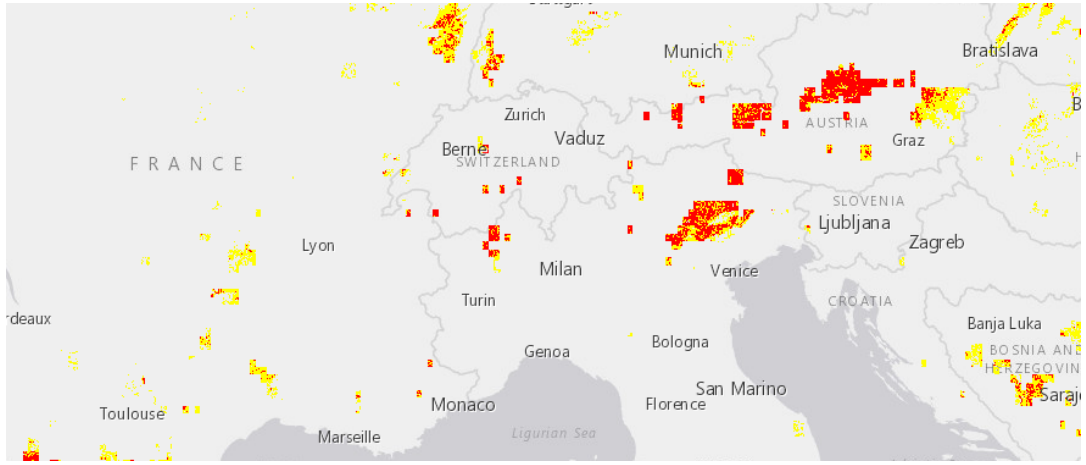


The Landslide Hazard Assessment for Situational Awareness (LHASA) Model

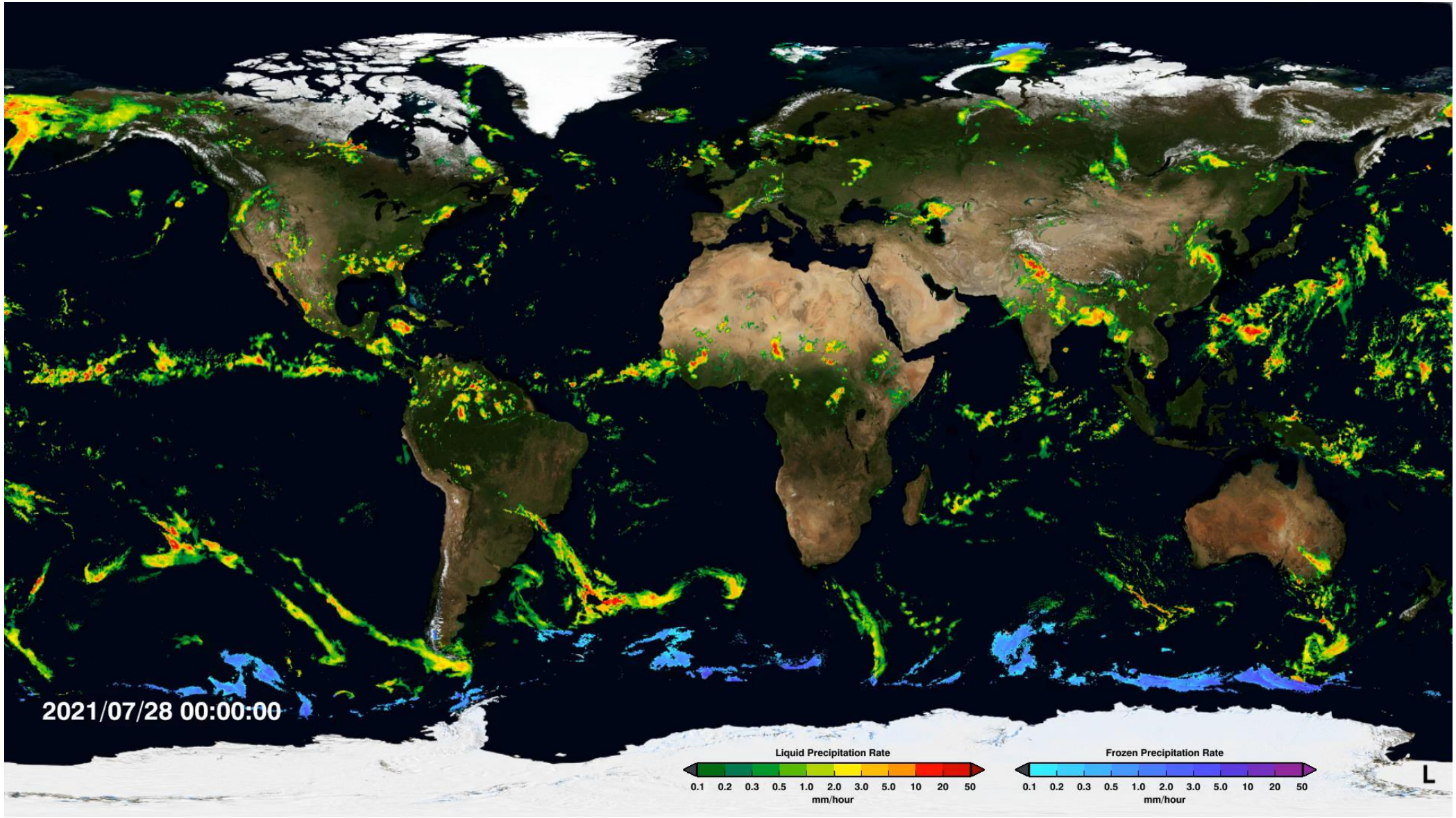
Version 1.1





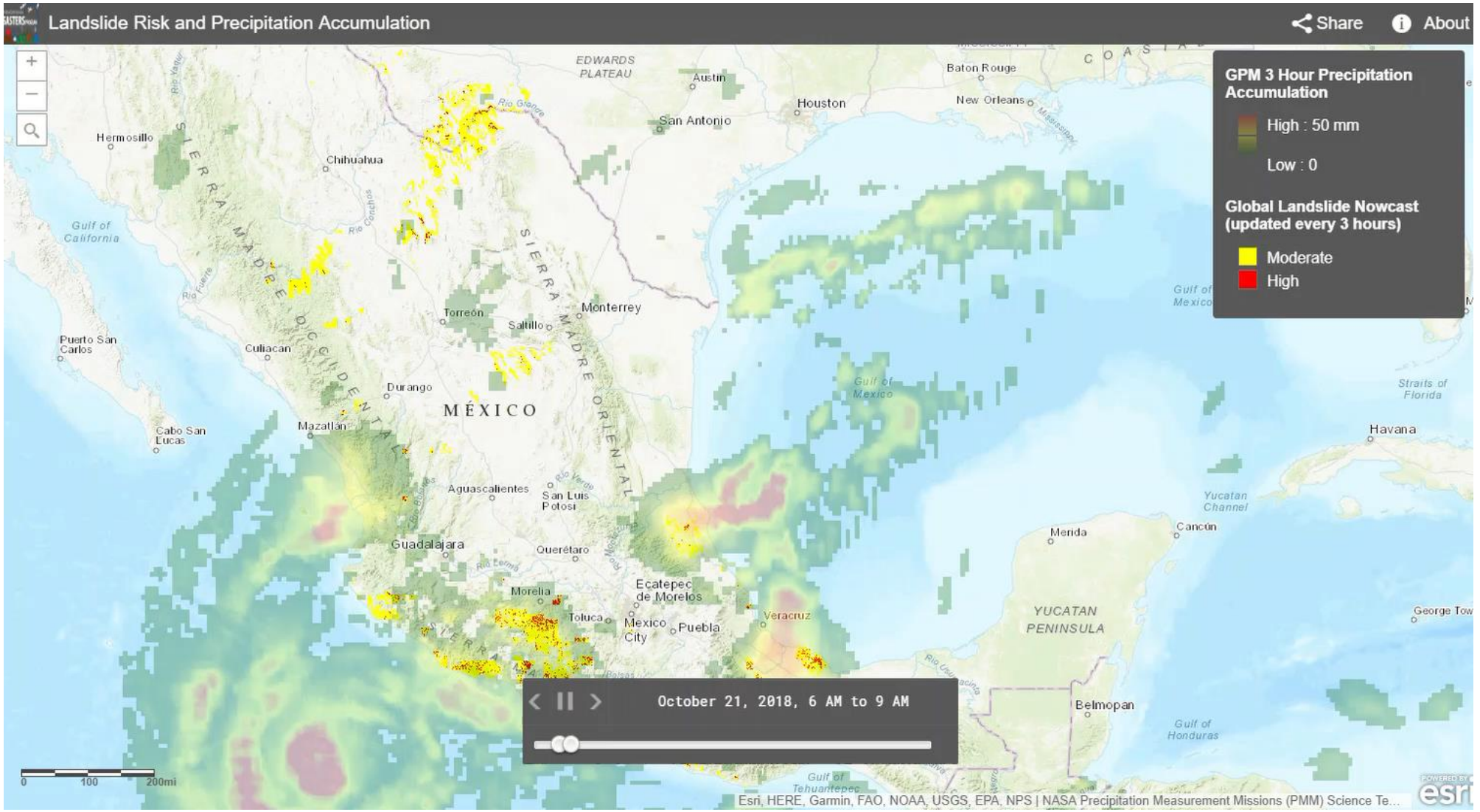


IMERG: Integrated Multi-satellitE Retrievals for GPM



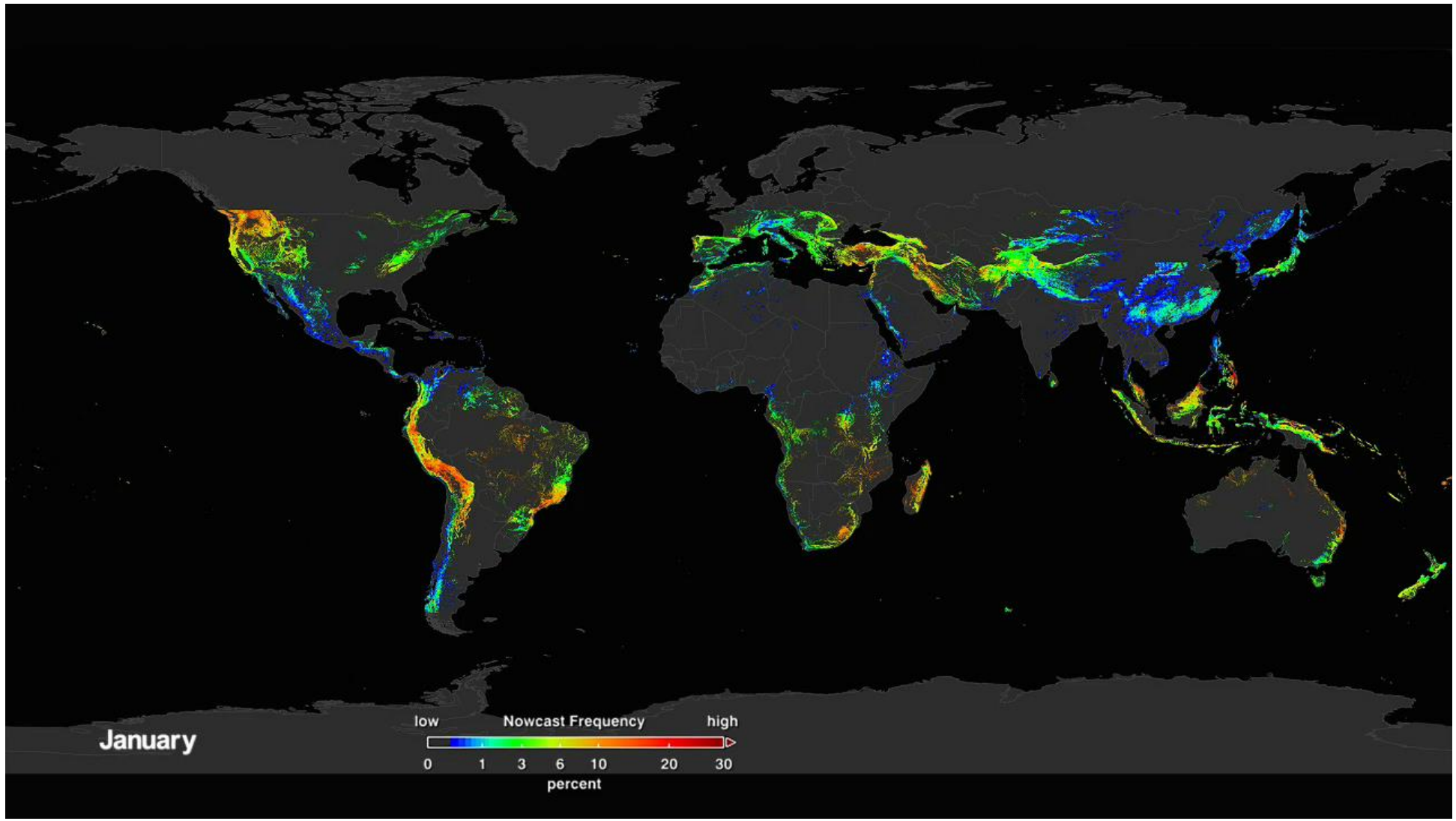
LHASA Output for Hurricane Willa, 2018

Version 1.1



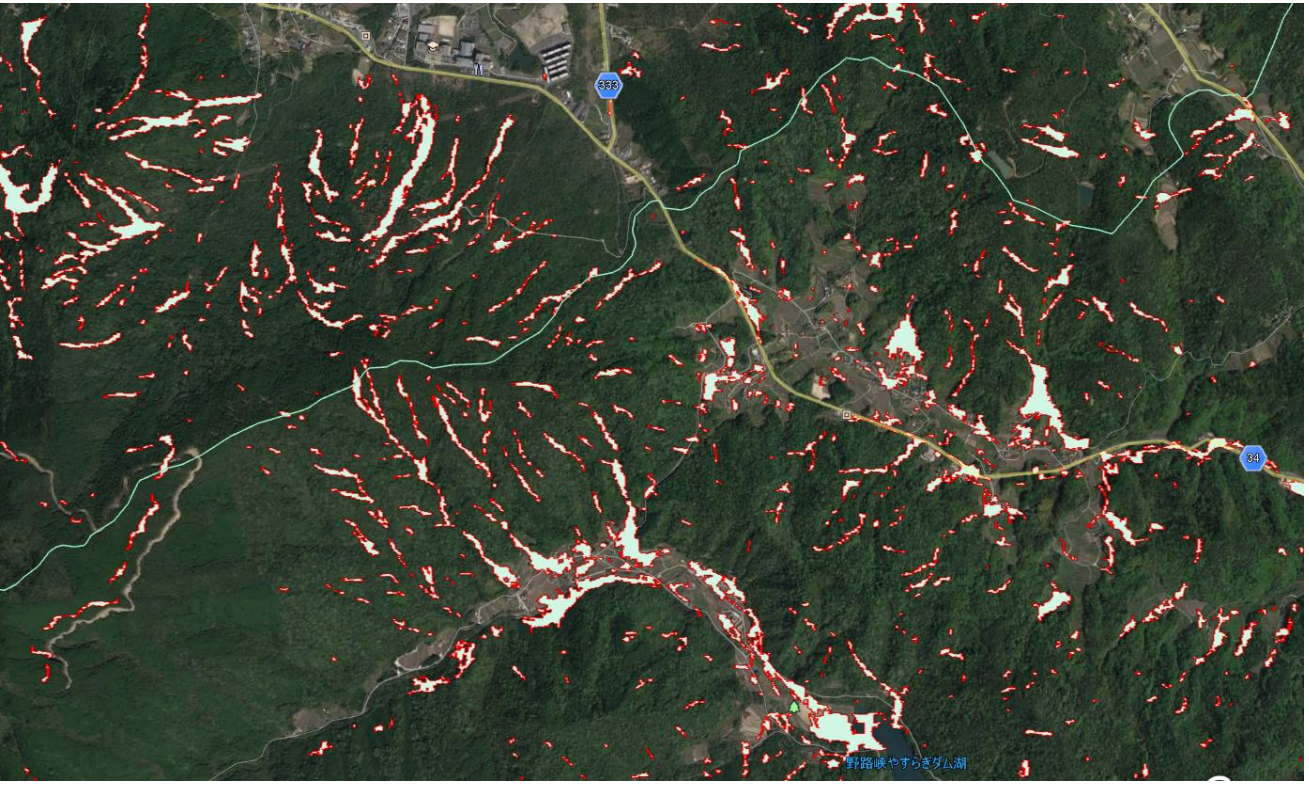
The Landslide Hazard Assessment for Situational Awareness (LHASA) Model

