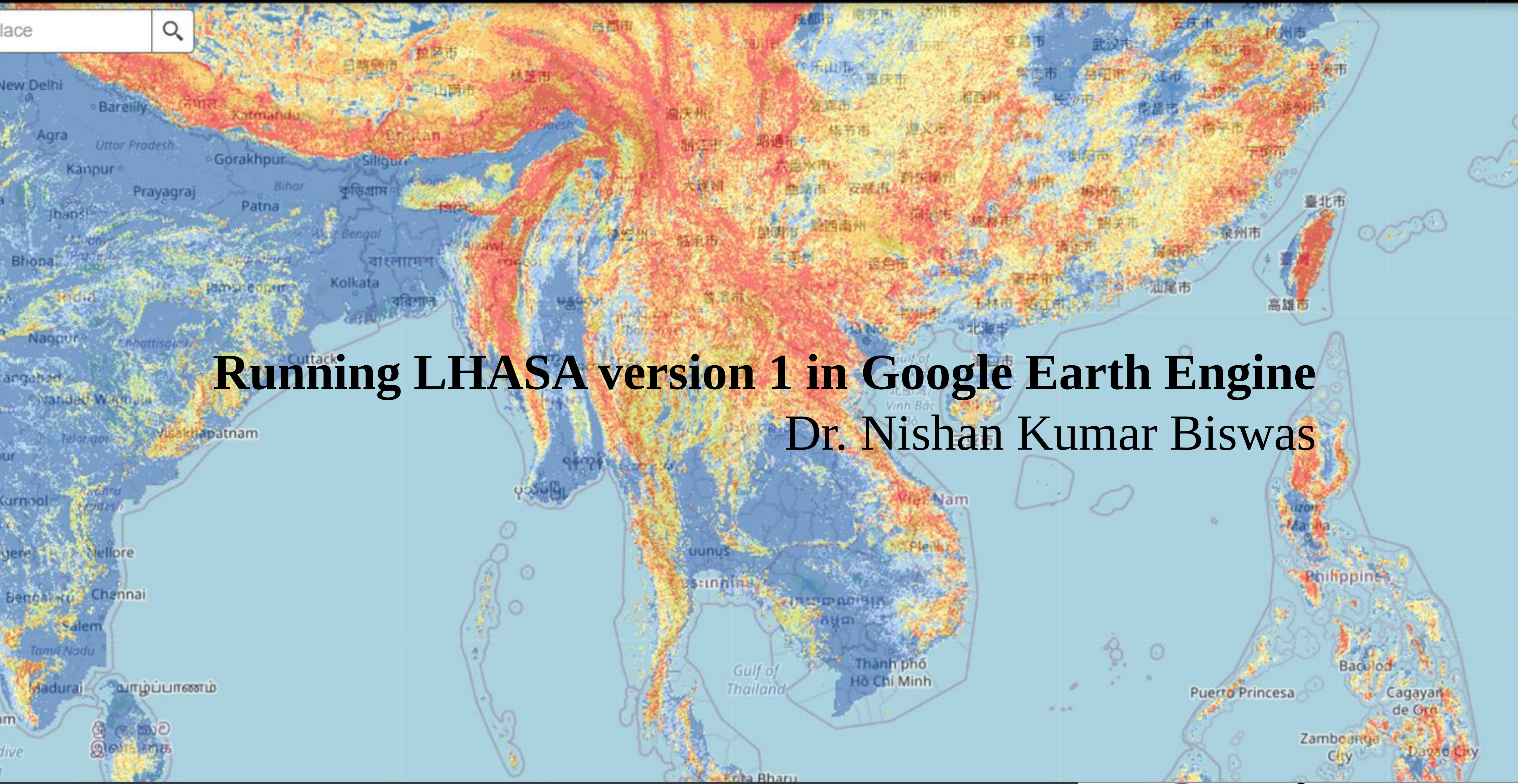
Running LHASA version 1 in Google Earth Engine

Dr. Nishan Kumar Biswas



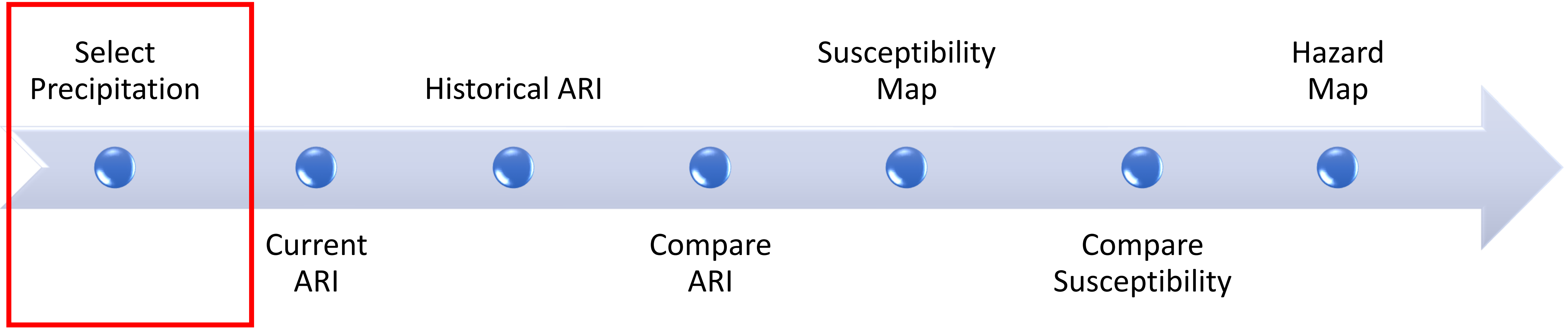
SPACE FLIGHT CENTER

Methodology

LHASA version 1

1. Select Precipitation
2. Current ARI
3. Historical ARI
4. Compare ARI
5. Susceptibility Map
6. Compare Susceptibility
7. Hazard Map

Step 1: Precipitation



Requirements:

1) Access to code window of Earth Engine
2) Precip_Visualization_Code.txt

Precipitation availability in Google Earth Engine (GEE)

Earth Engine Data Catalog

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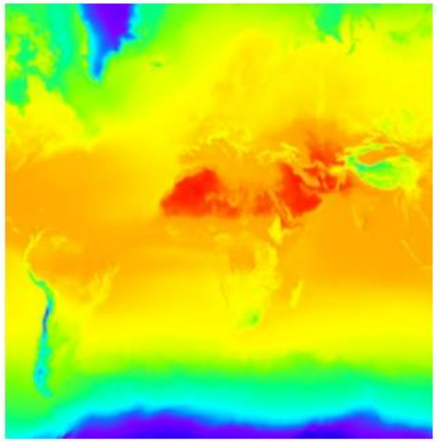
Datasets tagg

Filter list of datasets

34 different datasets

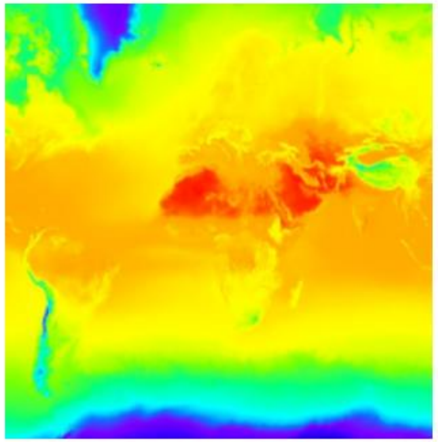
Link: https://developers.google.com/s/results/earth-engine/datasets/?q=precipitation

ERA5 Daily Aggregates - Latest Climate Reanalysis Produced by ECMWF / Copernicus Climate



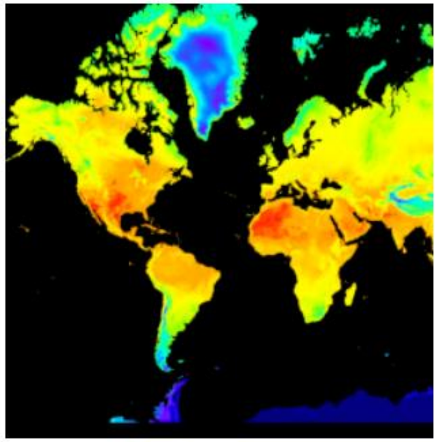
ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset. ERA5 replaces its predecessor, the ERA-Interim reanalysis.

ERA5 Monthly Aggregates - Latest Climate Reanalysis Produced by ECMWF /



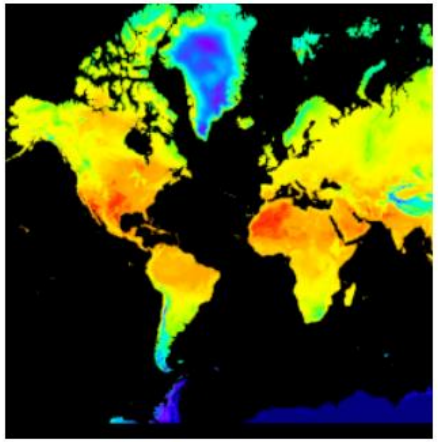
ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset. ERA5 replaces its predecessor, the ERA-Interim reanalysis.

ERA5-Land Hourly - ECMWF Climate Reanalysis



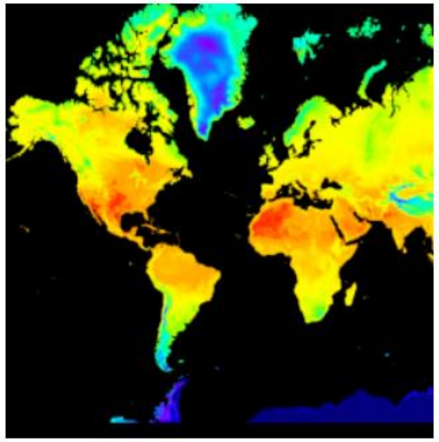
ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5. ERA5-Land has been produced by replaying the land component of the ECMWF ERA5 climate

ERA5-Land Monthly Averaged - ECMWF Climate Reanalysis



ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5. ERA5-Land has been produced by replaying the land component of the ECMWF ERA5 climate