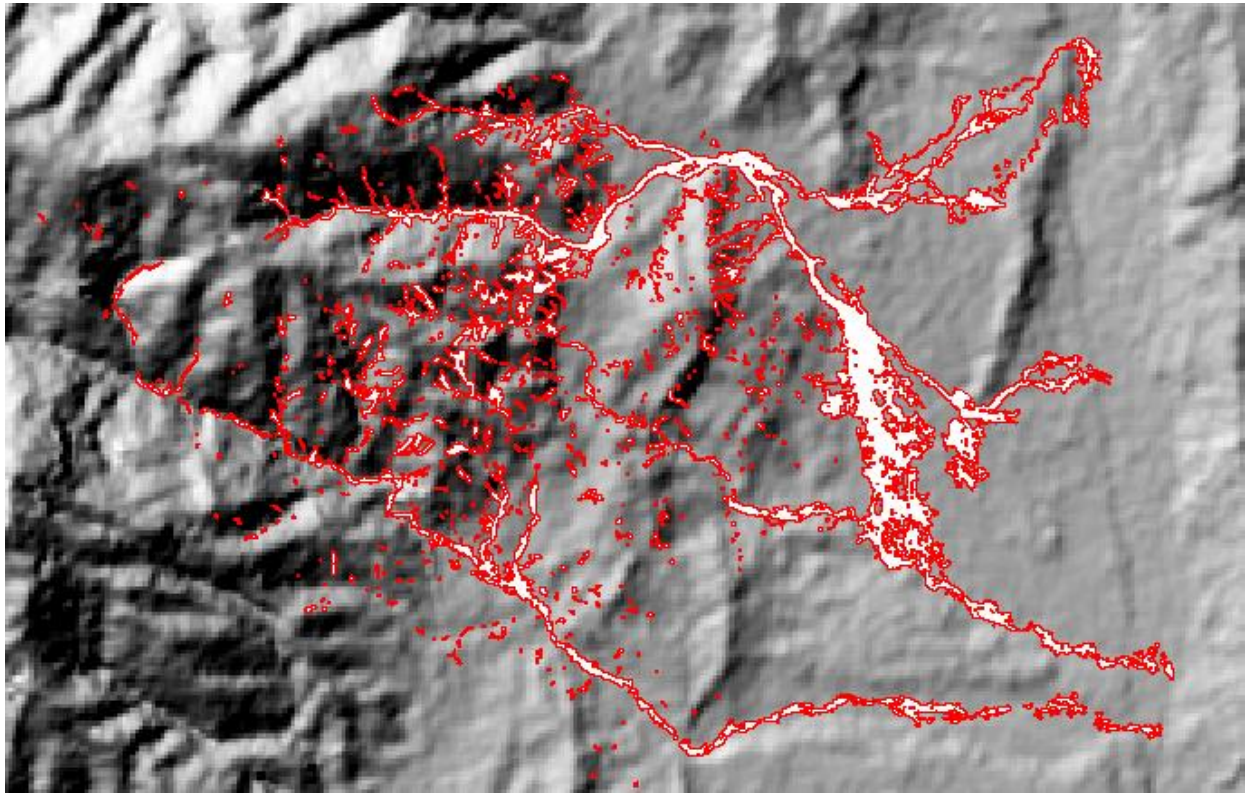
Version 1.1



The Landslide Hazard Assessment for Situational Awareness (LHASA) Model

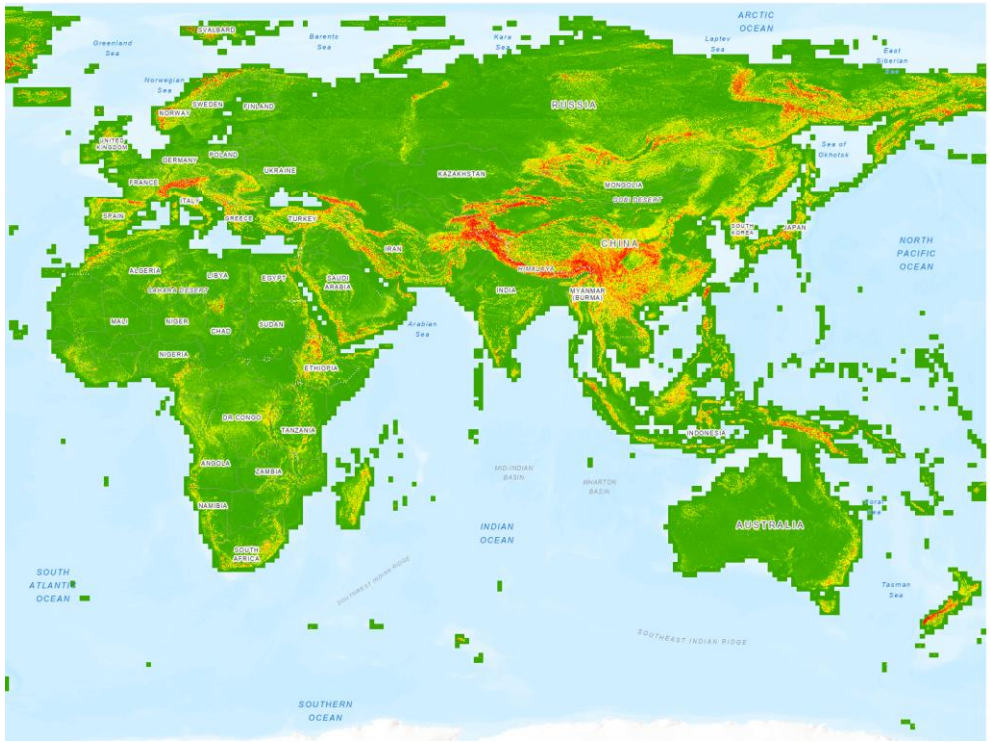
Version 2.0





The Landslide Hazard Assessment for Situational Awareness (LHASA) Model

Version 2.0

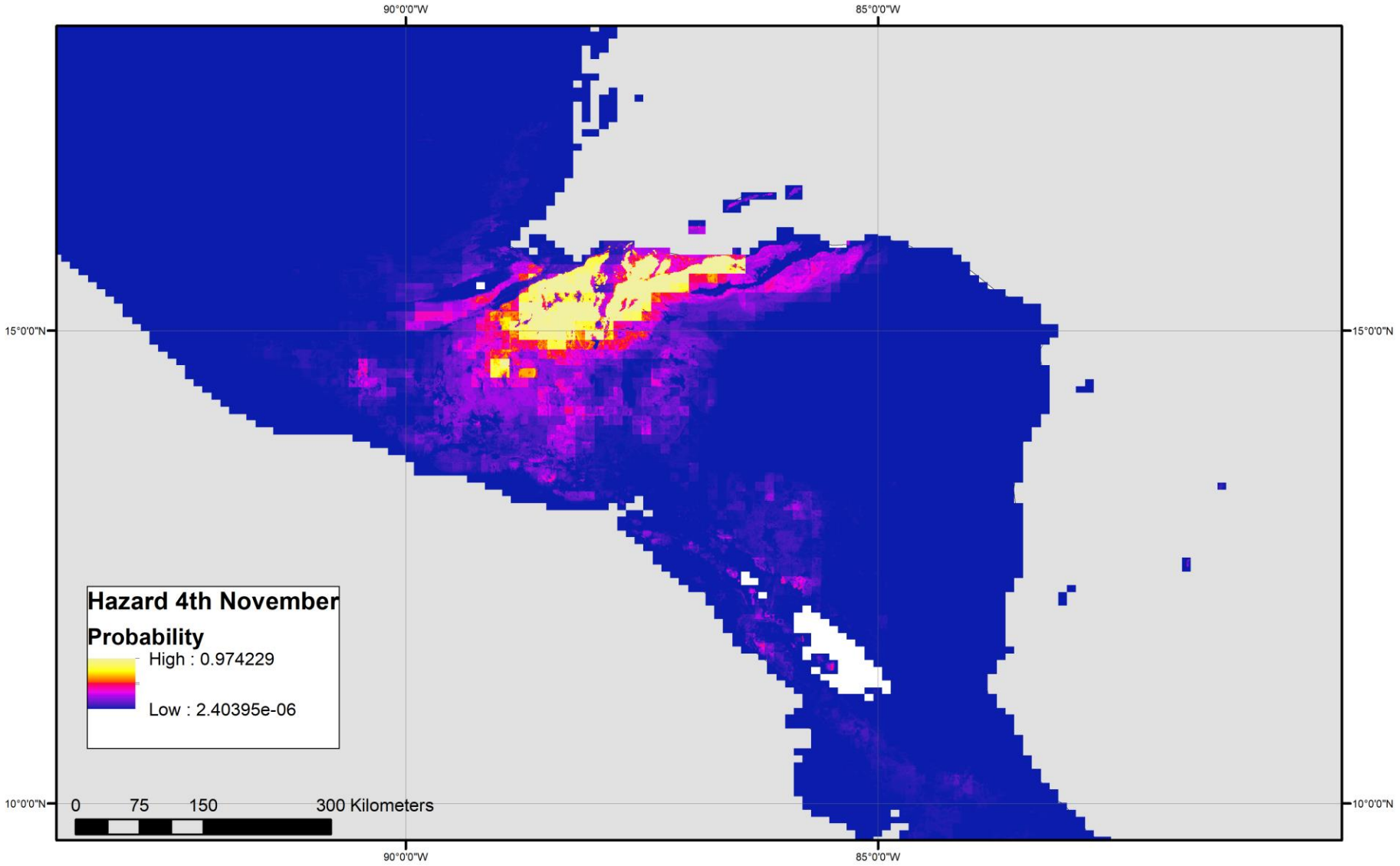


Slope Gradient

Distance to Fault

The Landslide Hazard Assessment for Situational Awareness (LHASA) Model

Version 2.0



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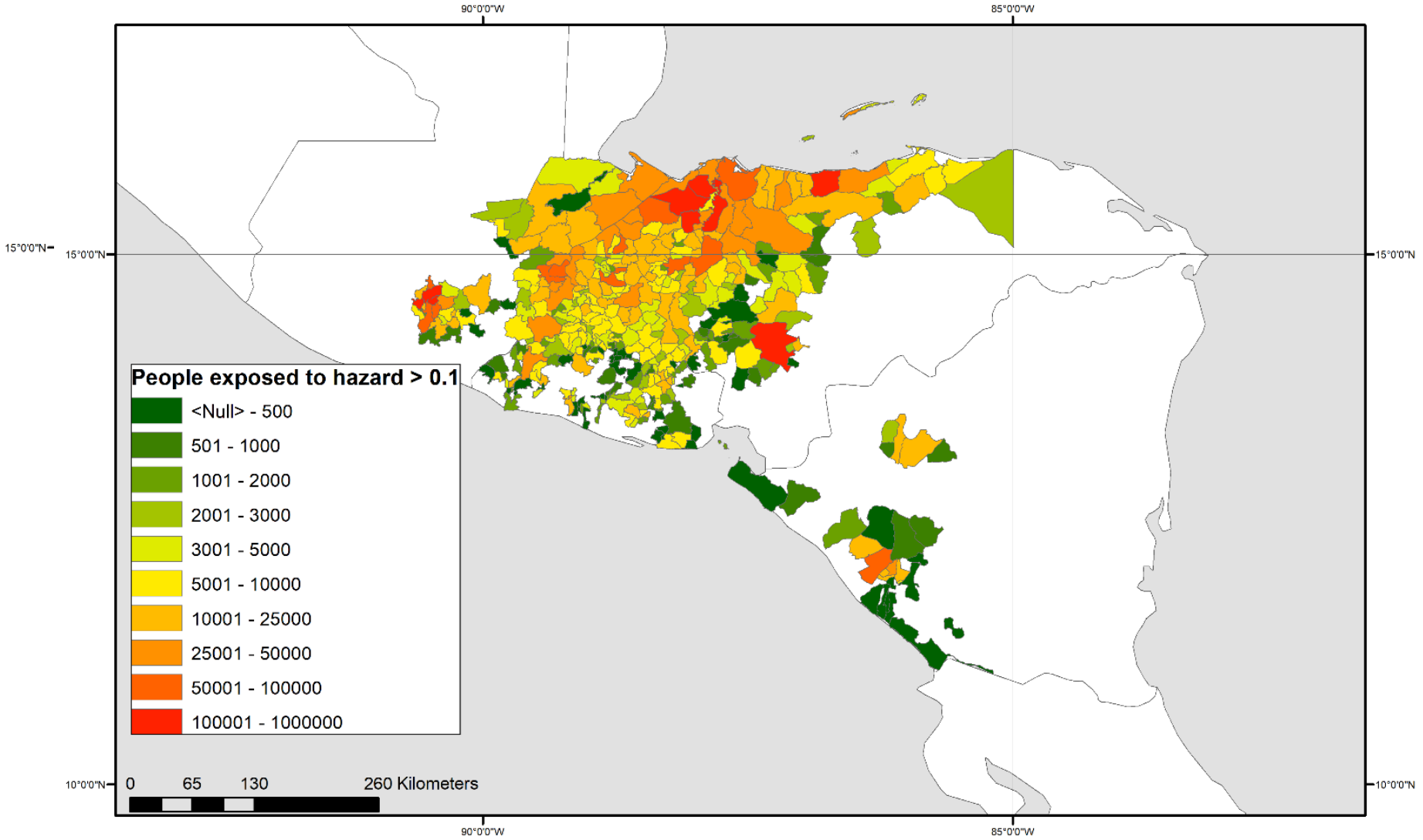
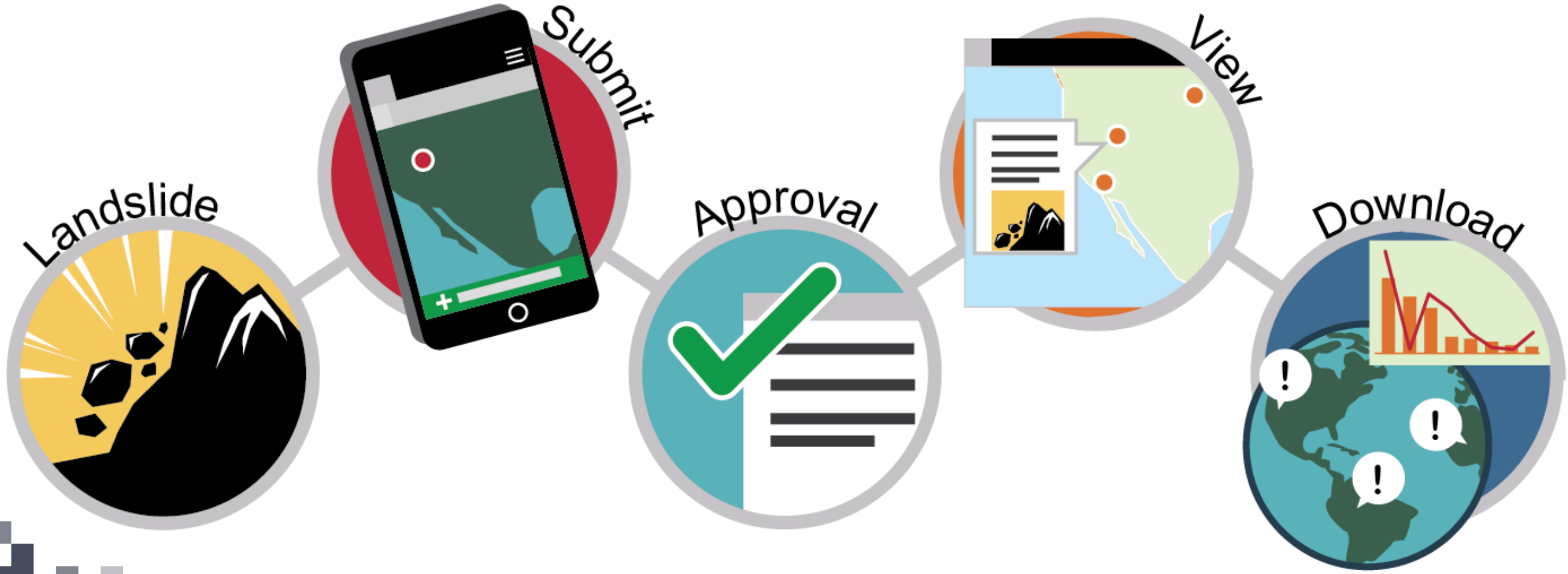
Version 2.0