ERA5-Land Monthly Averaged by Hour of Day - ECMWF Climate Reanalysis

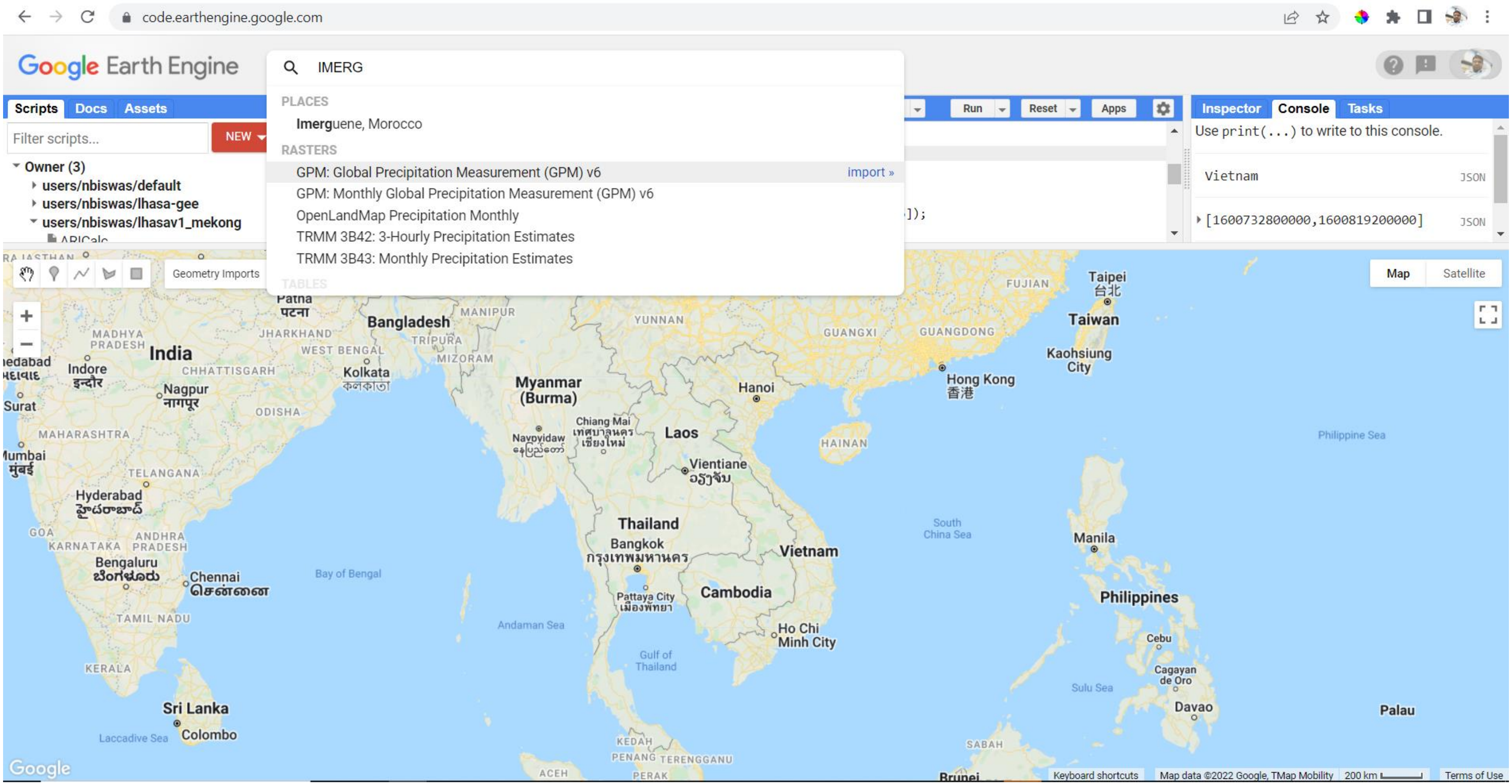


ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5. ERA5-Land has been produced by replaying the land component of the ECMWF ERA5 climate

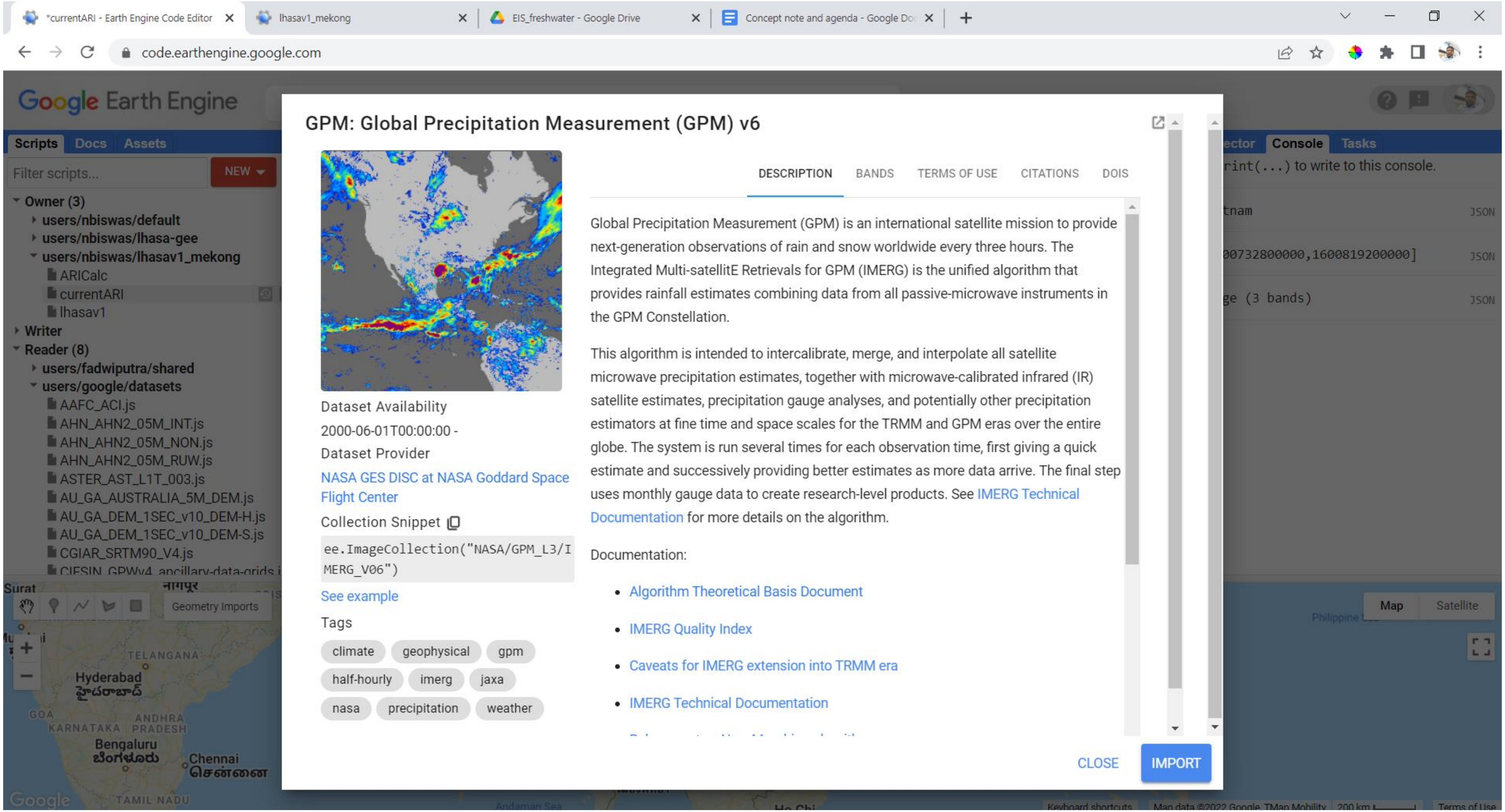
First, import precipitation data in GEE

https://code.earthengine.google.com/

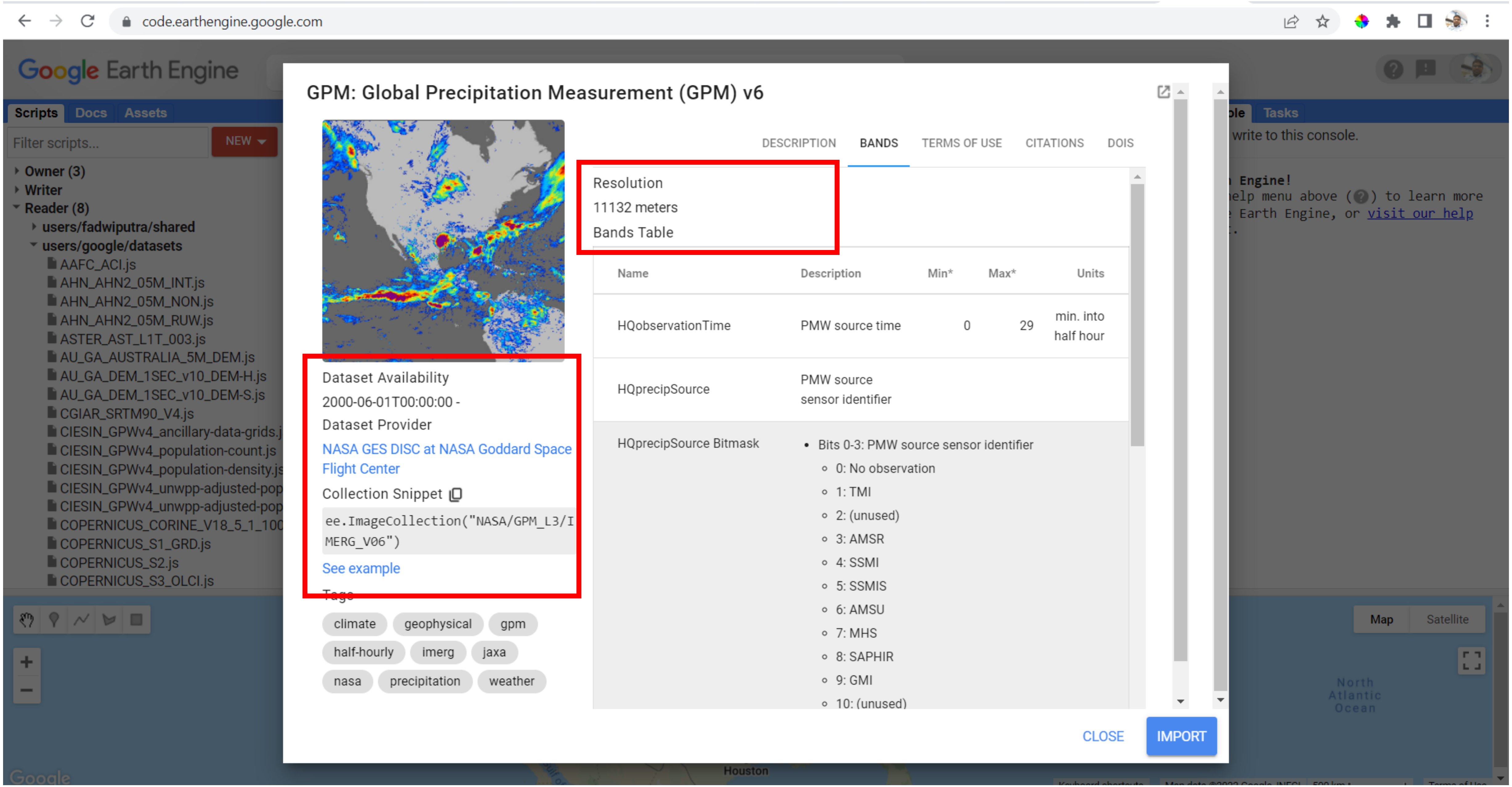
Searching and selecting precipitation



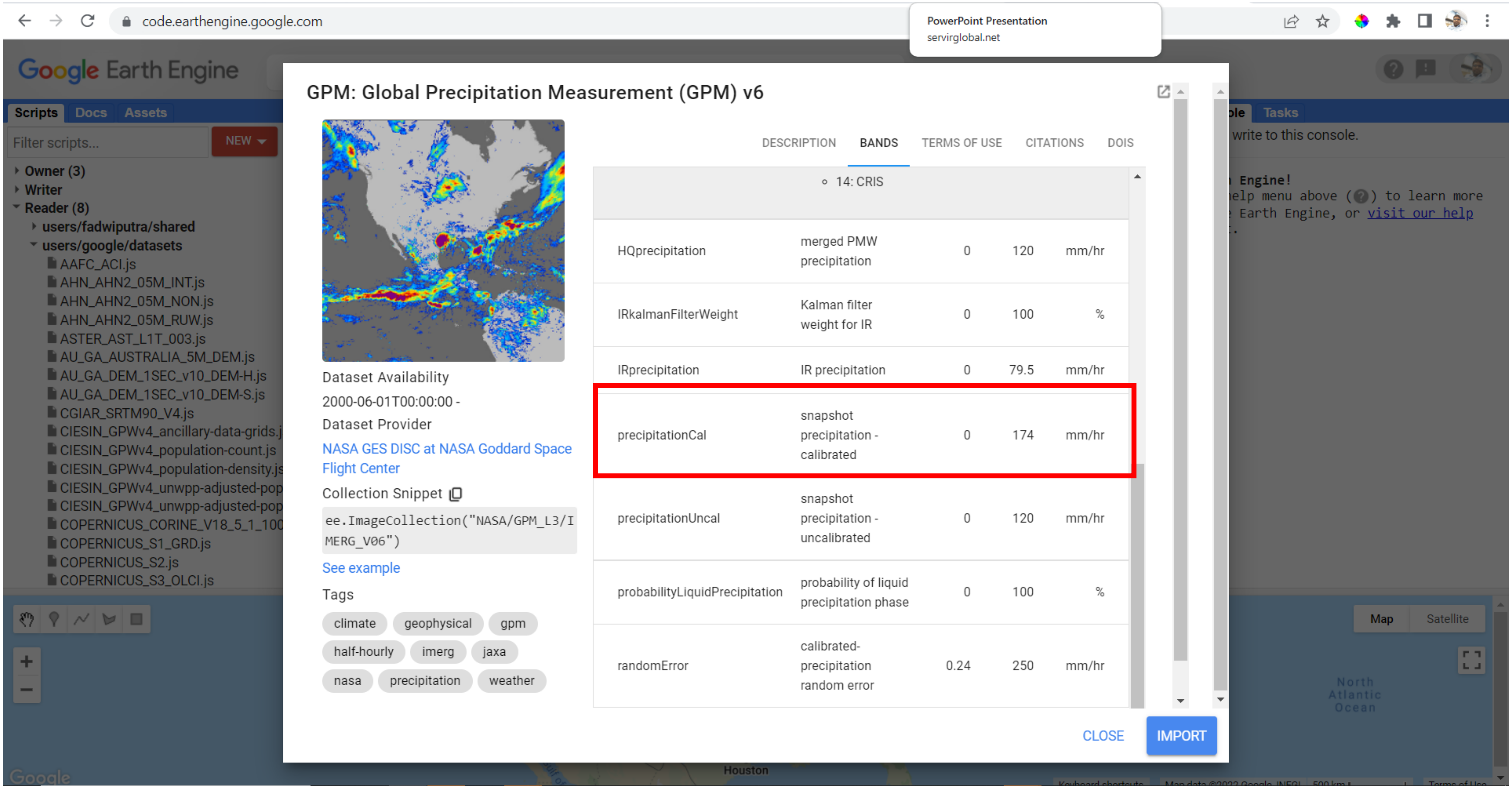
Importing precipitation



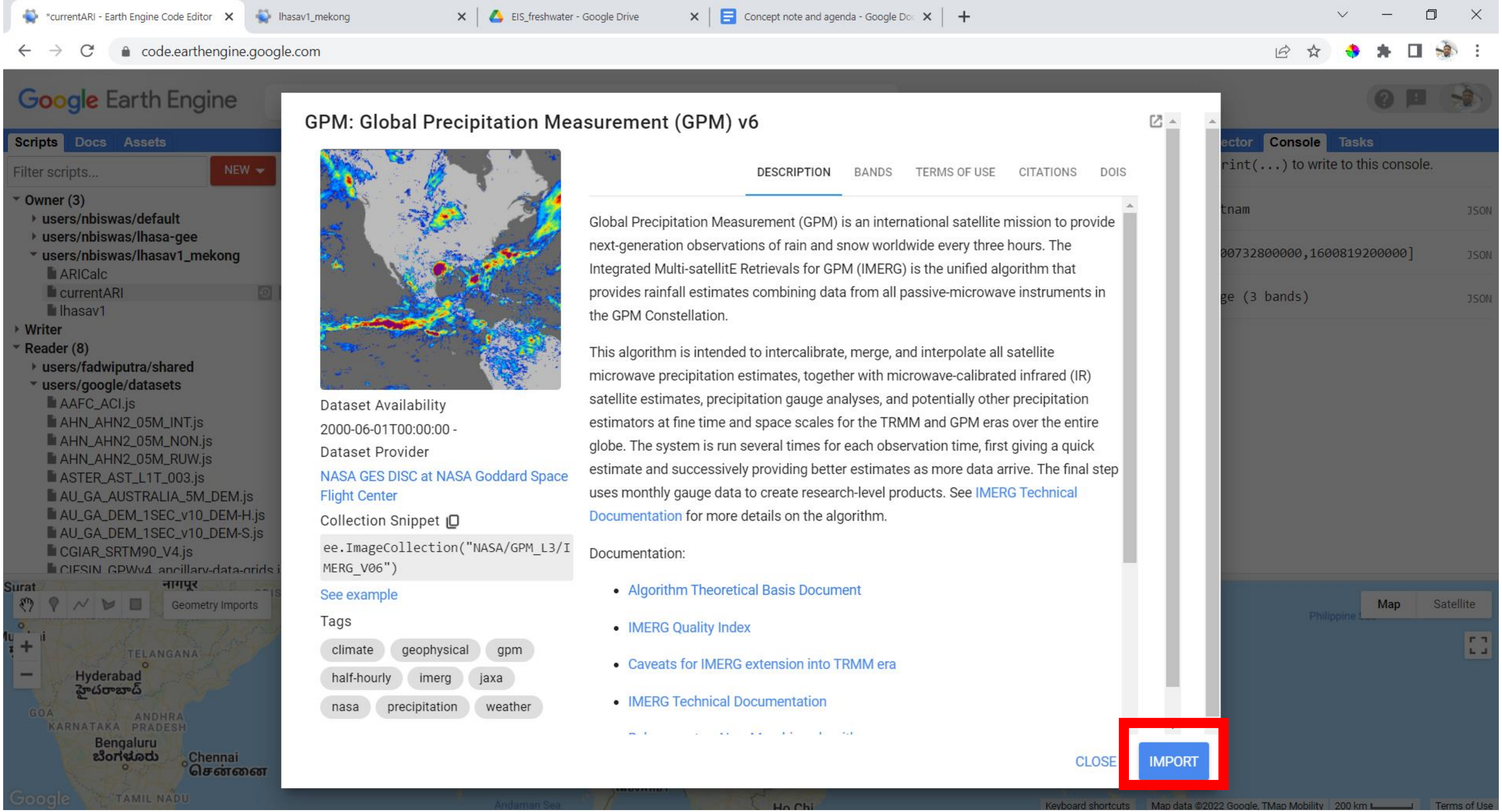
Importing precipitation



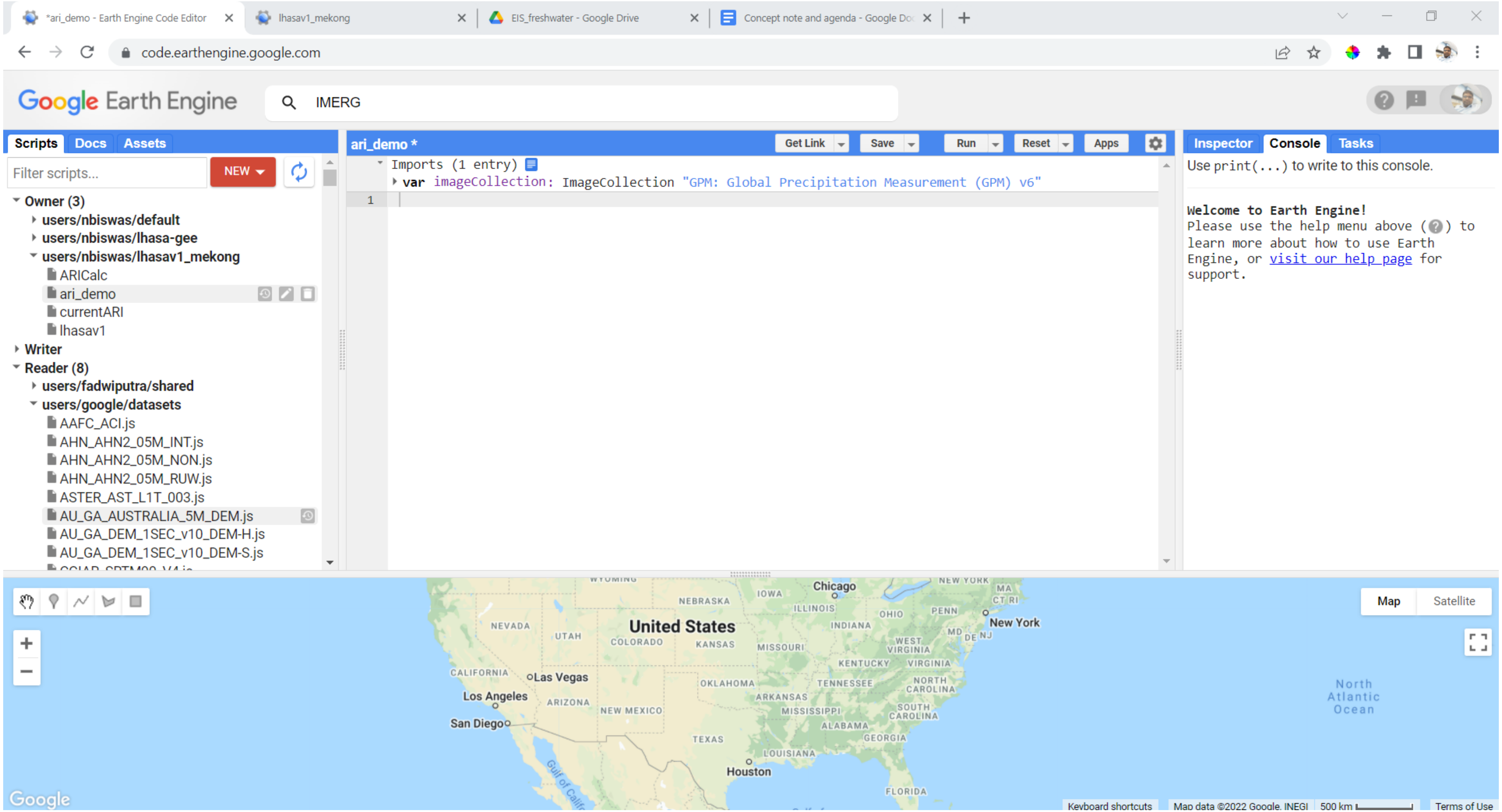
Importing precipitation



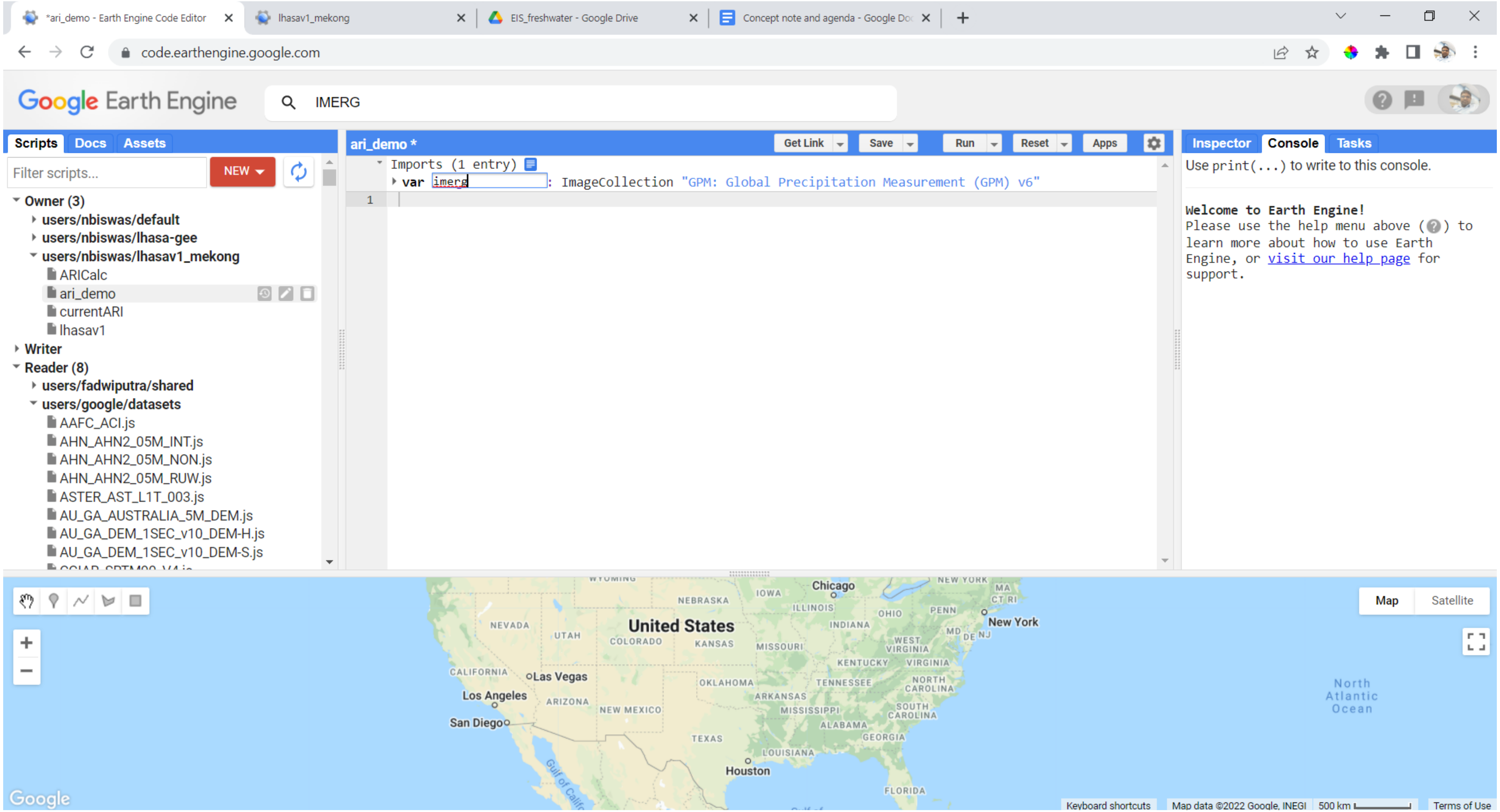
Importing precipitation



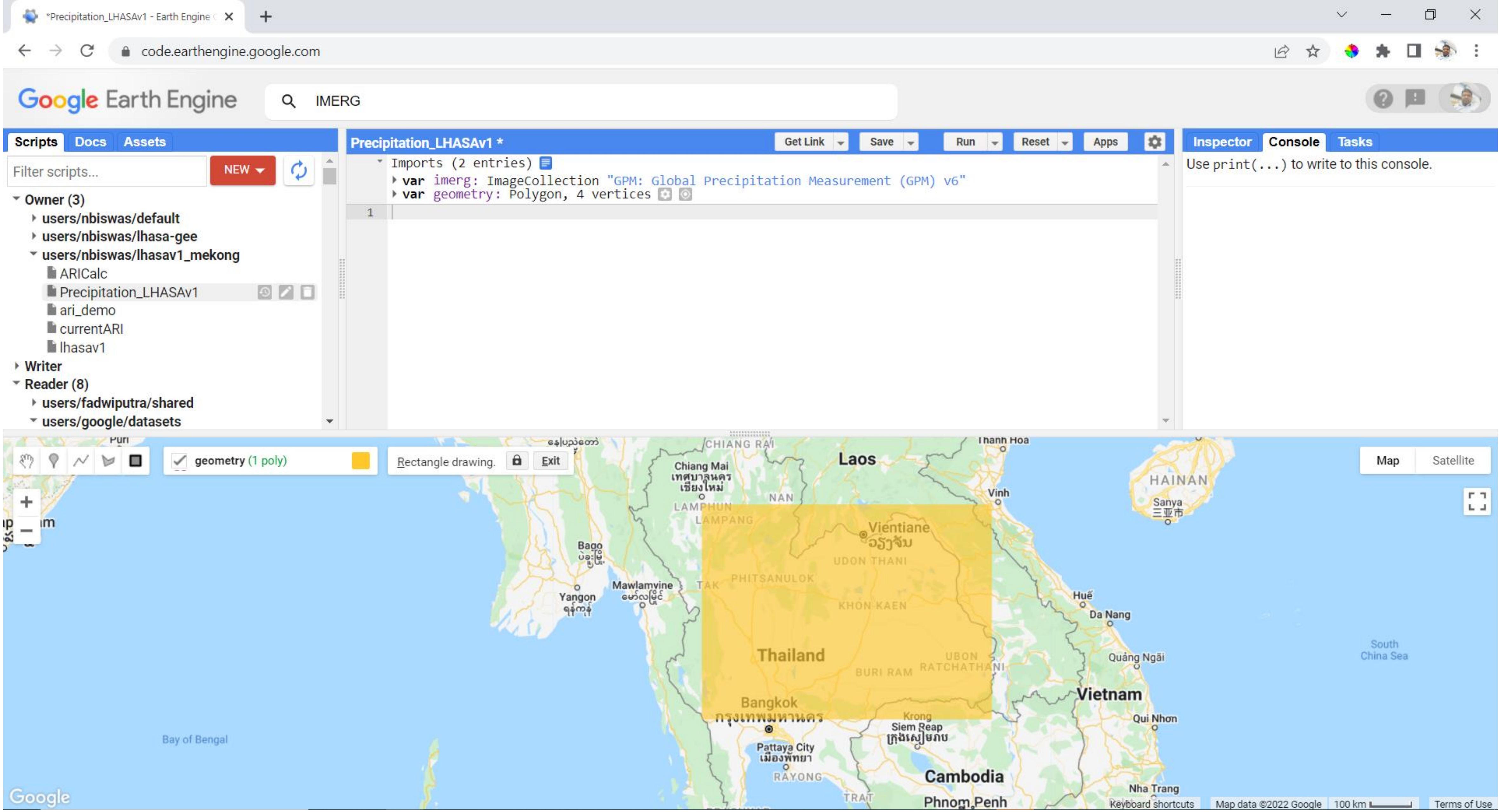
Imported precipitation



Rename precipitation variable



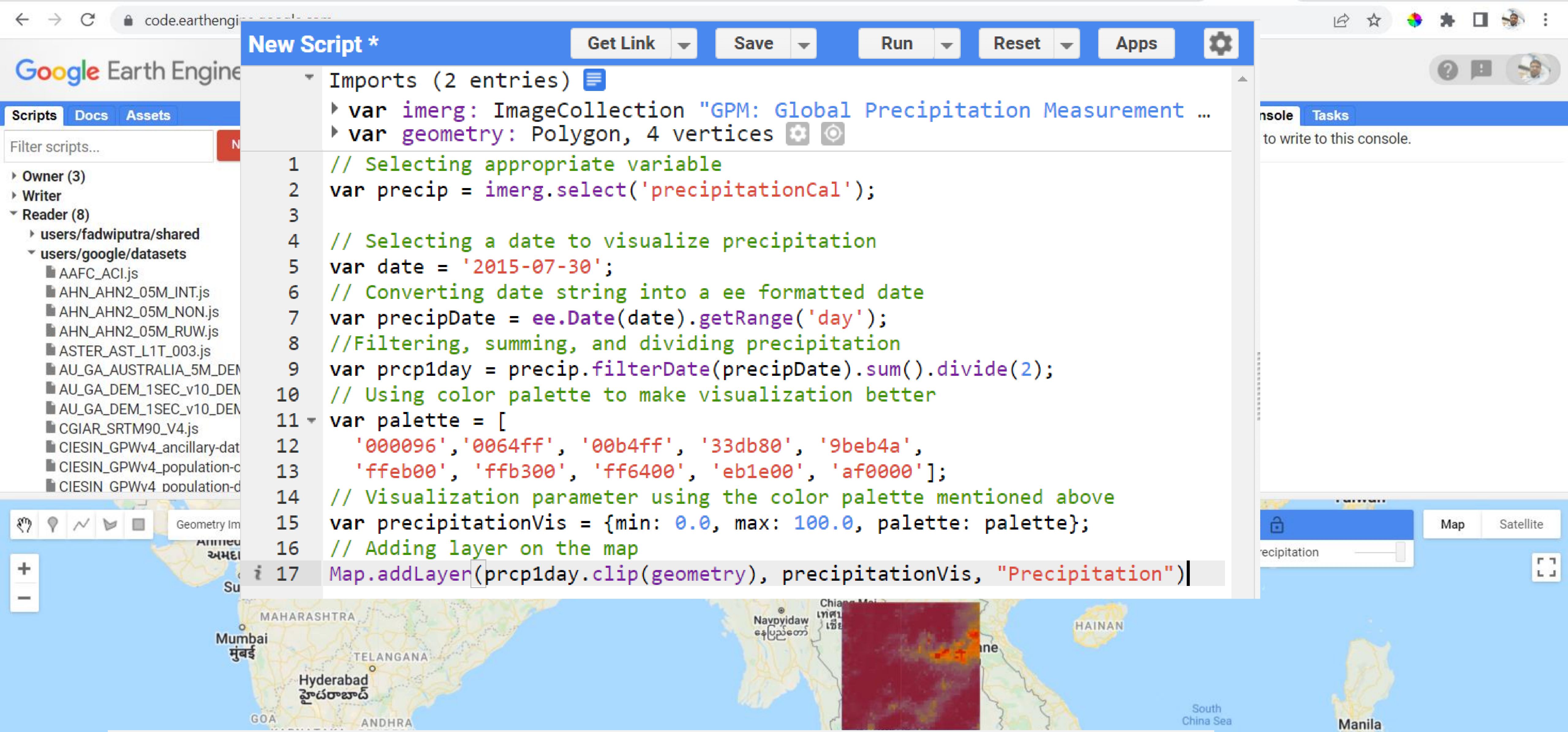
Draw a geometry or upload a study area shapefile



Copy and paste code to display precipitation

```
// Selecting appropriate variable
var precip = imerg.select('precipitationCal');