Reporting Landslides During or After an Event

At Landslide Reporter (landslides.nasa.gov/reporter)



Why report landslides?

At Landslide Reporter (landslides.nasa.gov/reporter)

Benefits to Science:

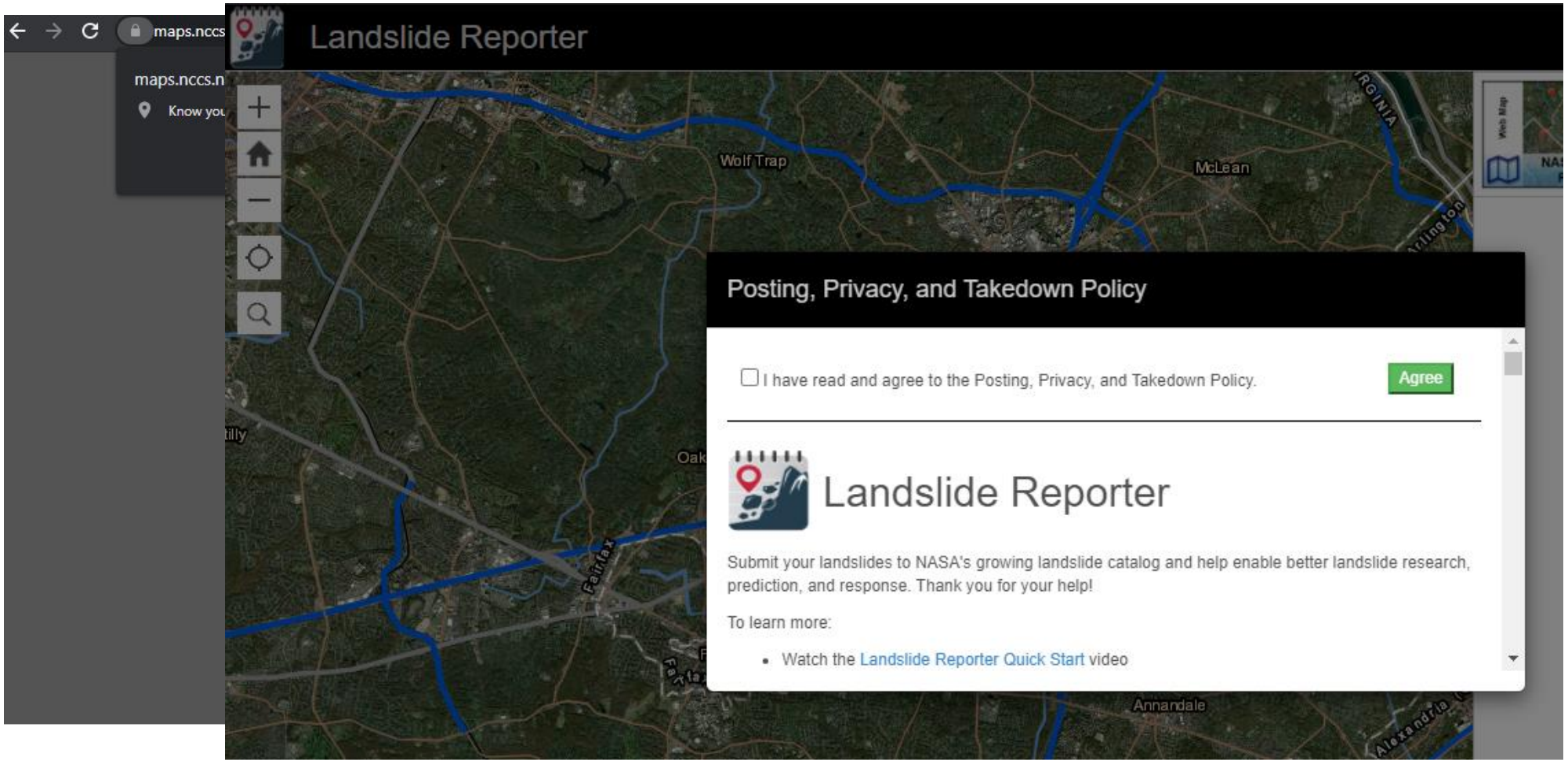
- We use this data to evaluate the nowcast and other models.
- Helps to quantify the impacts of landslides, which are currently underreported
- Fills in the gaps in our knowledge due to reporting biases in other landslide inventories like the GLC
  - This might lead to a fairer distribution of research and mitigation efforts to the locations that need it the most.