// Selecting a date to visualize precipitation
var date = '2015-07-30';
// Converting date string into a ee formatted date
var precipDate = ee.Date(date).getRange('day');
//Filtering, summing, and dividing precipitation
var prcp1day = precip.filterDate(precipDate).sum().divide(2);
// Using color palette to make visualization better
var palette = [
  '000096','0064ff', '00b4ff', '33db80', '9beb4a',
  'ffeb00', 'ffb300', 'ff6400', 'eb1e00', 'af0000'];
// Visualization parameter using the color palette mentioned above
var precipitationVis = {min: 0.0, max: 100.0, palette: palette};
// Adding layer on the map
Map.addLayer(prcp1day.clip(geometry), precipitationVis, "Precipitation")
```

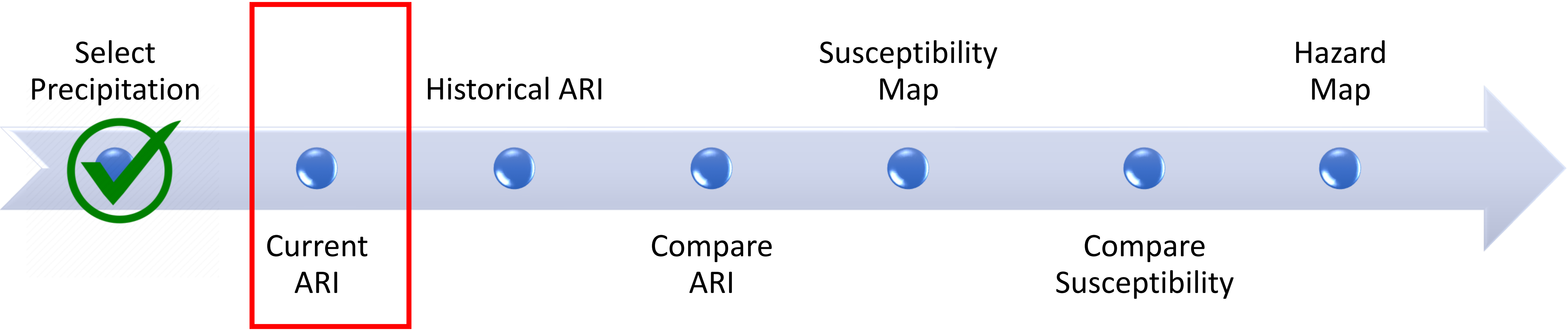
Displayed precipitation



Now you are ready to use Precipitation!!