Benefits to Your Community:

- Brings global attention to your work on disaster risk reduction
- Can be a tool for educating citizens on landslide hazard
- Helps improve the accuracy of landslide models in your area
- Encourages data sharing by other stakeholders
- May provide the rationale for future funding requests
- You don't have build your own app to do the same thing!

Reporting Landslides During or After an Event

At Landslide Reporter (landslides.nasa.gov/reporter)



Reporting Landslides During or After an Event

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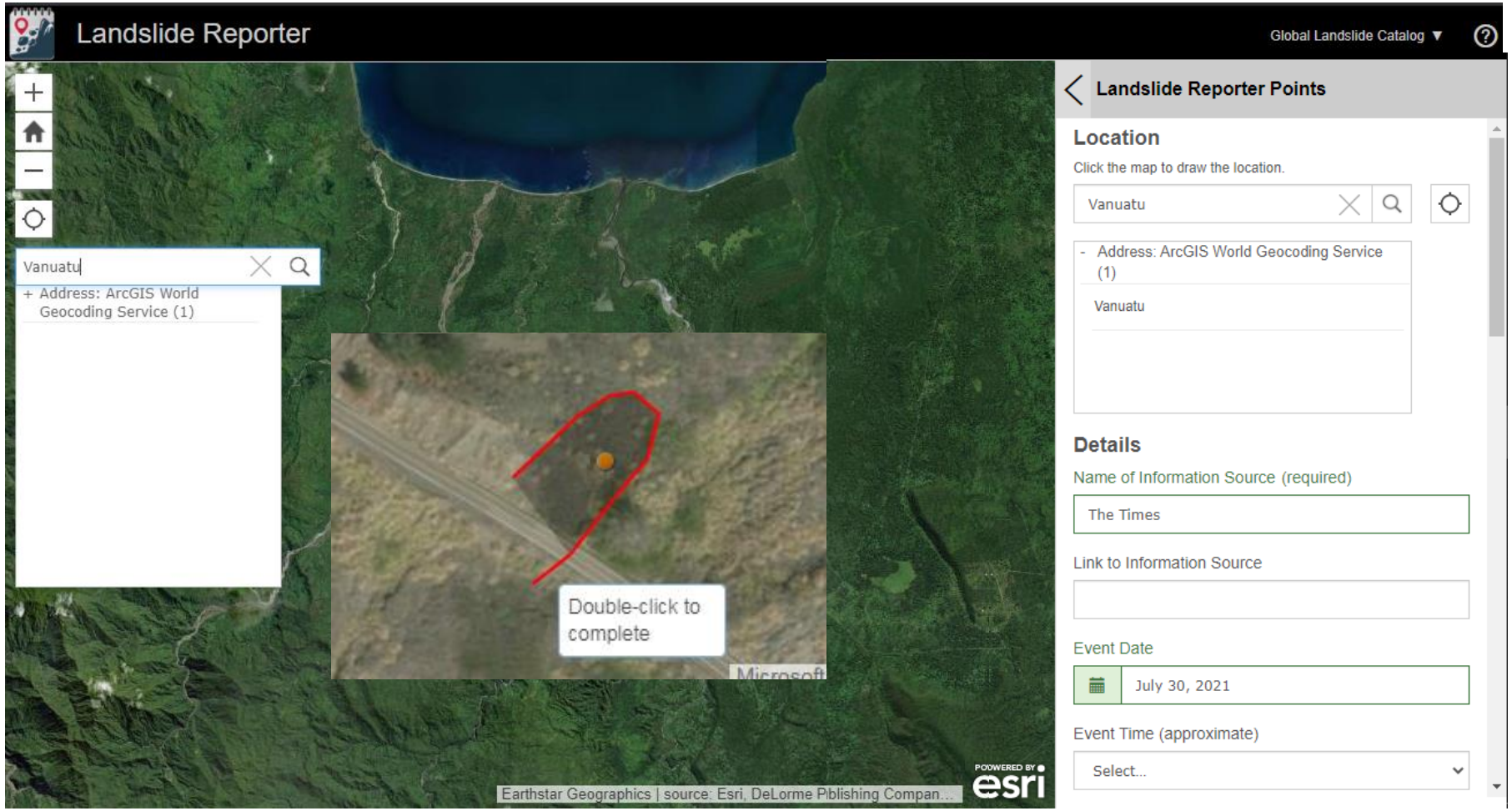
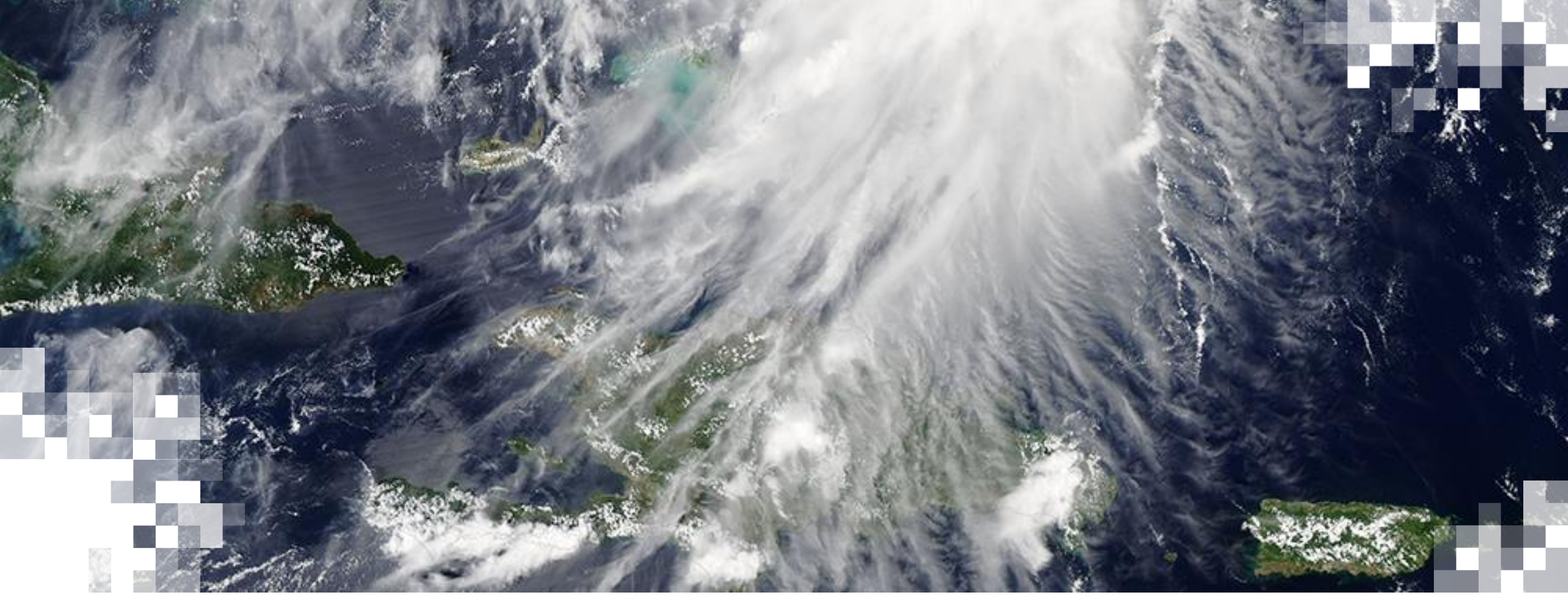


Learning More about Landslide Reporter

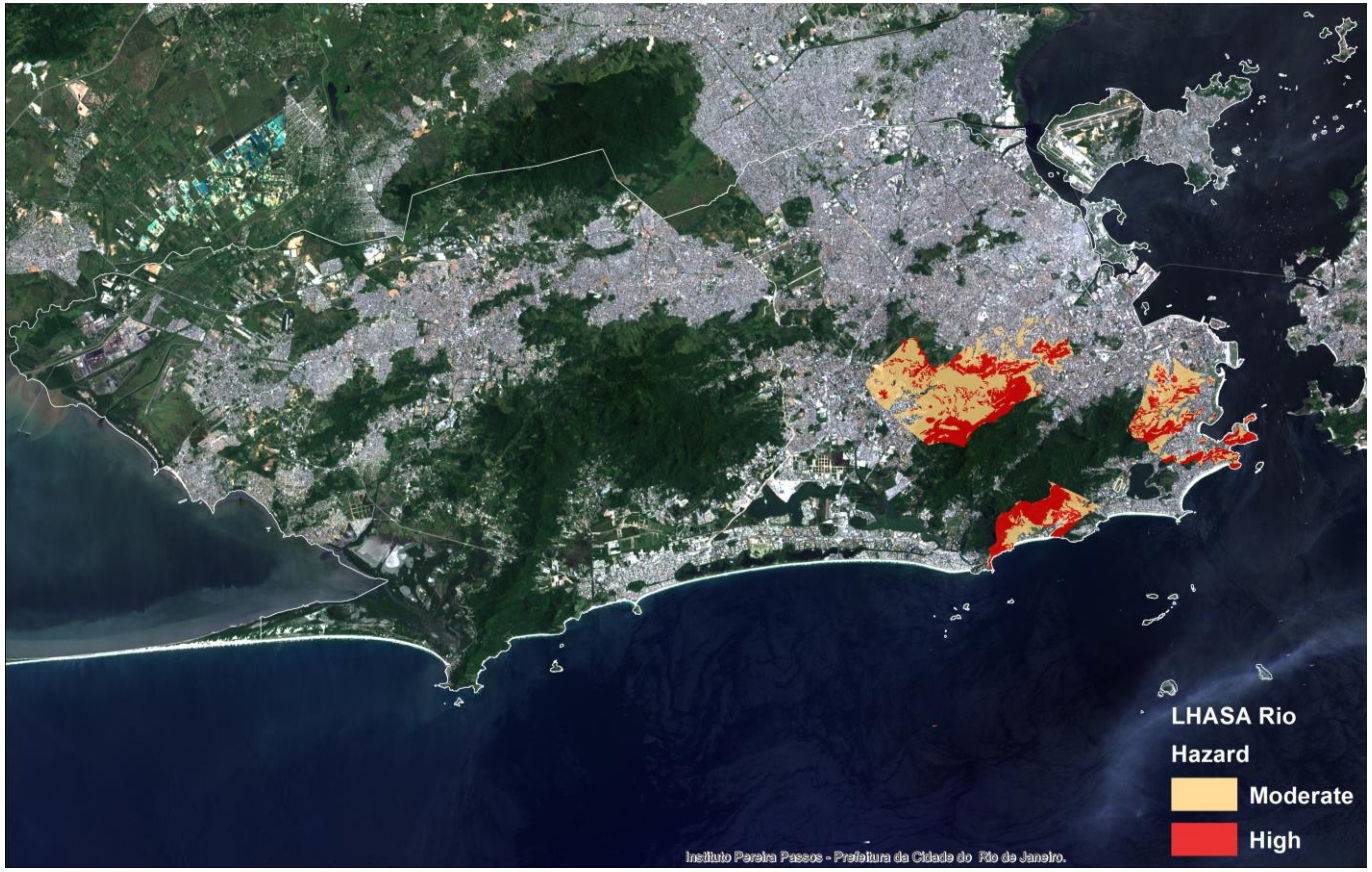
At landslides.nasa.gov

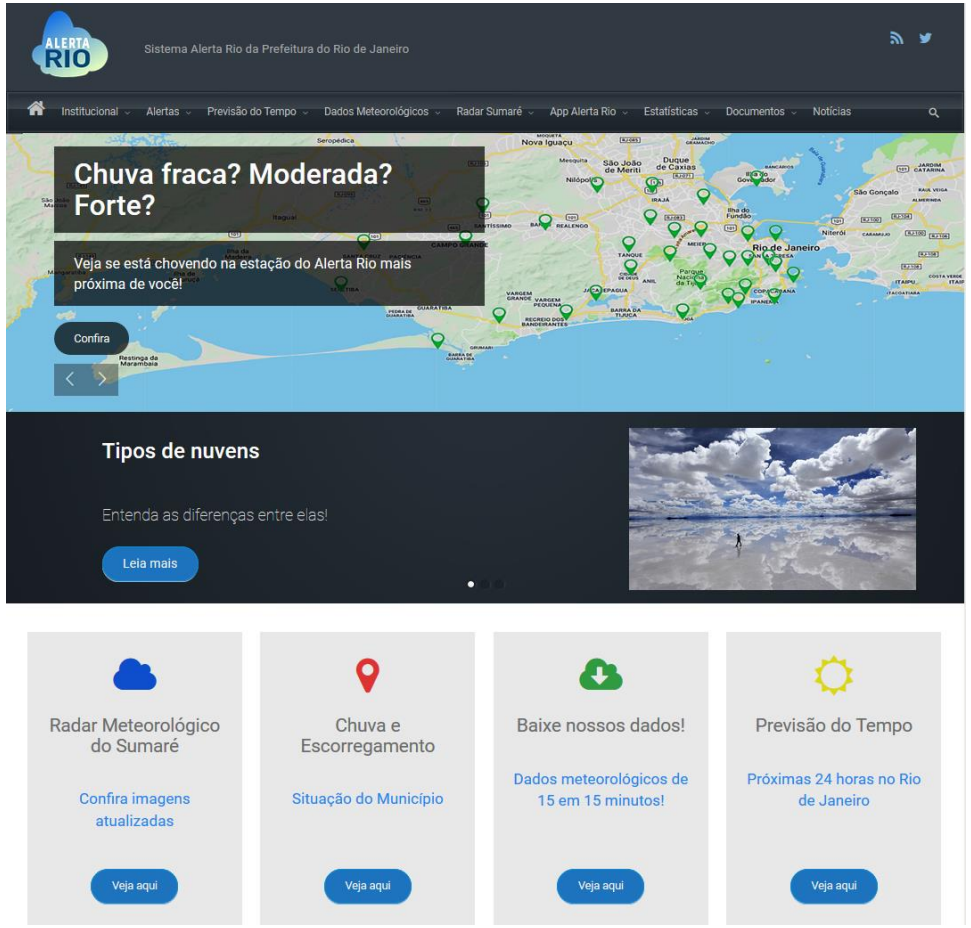


Rio de Janeiro Case Study

LHASA-Rio 1.0

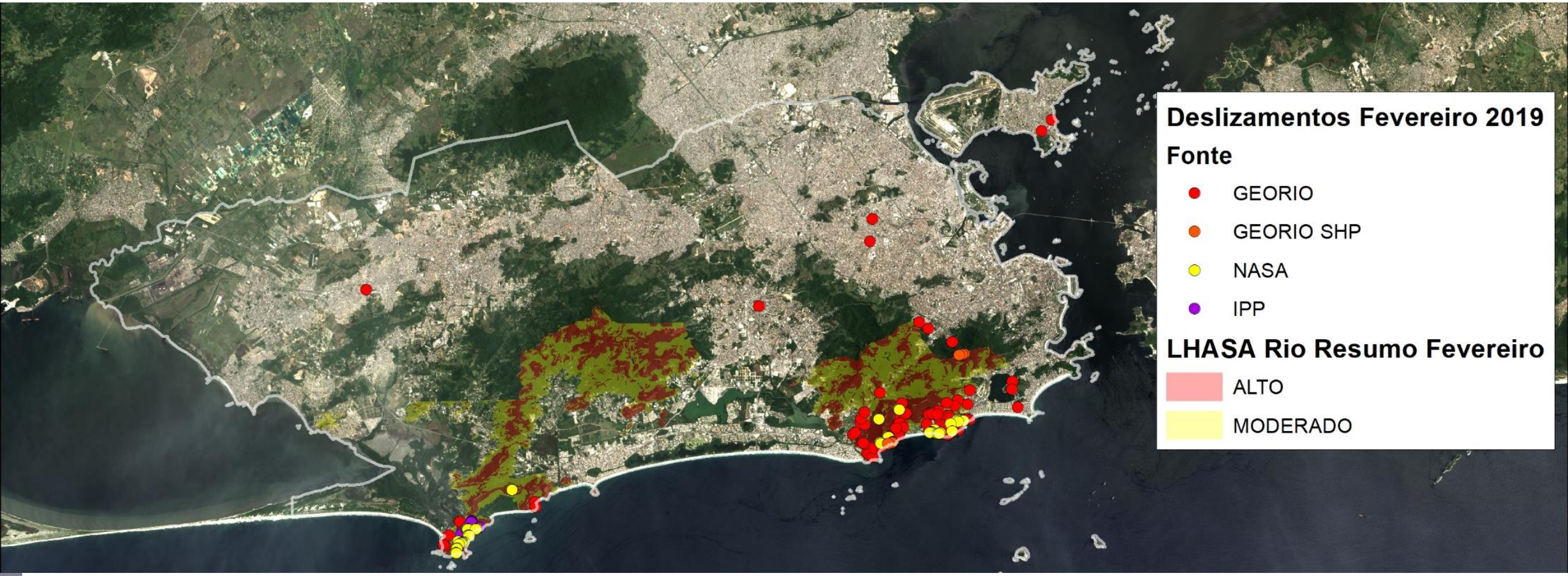
LHASA-Rio 1.0


LHASA Rio
Hazard
Moderate
High
Instituto Pereira Passos - Prefeitura da Cidade do Rio de Janeiro.

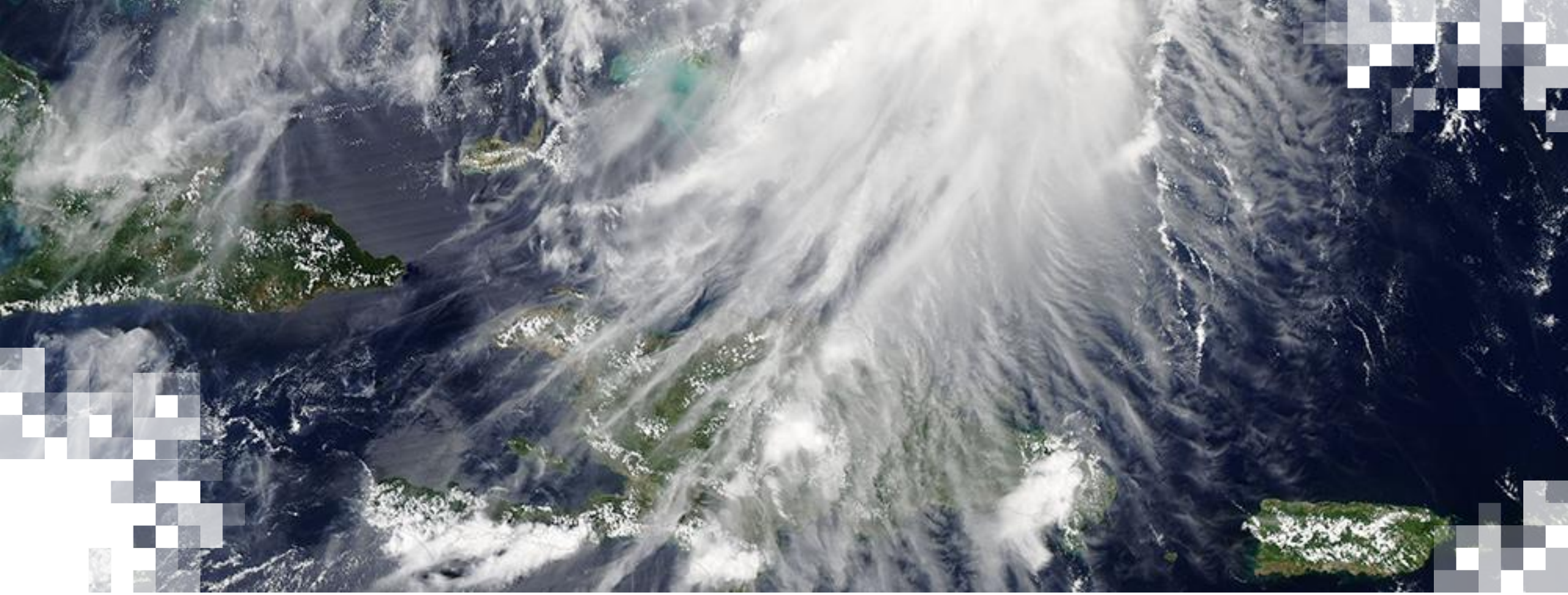

Sistema Alerta Rio da Prefeitura do Rio de Janeiro
Institucional
Alertas
Previsão do Tempo
Dados Meteorológicos
Radar Sumaré
App Alerta Rio
Estatísticas
Documentos
Notícias
Chuva fraca? Moderada? Forte?
Veja se está chovendo na estação do Alerta Rio mais próxima de você!
Confira
Tipos de nuvens
Entenda as diferenças entre elas!
Leia mais
Radar Meteorológico do Sumaré
Confira imagens atualizadas
Veja aqui
Chuva e Escorregamento
Situação do Município
Veja aqui
Baixe nossos dados!
Dados meteorológicos de 15 em 15 minutos!
Veja aqui
Previsão do Tempo
Próximas 24 horas no Rio de Janeiro
Veja aqui

LHASA-Rio 1.0

169 landslides mapped, 156 hazard areas detected by LHASA Rio (92.3% hit rate).



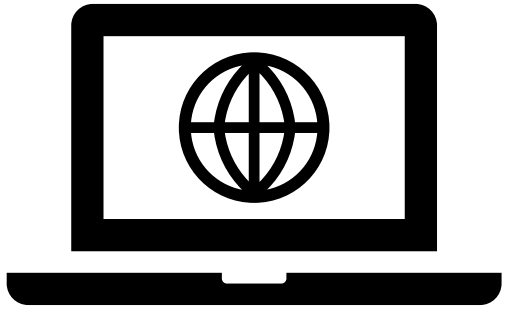
Data Sources: LHASA Rio, Geo-Rio, NASA e IPP (imagens de alta resolução)
Slide courtesy of Felipe C. Mandarino, Rio de Janeiro



Getting Started with LHASA Version 1.1

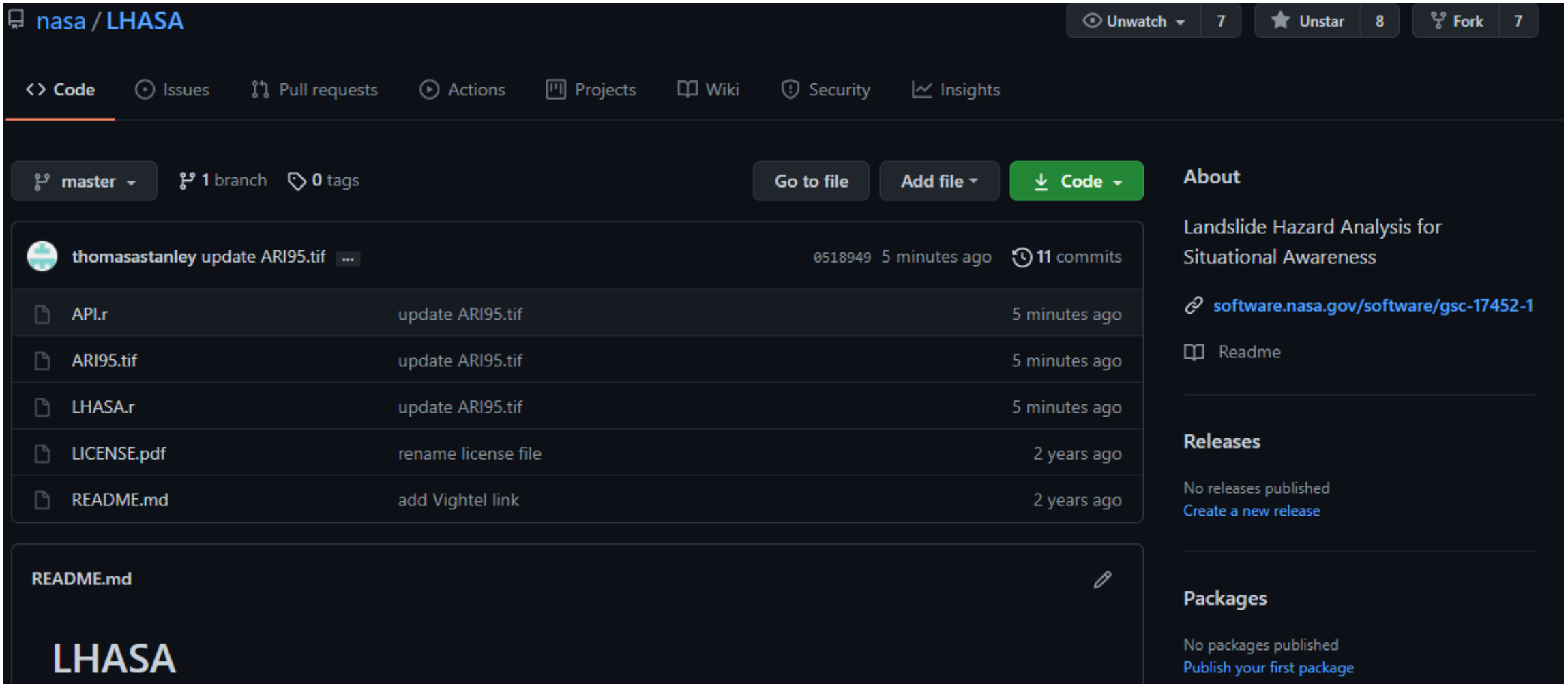
What You Need to Run LHASA Version 1.1

- A computer with the Windows operating system
  - (LHASA runs on other operating systems, but the appearance and key bindings are different from those shown here.)
- An internet connection
- R statistical software
  - Download at https://cloud.r-project.org/
  - (It's free of charge.)