LHASA version 1

Step 2: Current ARI



Requirements:

1) Access to code window of Earth Engine
2) ARI _Calculation_Code.txt, available in [SERVIR Landslide Page]

Antecedent Rainfall Index (ARI)

ARI calculation formula:

$$Antecedent\ Rainfall\ Index\ (ARI) = \frac{\sum_{t=0}^{6} P_t W_t}{\sum_{t=0}^{6} W_t}$$

$$Where\ \ W_t = (t+1)^{-2}$$

Here, P = precipitation, t=days, w=weightage

Day-0
- * 1.0

Day-1
- * 0.25

Day-2
- * 0.11

Day-3
- * 0.06

Day-4
- * 0.04

Day-5
- * 0.027

Day-6
- * 0.02

Accumulation
- */1.511797*

Copy and paste code to calculate ARI from precipitation

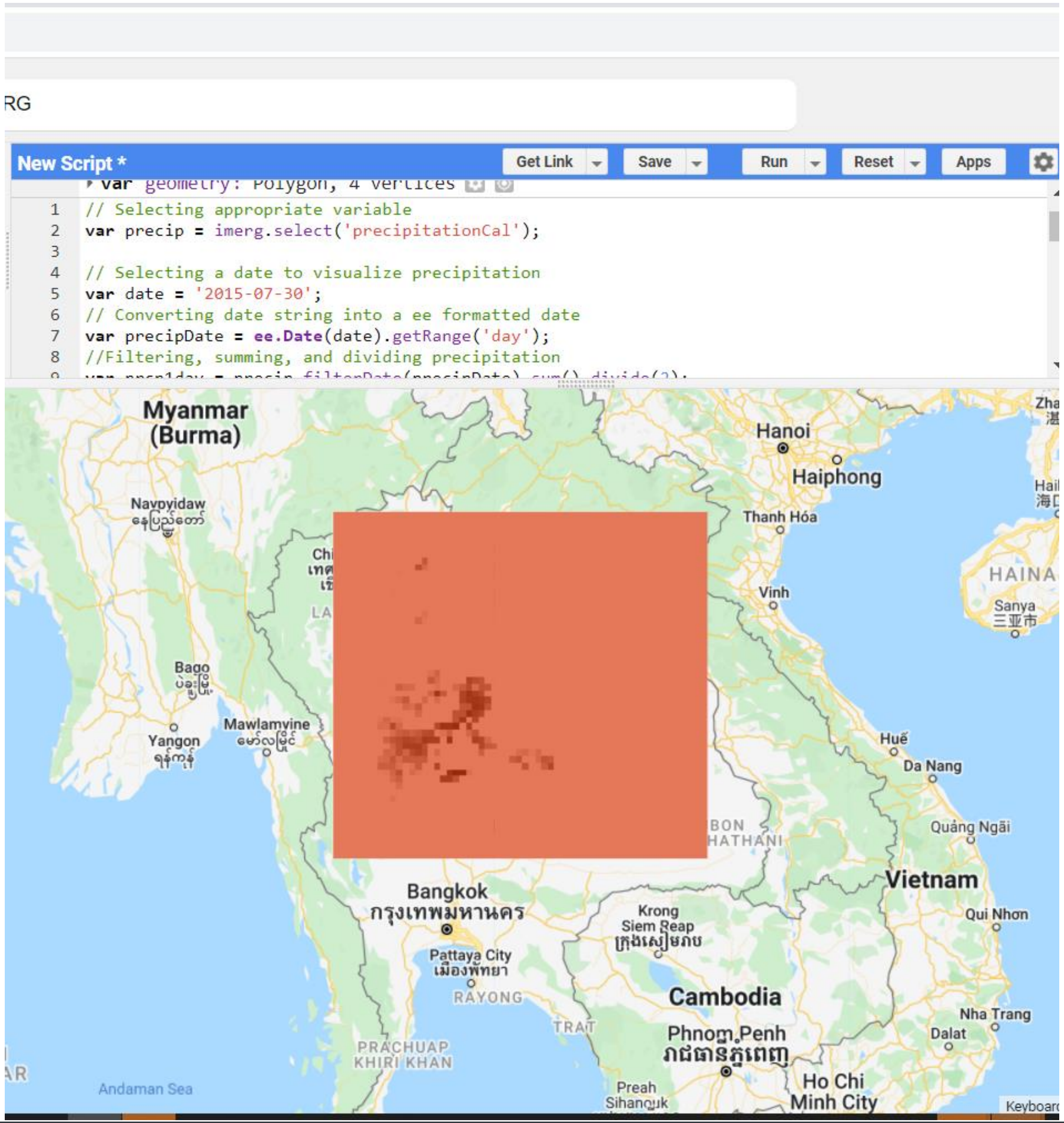
```
var precipDate = ee.Date(date)
// Selecting days to consider for calculating ARI
var daysofWeek  = ee.List.sequence(0,6,1);
   // Declaring list of weightage for those days
  var weight = ee.List([1.0,0.25,0.111,0.0625, 0.04, 0.02778, 0.02040816]);
 // Summing up weightage
  var ws = 1.511797;
  // calculate the daily precipitation in this case we just use the immerg data
  var ari = ee.ImageCollection(daysofWeek.map(function(m){
      // parse M to a number
      m = ee.Number.parse(m);
      // set the date range
      var startDay = precipDate.advance(m.multiply(-1),"day");
      // Offsetting one day to make a 24 hour span
      var endDay = startDay.advance(1,"day");
      // get the weight
      var w = ee.Number.parse(weight.get(m));
      // get the rainfall of day x
      var dayPrecip = ee.Image(precip.filterDate(startDay,endDay).sum()).divide(2);
      // multiply with weight factor
      var riDay = dayPrecip.multiply(ee.Image(w));
      return riDay;
  })).sum().divide(ws).rename('api').clip(geometry);
Map.addLayer(ari, {}, "Current ARI of " + date)
```

Code to calculate ARI from precipitation

```
// Selecting appropriate variable
var precip = imerg.select('precipitationCal');

// Selecting a date to visualize precipitation
var date = '2015-07-30';
// Converting date string into a ee formatted date
var precipDate = ee.Date(date).getRange('day');
//Filtering, summing, and dividing precipitation
var prcp1day = precip.filterDate(precipDate).sum().divide(2);
// Using color palette to make visualization better
var palette = [
  '000096','0064ff', '00b4ff', '33db80', '9beb4a',
  'ffeb00', 'ffb300', 'ff6400', 'eb1e00', 'af0000'];
// Visualization parameter using the color palette mentioned above
var precipitationVis = {min: 0.0, max: 100.0, palette: palette};
// Adding layer on the map
Map.addLayer(prcp1day.clip(geometry), precipitationVis, "Precipitation")

// Selecting days to consider for calculating ARI
var precipDate = ee.Date(date)
var daysofWeek  = ee.List.sequence(0,6,1);
   // Declaring list of weightage for those days
  var weight = ee.List([1.0,0.25,0.111,0.0625, 0.04, 0.02778, 0.02040816]);
 // Summing up weightage
  var ws = 1.511797;
  // calculate the daily precipitation in this case we just use the immerg data
  var ari = ee.ImageCollection(daysofWeek.map(function(m){
      // parse M to a number
      m = ee.Number.parse(m);
      // set the date range
      var startDay = precipDate.advance(m.multiply(-1),"day");
      // Offsetting one day to make a 24 hour span
      var endDay = startDay.advance(1,"day");
      // get the weight
      var w = ee.Number.parse(weight.get(m));
      // get the rainfall of day x
      var dayPrecip = ee.Image(precip.filterDate(startDay,endDay).sum()).divide(2);
      // multiply with weight factor
      var riDay = dayPrecip.multiply(ee.Image(w));
      return riDay;
  })).sum().divide(ws).rename('api').clip(geometry);
Map.addLayer(ari, {}, "ARI of " + date)
```



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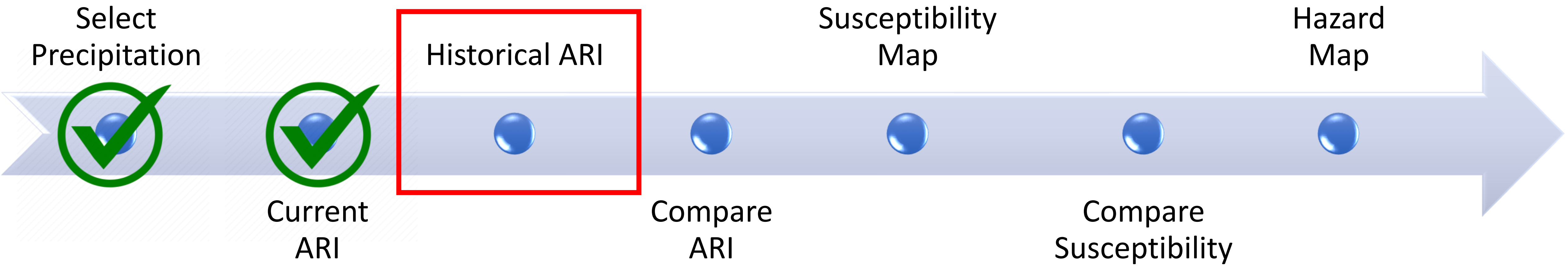
LHASA version 1

Step 3: Historical ARI



Historical ARI: Methodology

$$Antecedent\ Rainfall\ Index\ (ARI) = \frac{\sum_{t=0}^{6} P_t W_t}{\sum_{t=0}^{6} W_t}$$