Getting Started with LHASA Version 1.1

Step 1: Download the code from https://github.com/nasa/LHASA

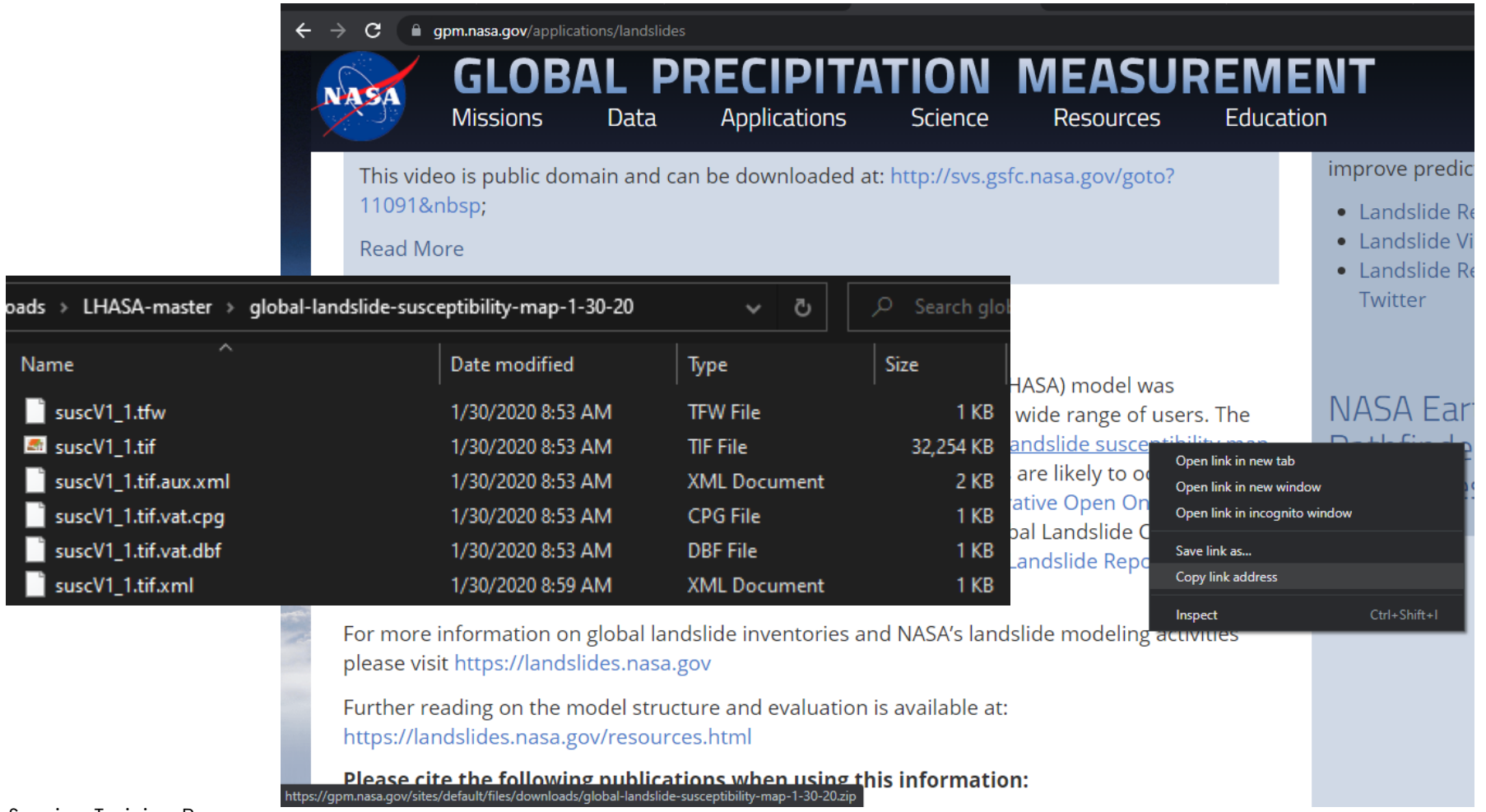


Getting Started with LHASA Version 1.1

Step 2: Download the global landslide susceptibility map from:

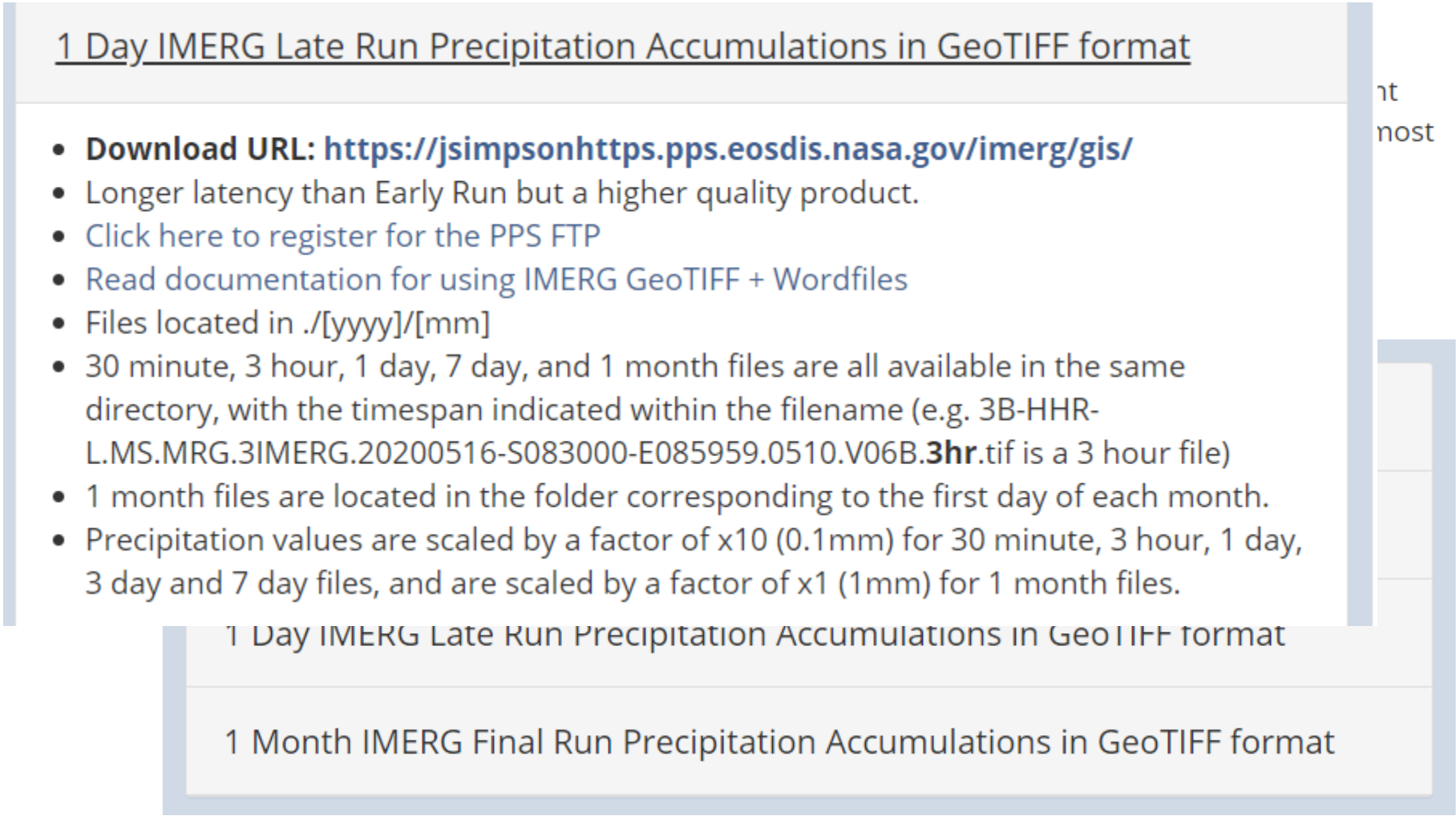
https://gpm.nasa.gov/sites/default/files/downloads/global-landslide-susceptibility-map-1-30-20.zip

Or use your own susceptibility map (in GeoTIFF format)



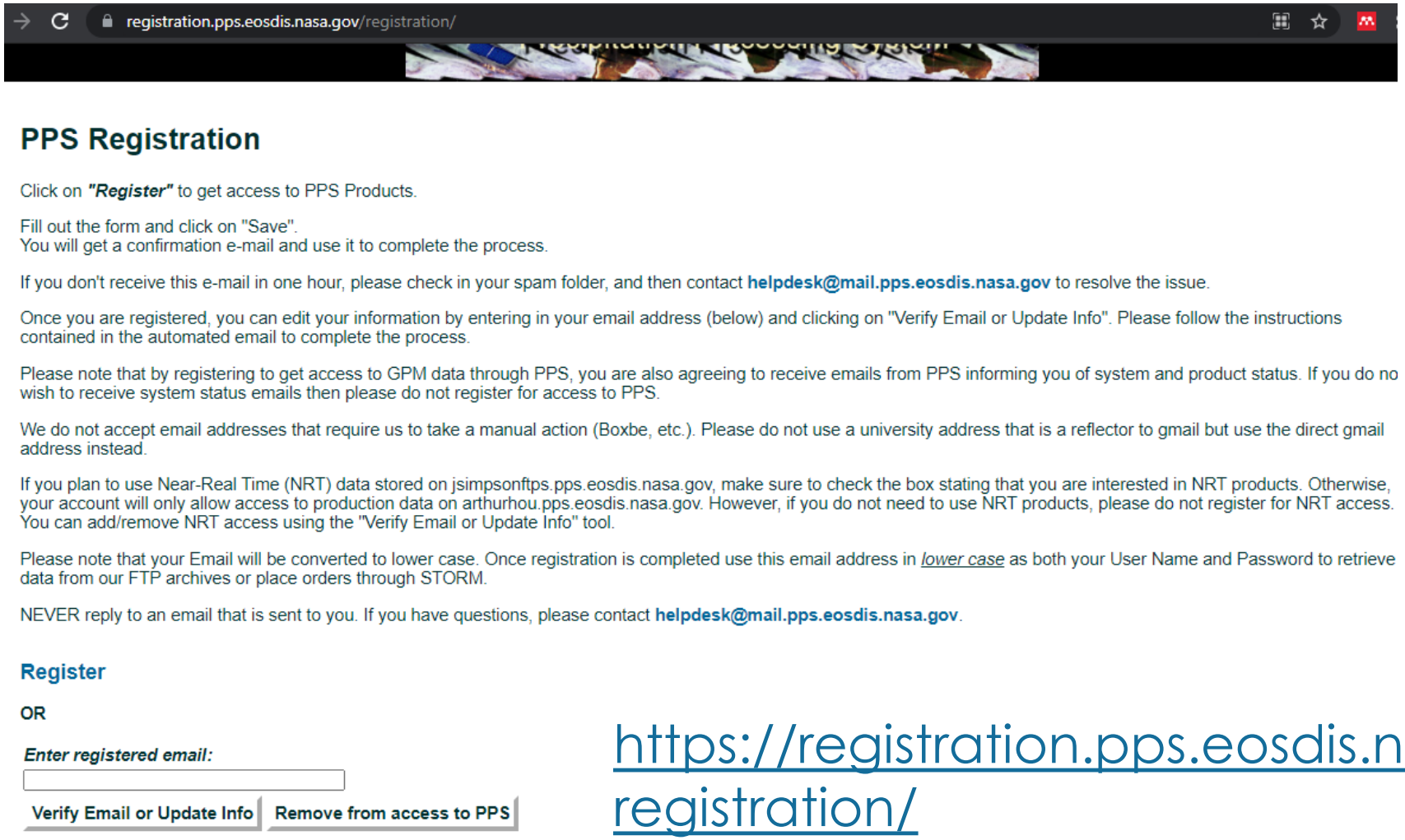
Getting Started with LHASA Version 1.1

Step 3: Download the IMERG data from https://gpm.nasa.gov/data/imerg



Getting Started with LHASA Version 1.1

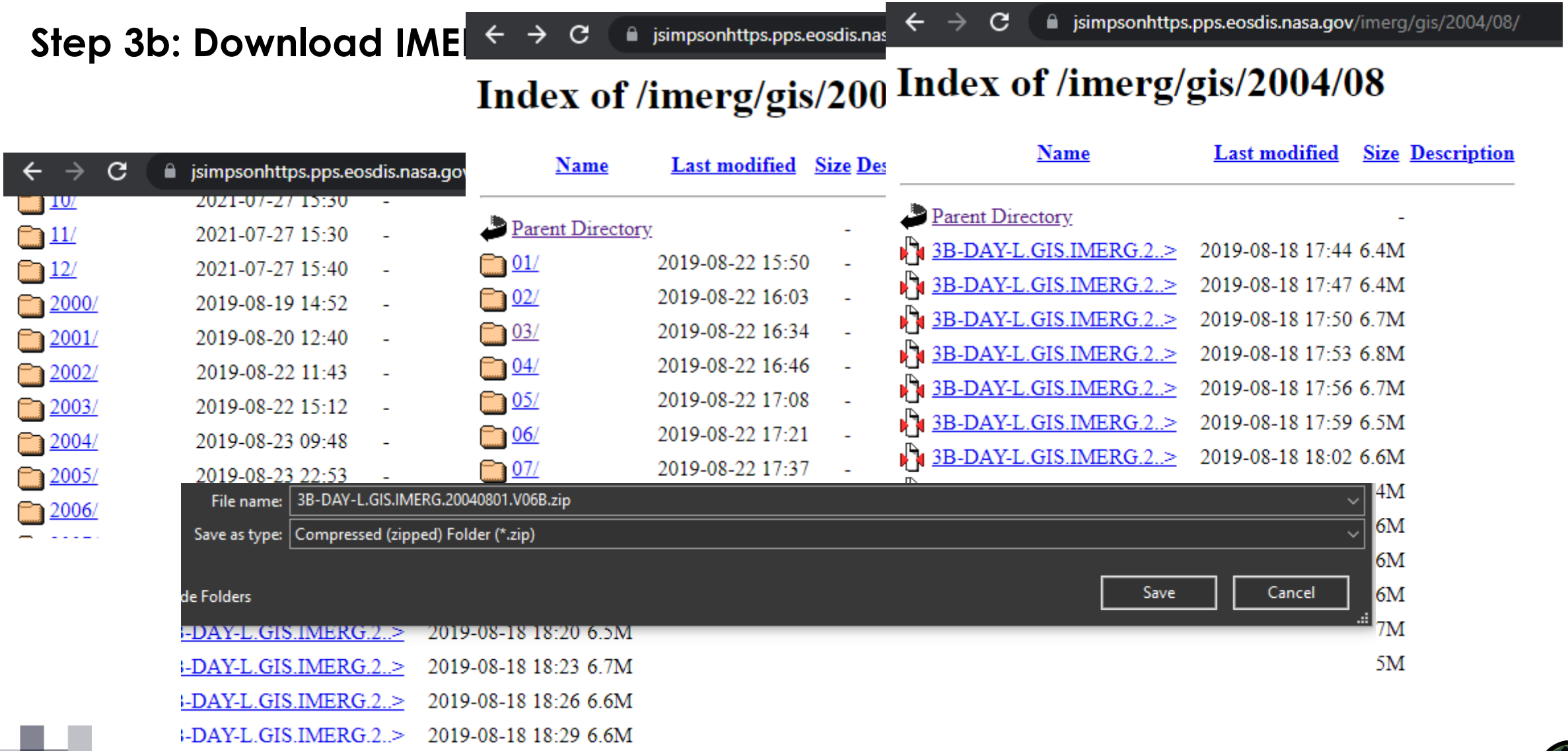
Step 3a: Register with the NASA Precipitation Processing System (PPS)



https://registration.pps.eosdis.nasa.gov/registration/

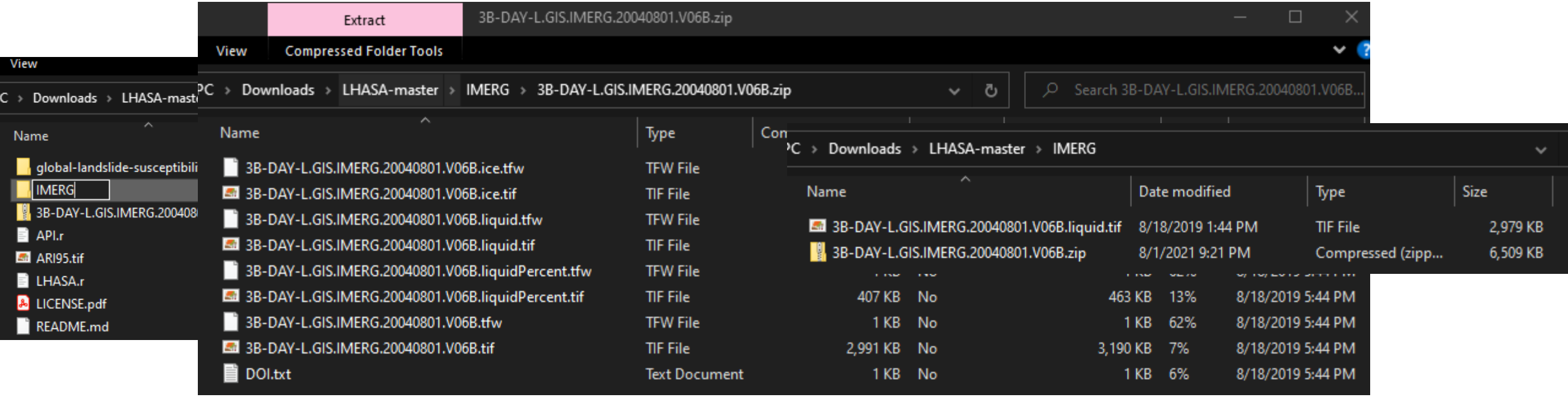
Getting Started with LHASA Version 1.1

Step 3b: Download IME



Getting Started with LHASA Version 1.1

Step 3c: Extract rainfall data files



Getting Started with LHASA Version 1.1

Step 4: Calculate the Antecedent Rainfall Index

RGui (64-bit) - [C:\Users\tastanle\Downloads\LHASA-master\API.r - R Editor]

File Edit Packages Windows Help

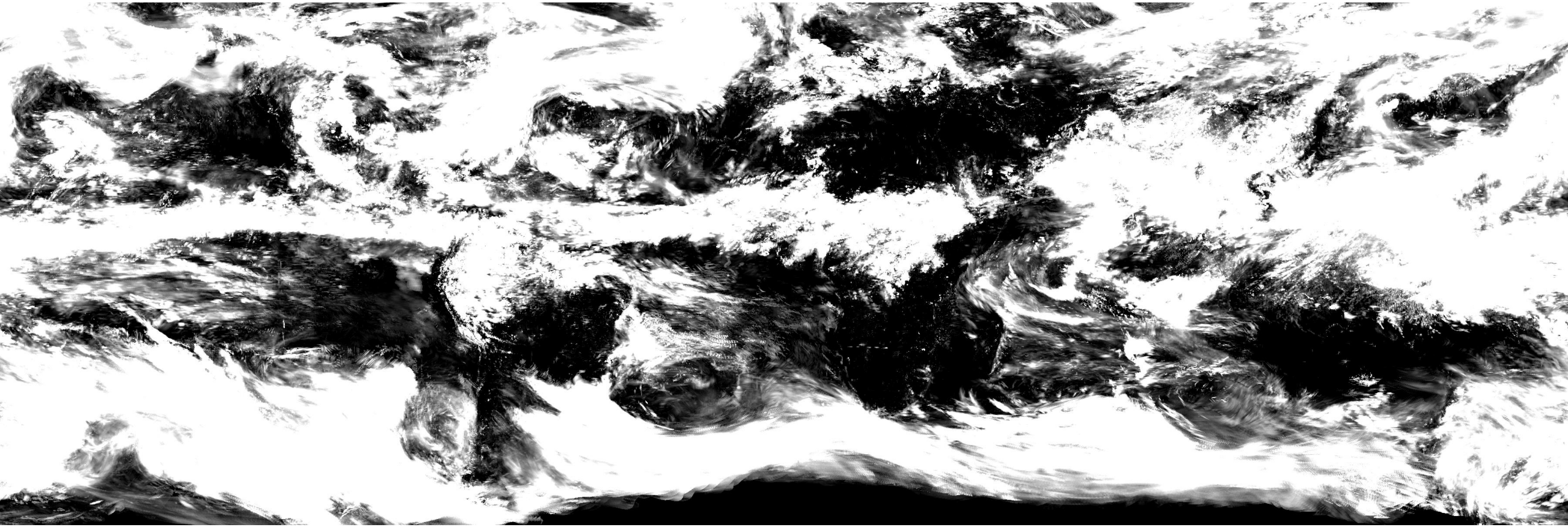
```
# 7-day ARI calculation v1.1.1
# 2021-8-2
# Thomas Stanley NASA
# Calculates a 7-day

# Load R packages
library(raster)

# Set working directo
setwd('C:/LHASA')
files <- list.files(p

# Set antecedent rai
ARI.window <- 7
# Set IDW exponent
exponent <- 2
# Calculate weights
w <- 1/seq(ARI.window, 1)^exponent
# Iterate through every day, starting at the end of the 1st ARI window
for(day in ARI.window:length(files)){
    # Open files within window, including current day
    IMERG <- crop(stack(files[(day - ARI.window + 1):day]), extent(-180, 180, -60, 60))
    # Calculate antecedent rainfall index
    ARI <- calc(w*IMERG,sum)/sum(w)
    # Save to disk
    writeRaster(ARI,filename=gsub('IMERG/','ARI/', files[day]))
}
```

C > Downloads > LHASA-master

Name	Date modified	Type	Size
API	8/2/2021 10:53 AM	File folder	
global-landslide-susceptibility-map-1-30...	8/1/2021 4:42 PM	File folder	
IMERG	8/2/2021 10:34 AM	File folder	
API.r	1/12/2021 8:20 PM	R File	1 KB
ARI95.tif	1/12/2021 8:20 PM	TIF File	24,122 KB
LHASA.r	1/12/2021 8:20 PM	R File	2 KB
LICENSE.pdf	1/12/2021 8:20 PM	Adobe Acrobat D...	132 KB
README.md	1/12/2021 8:20 PM	MD File	1 KB

Getting Started with LHASA Version 1.1

Step 4: Calculate the Antecedent Rainfall Index



Getting Started with LHASA Version 1.1

Step 4: Run the LHASA model

RGui (64-bit) - [C:\Users\tastanle\Downloads\LHASA-master\LHASA.r - R Editor]