$$Where\ \ W_t = (t+1)^{-2}$$

Here, P = precipitation, t=days, w=weightage

Day-0
- * 1.0

+

Day-1
- * 0.25

+

Day-2
- * 0.11

+

Day-3
- * 0.06

+

Day-4
- * 0.04

+

Day-5
- * 0.027

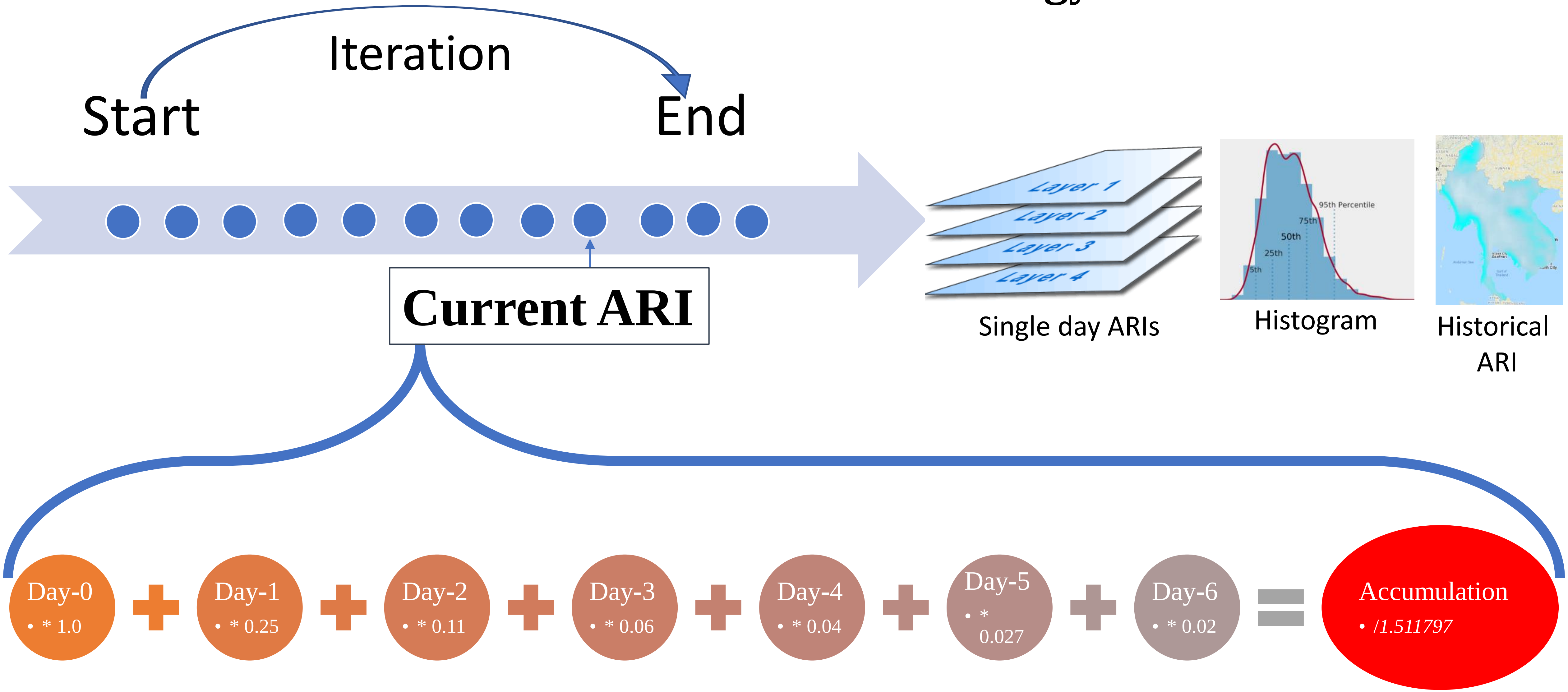
+

Day-6
- * 0.02

=

Accumulation
- */1.511797*

Historical ARI: Methodology

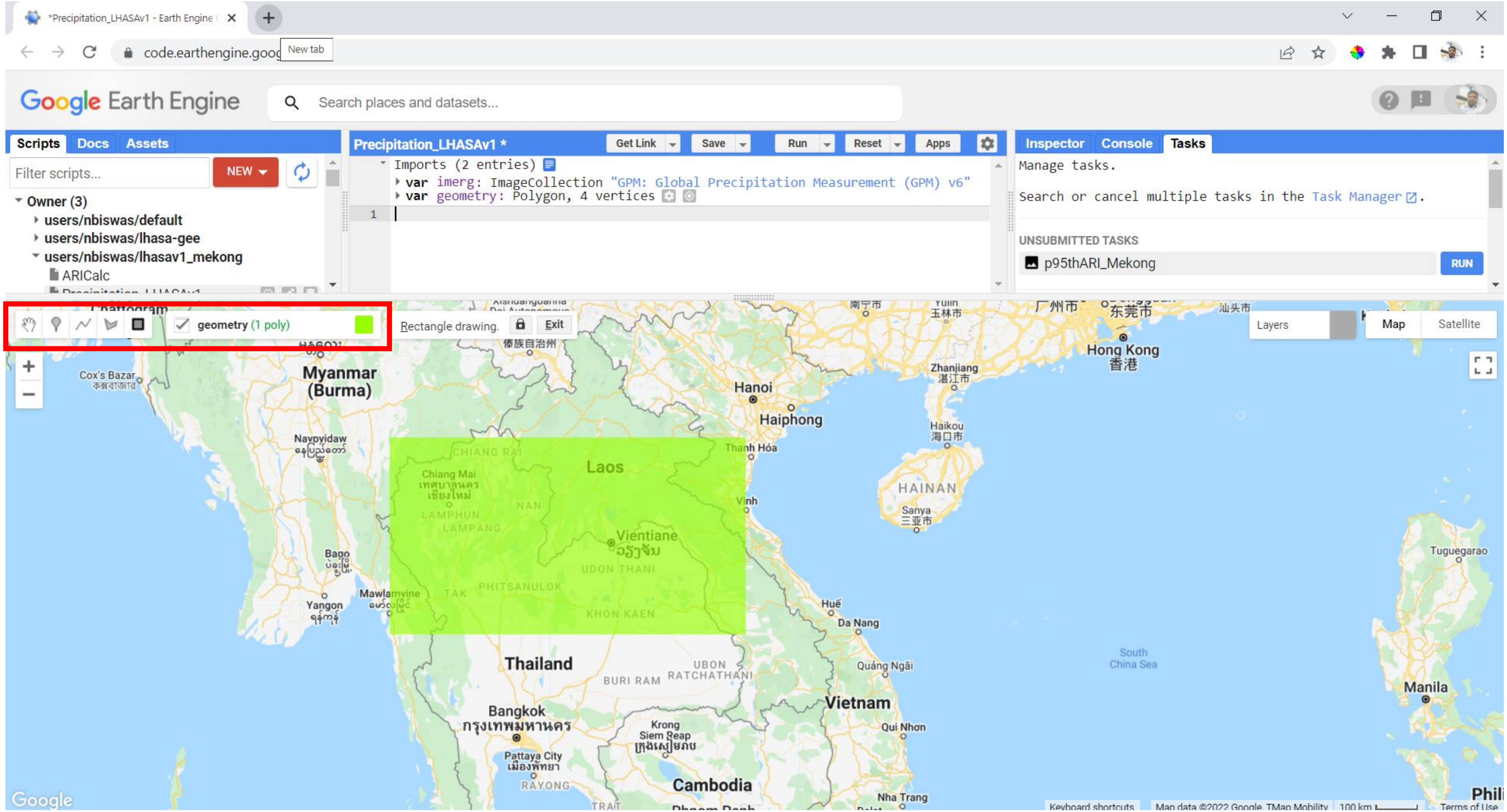


Historical ARI Calculation

Write the code in a fresh GEE project
https://code.earthengine.google.com/.

First, follow page 7-14 to import precipitation and draw geometry. Try to draw the geometry close to or bigger than in you did on page 14.

Historical ARI Calculation



Historical ARI Calculation

Historical Antecedent Rainfall Index Calculation code in GEE

```
//////************ Historical ARI Calculation for LHASA V1 implementation ********
// Step 1: declaration of the appropriate variables
var imerg = ee.ImageCollection("NASA/GPM_L3/IMERG_V06")
var precip = imerg.select('precipitationCal');
```

Saying that we will select precip variable

```
// declaring the days 0-6 of a whole week
var daysofWeek  = ee.List.sequence(0,6,1);
```

Saying that we will consider 7 last days

```
// declaring the weights for the individual days
var weight = ee.List([1.0,0.25,0.111,0.0625, 0.04, 0.0278, 0.02040816]);
// Sum of the weightage factors
var ws = 1.511797;
```

Weightage for those days

```
// set time period of 20 years
var start = ee.Date.fromYMD(2001,1,1);
var end = ee.Date.fromYMD(2021,1,1);
```

Timeframe to calculate ARI using data of last 20 years

```
// set date bounds for ARI starting from 7th day
start = start.advance(7,"day");
var nDays = (end.difference(start,"day"));
var seq = ee.List.sequence(1,nDays,1);
```

Calculating the days from the 7th and making a list of it

Historical ARI Calculation

```
////  Step 2: Function to iterate through days to generate ARI Layers
var historical_ari = ee.ImageCollection(seq.map(function(n){
  return ee.ImageCollection(daysofWeek.map(function(m){
     // parse to number for serverside computation
     m = ee.Number.parse(m);
     // set the day
     var startDay = start.advance(n,"day").advance(m.multiply(-1),"day");
     var endDay = startDay.advance(1,"day");
     // get the weights
     var w = ee.Number.parse(weight.get(m))
      // select precip layers, filter based on date, sum, divide, clip
     var dailyrain= ee.Image(precip.filterDate(startDay,endDay).sum().divide(2).clip(geometry));
     // multiply ari with weight factor
     var riDay = dailyrain.multiply(w);
      // Returing rainfall index of that day
       return riDay;
})).sum().divide(ws)
}));
////  Step 3: calculate the 95th percentile
var ari95 = historical_ari.reduce(ee.Reducer.percentile([95])).clip(geometry);
```

Mapping over the list to calculate Historical ARI

Mapping over 7 days to return an image of a single day ARI

Selecting a one-day span

Selecting weight of that day

Select precip, filter, sum, divide, clip

Multiplying with the weightage

Returning rainfall index of that day

Summing 7 day's rainfall index and dividing by weight

Getting the 95th percentile from the precipitation histogram

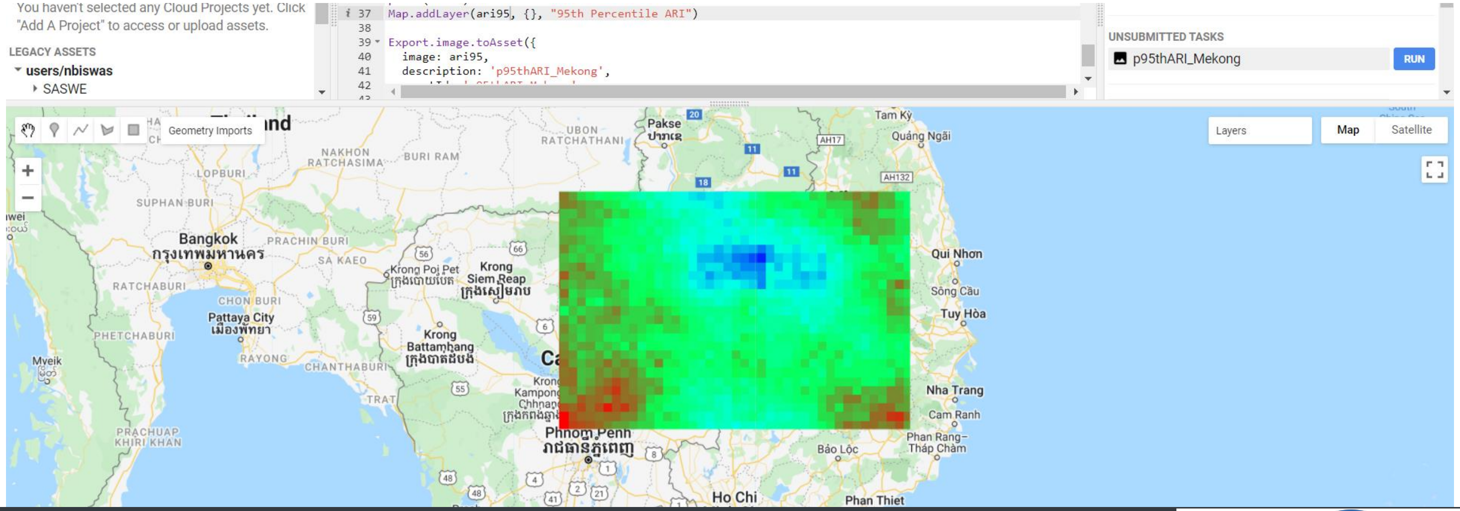
Historical ARI Calculation

```
////  Step 4: Adding 95th percentile image in the map
Map.addLayer(ari95, {}, "95th Percentile ARI")
```

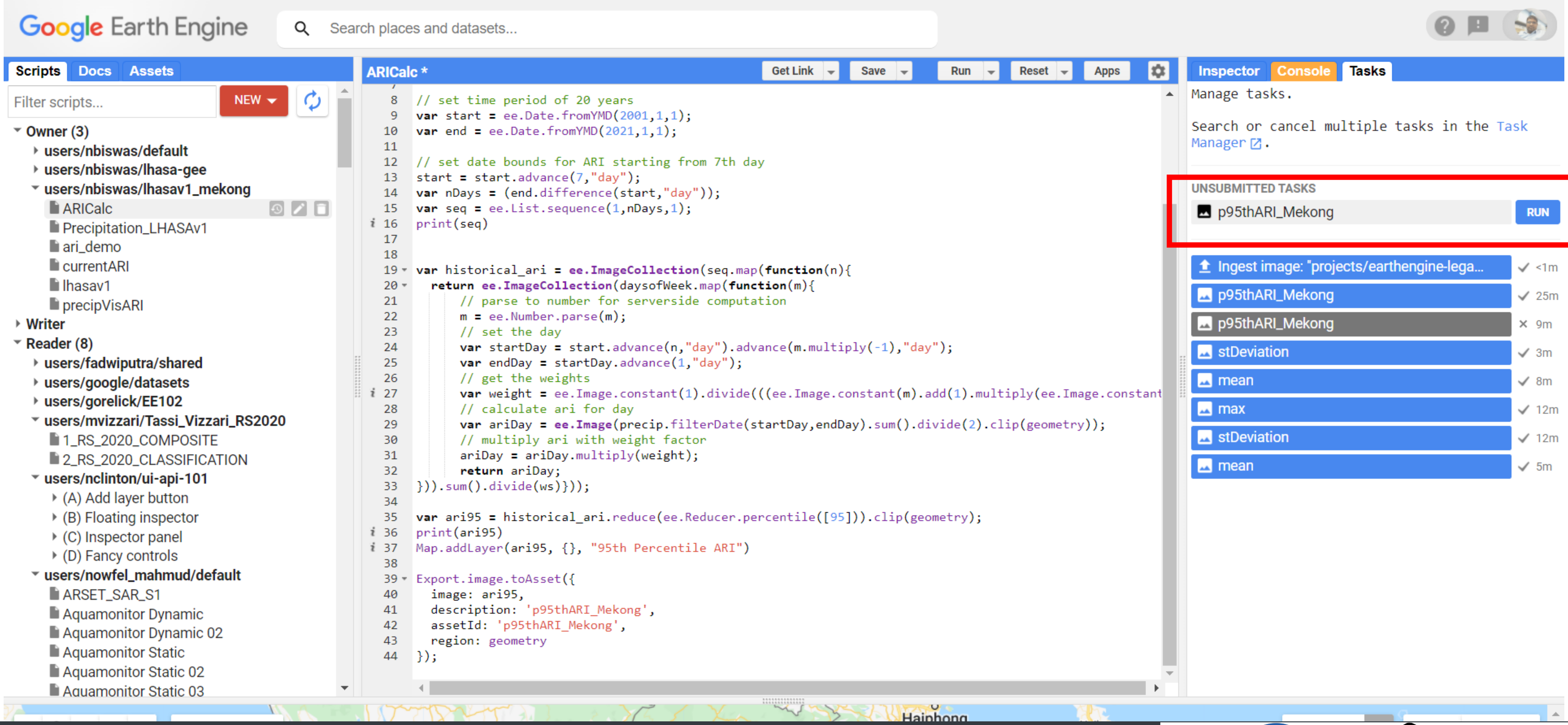
Adding historical ARI in GEE Map

```
////  Step 5: Exporting 95th percentile map in GEE Asset
Export.image.toAsset({
  image: ari95,
  description: 'p95thARI_Mekong',
  assetId: 'p95thARI_Mekong',
  region: geometry
});
```