File Edit Packages Windows Help

```
# NASA Goddard Space Flight Center
# Maps the potential for landslides by identifying which locations
# exceed thresholds for a 7-day antecedent precipitation index
# and a landslide susceptibility map.

# Load packages

# Set working directory
setwd('C:/LHASA')

# Open antecedent rainfall threshold file
# Note that the version of this file posted at https://github
# is based on the use of daily geotiff files, which are in te
# To use with the netcdf version of IMERG, divde by 10.
# Open the susceptibility map
susceptible <- crop(raster('global.tif'), extent(-180, 180,
files <- list.files(path='ARI', pattern='*.tif', full.names=T

# Iterate through all days in record
for(f in files){
    # Open antecedent rainfall index file for current date
    ARI <- raster(f)
    # Compare to ARI threshold
    wet <- ARI > threshold
    # Run decision tree model at resolution of susceptibility map
    moderate <- resample(wet, susceptible, method='ngb') & (susceptible > 2)
    high <- moderate & (susceptible > 4)
    # Save outputs
    writeRaster(nowcast,filename=gsub('ARI/','nowcast/',f), datatype='INT1U')
}
```

C › Downloads › LHASA-master — Search LHASA-master

Name	Date modified	Type	Size
ARI	8/2/2021 10:02 PM	File folder	
IMERG	8/2/2021 5:23 PM	File folder	
nowcast	8/2/2021 10:02 PM	File folder	
API.r	8/2/2021 10:01 PM	R File	1 KB
ARI95.tif	8/2/2021 10:01 PM	TIF File	23,234 KB
global.tif	8/2/2021 4:44 PM	TIF File	32,583 KB
LHASA.r	8/2/2021 10:01 PM	R File	2 KB
LICENSE.pdf	8/2/2021 10:01 PM	Adobe Acrobat D...	132 KB
README.md	8/2/2021 10:01 PM	MD File	1 KB

Getting Started with LHASA Version 1.1

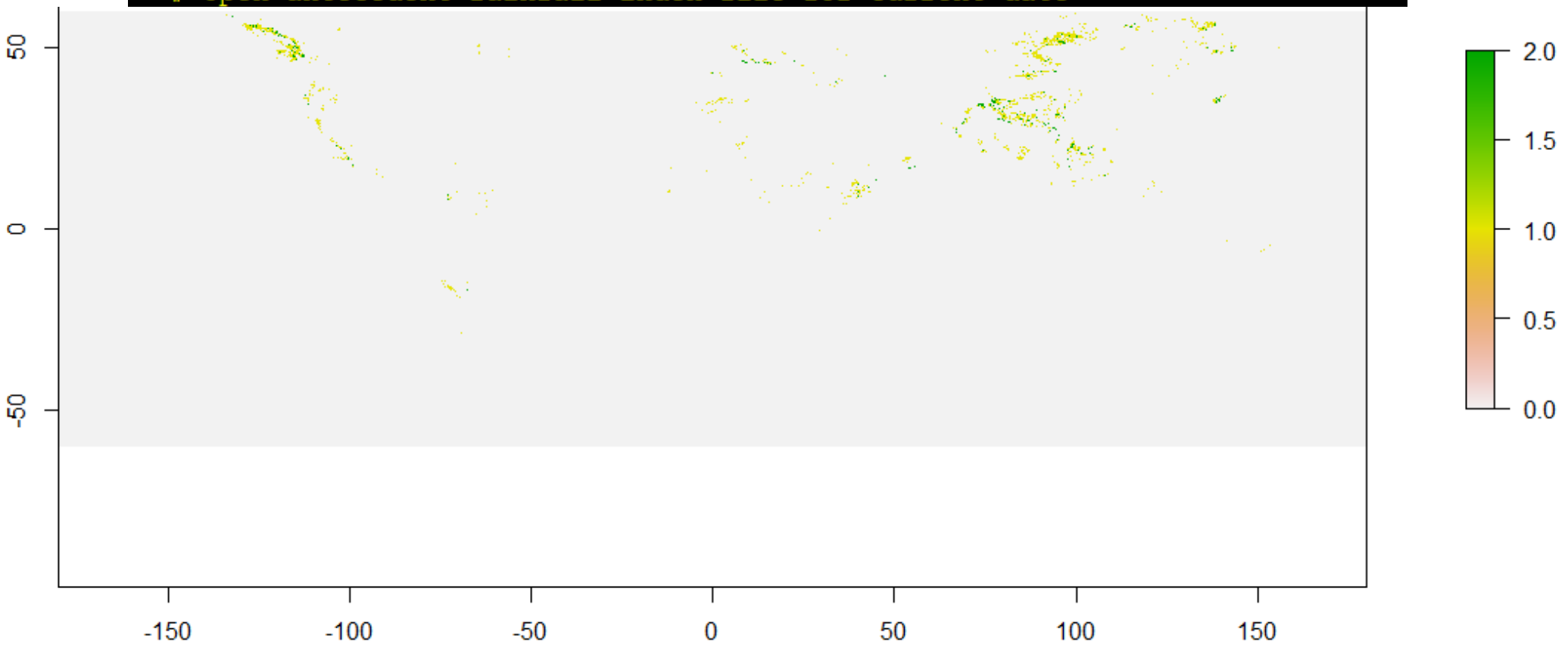
Step 4: Run the LHASA model

```
> # Landslide Hazard Assessment for Situational Awareness, version 1.1.1
> # By Thomas Stanley USRA/GESTAR 2021-8-2
> # NASA Goddard Space Flight Center
> # Maps the potential for landslides by identifying which locations
> # exceed thresholds for a 7-day antecedent precipitation index
> # and a landslide susceptibility map.
>
> # Load packages
> library(raster)
> # Set working directory
> setwd('C:/Users/tastanle/Downloads/LHASA-master')
>
> # Open antecedent rainfall threshold file
> # Note that the version of this file posted at https://github.com/nasa/LHASA
> # is based on the use of daily geotiff files, which are in tenths of mm.
> # To use with the netcdf version of IMERG, divde by 10.
> threshold <- crop(raster('ARI95.tif'), extent(-180, 180, -60, 60))
> # Open the susceptibility map
> susceptible <- crop(raster('global.tif'), extent(-180, 180, -60, 60))
```

Getting Started with LHASA Version 1.1

Step 5: View the Nowcast

```
> for(f in files){
+ # Open antecedent rainfall index file for current date
```



Next Steps with LHASA Version 1.1

How to make it work better for your island:

1. Evaluate the model's historic performance
   - Did it predict most landslides?
   - Was there a type of landslide or rainstorm it didn't do well on?
   - Is there a part of the island for which it's more accurate?
2. Raise or lower the rainfall threshold or susceptibility threshold
3. Replace the global susceptibility map with a national one
4. Replace IMERG with a high-resolution rainfall dataset from radar, gauges, or models

Review

Assessing Landslide Hazard on Small Island Nations

- Information on landslides can be useful at all stages of the disaster life cycle.
- NASA has several online resources:
  - At Landslide Viewer
  - At Landslide Reporter
- The LHASA model uses IMERG precipitation to produce global landslide nowcasts.
- You can implement LHASA version 1.1 with open-source code and open data.
  - But customizing it for your region is recommended.

References

- Stanley, T. A., D. B. Kirschbaum, G. Benz, et al. 2021. "Data-Driven Landslide Nowcasting at the Global Scale." Frontiers in Earth Science, 9: [10.3389/feart.2021.640043]
- Emberson, R., D. Kirschbaum, and T. Stanley. 2021. "Global connections between El Nino and landslide impacts." Nature Communications, 12 (1): 2262 [10.1038/s41467-021-22398-4]
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- Juang, C. S., T. A. Stanley, and D. B. Kirschbaum. 2019. "Using citizen science to expand the global map of landslides: Introducing the Cooperative Open Online Landslide Repository (COOLR)." PLOS ONE, 14 (7): e0218657 [10.1371/journal.pone.0218657]
- Kirschbaum, D., and T. Stanley. 2018. "Satellite-Based Assessment of Rainfall-Triggered Landslide Hazard for Situational Awareness." Earth's Future, 6 (3): 505-523 [10.1002/2017ef000715]
- Stanley, T., and D. B. Kirschbaum. 2017. "A heuristic approach to global landslide susceptibility mapping." Natural Hazards, 1-20 [10.1007/s11069-017-2757-y]
- Kirschbaum, D. B., T. Stanley, and Y. Zhou. 2015. "Spatial and temporal analysis of a global landslide catalog." Geomorphology, 249 (Geohazard Databases): 4-15 [10.1016/j.geomorph.2015.03.016]
- Kirschbaum, D. B., R. F. Adler, Y. Hong, S. Hill, and A. Lerner-Lam. 2010. "A global landslide catalog for hazard applications: method, results, and limitations." Natural Hazards 52 (3): 561-575 [10.1007/s11069-009-9401-4]

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Homework will be made available on August 26th.
  - Due date for homework: September 15, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Contacts

Trainers:

- Erika Podest: erika.podest@jpl.nasa.gov
- Sean McCartney: sean.mccartney@nasa.gov
- Amita Mehta: amita.v.mehta@nasa.gov

Follow us on Twitter @NASAARSET

Training Webpage:

- https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-observations-analyzing-natural-hazards-small-island

ARSET Website:

- https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.

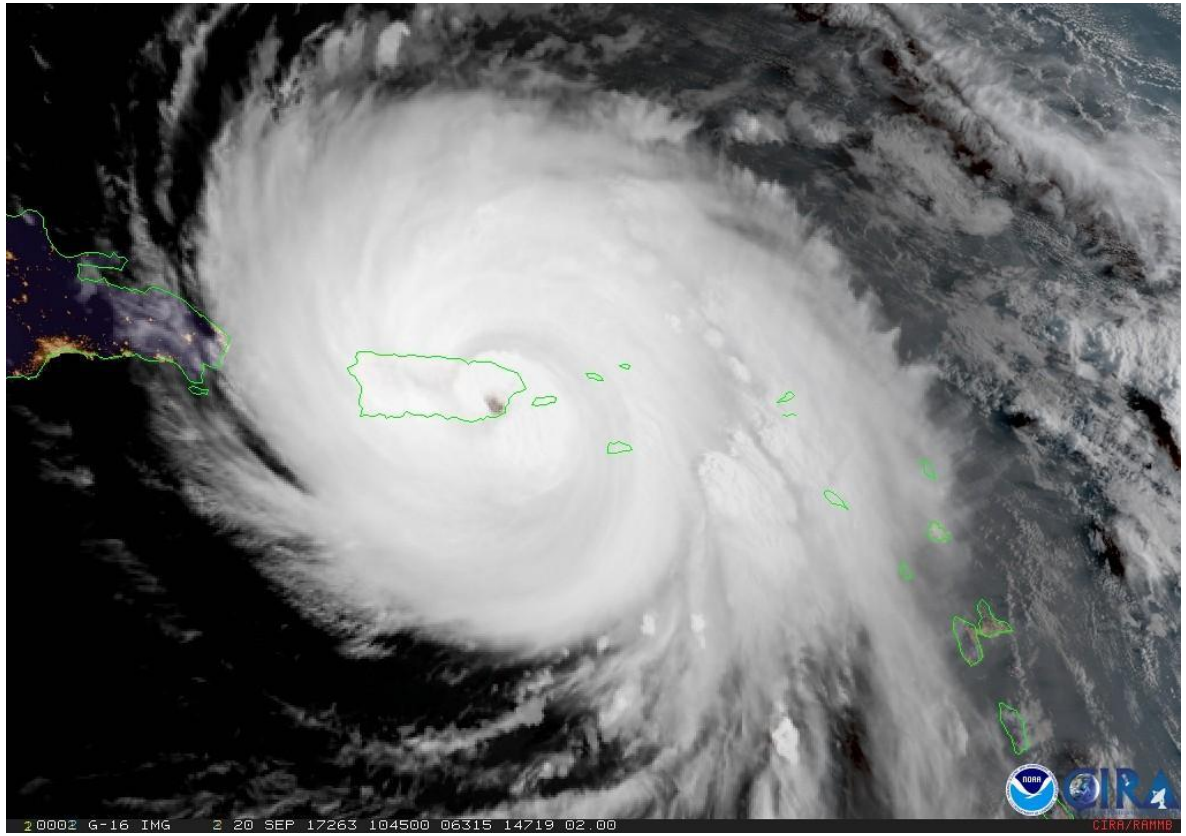

Image Credit: NOAA

The materials in this presentation draw on work by:

James Shute, Ryan Forbes, Neh Patel, Laura Carriere, Caroline Juang, Dalia Kirschbaum, Jack Simmons, Robert Emberson, Pukar Amatya, Garrett Benz, Marin Clark, William Medwedeff, Yaping Zhou, George Huffman, and many, many more.

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Thank You!