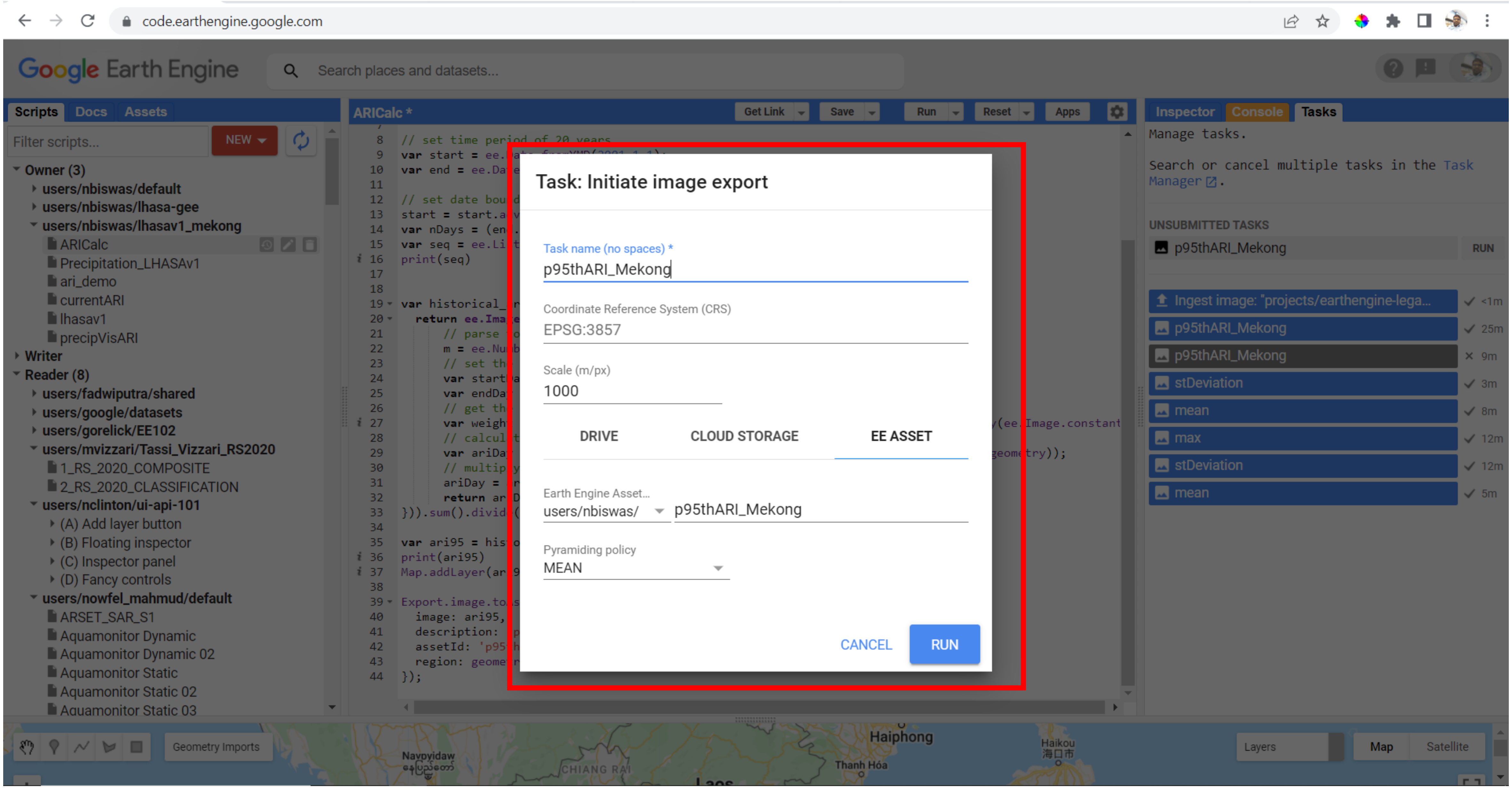
Exporting historical ARI in GEE



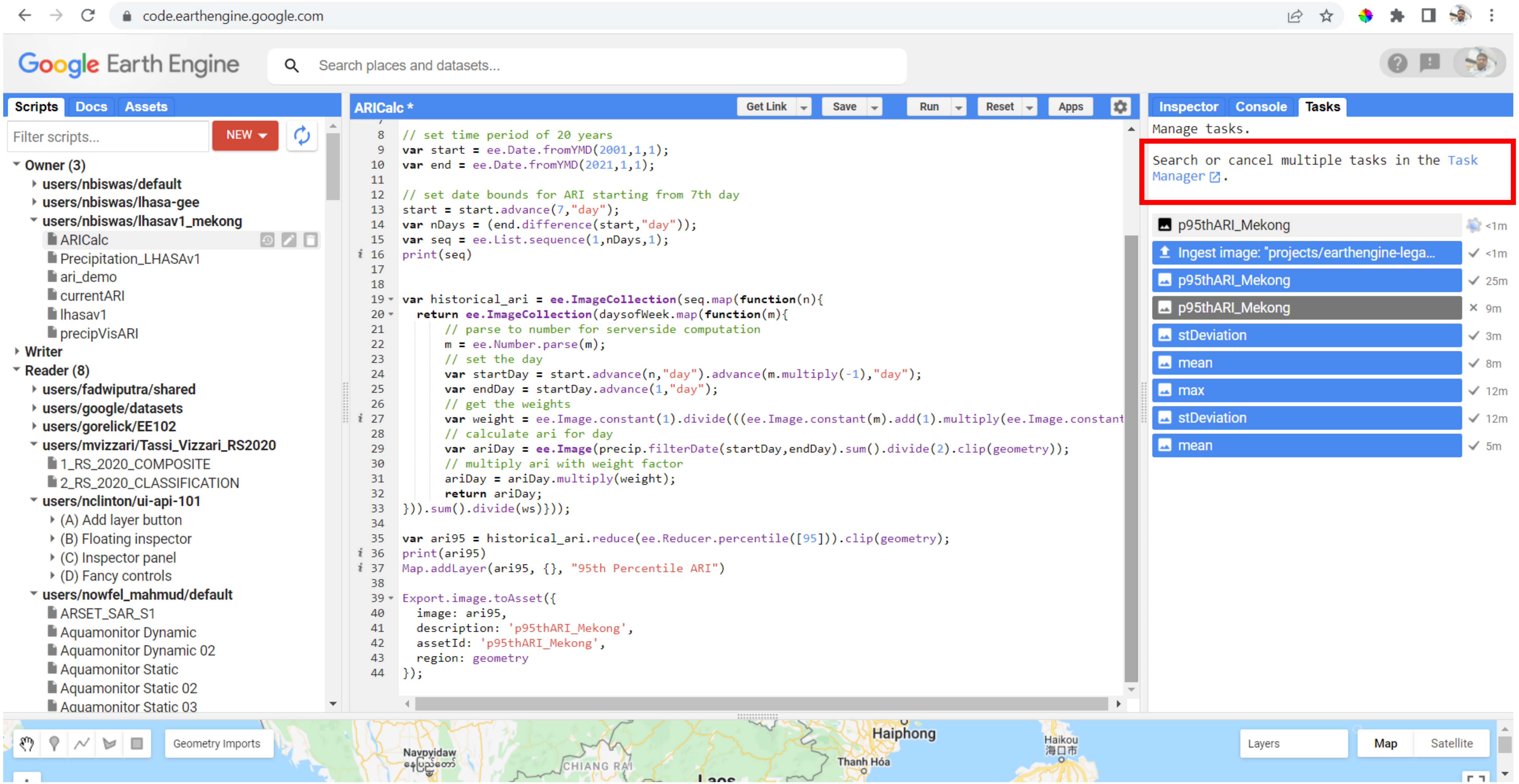
Complete Code to Historical ARI



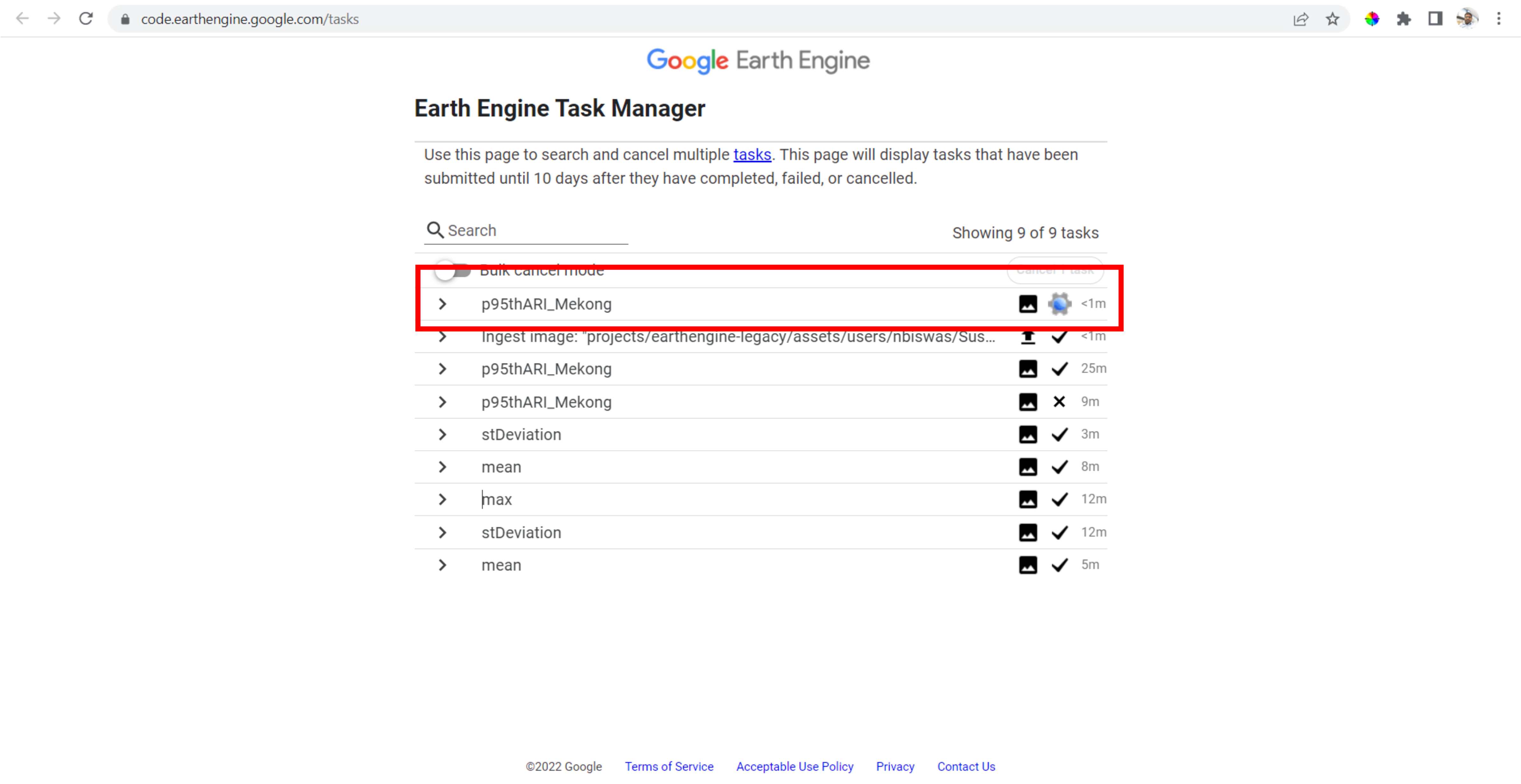
Historical ARI Calculation



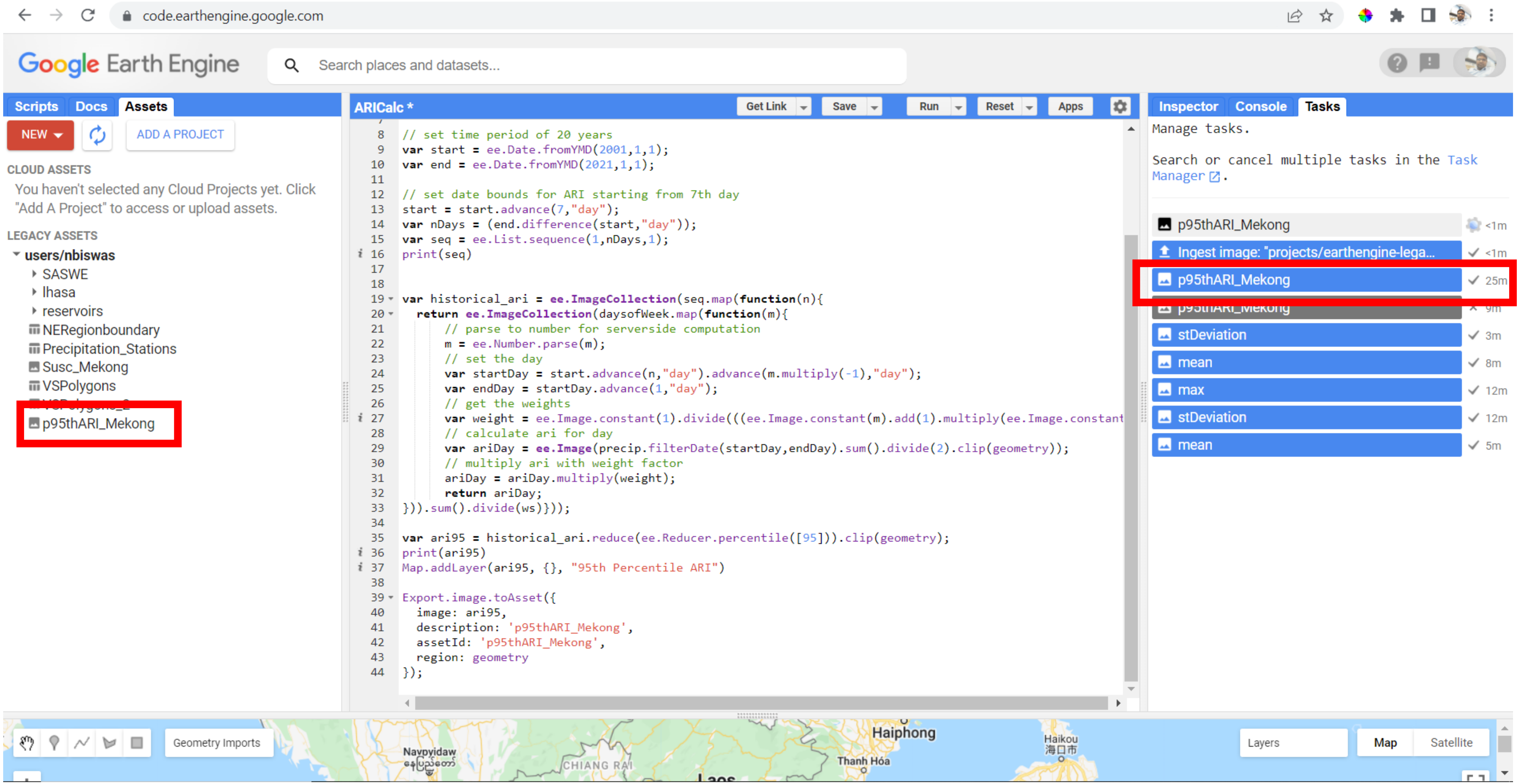
Historical ARI Calculation



Historical ARI Calculation

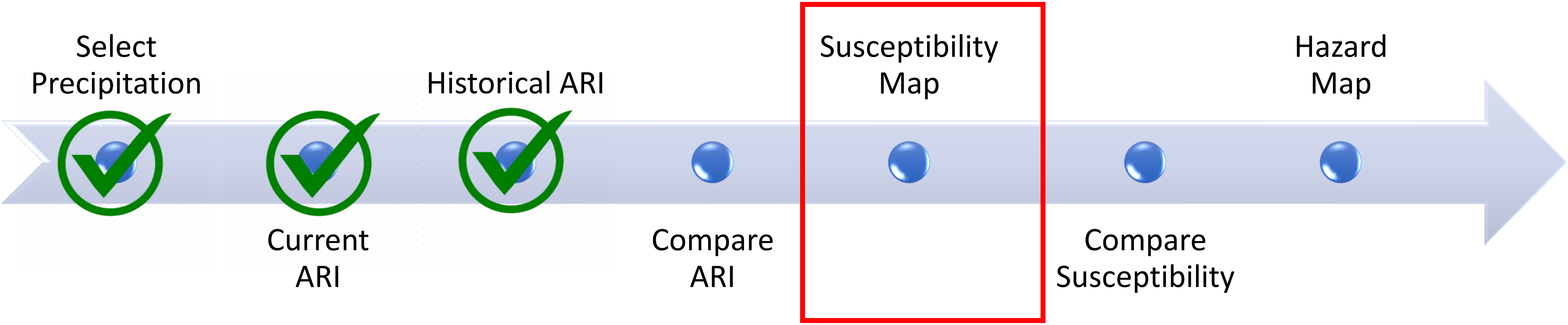


Historical ARI Calculation



LHASA version 1

Step 5: Susceptibility Map Ingestion

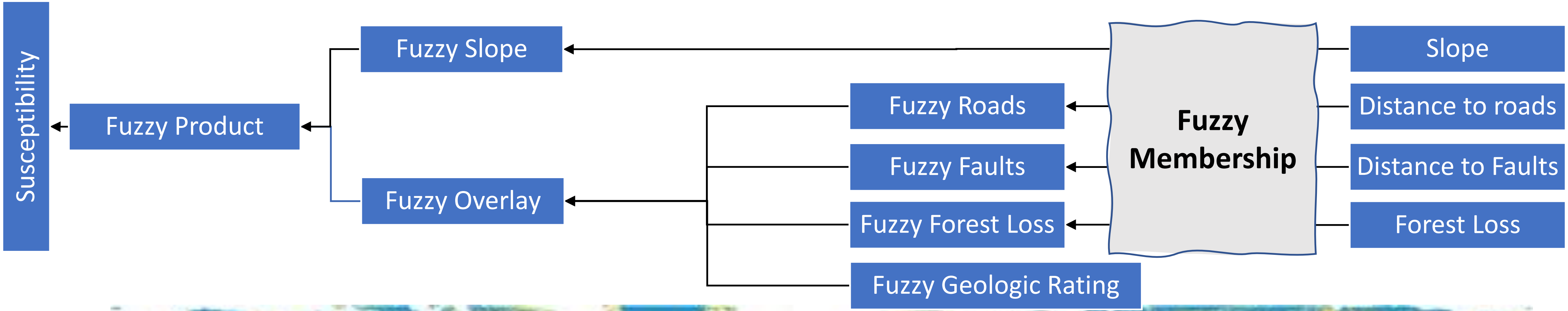


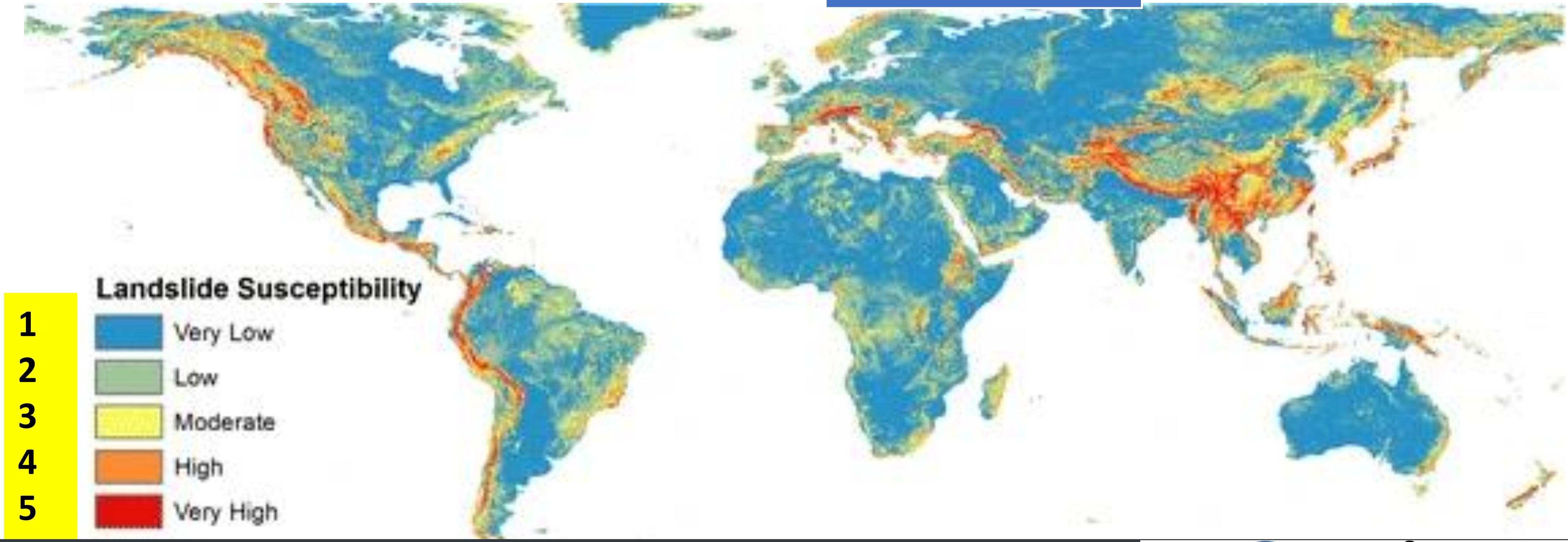
Requirements:

Susceptibility_Code.txt, available in SERVIR Landslide Page

Susceptibility_map_clipped.tif- Download the NASA Landslide Susceptibility map, and clip to your region of interest.

Susceptibility Map

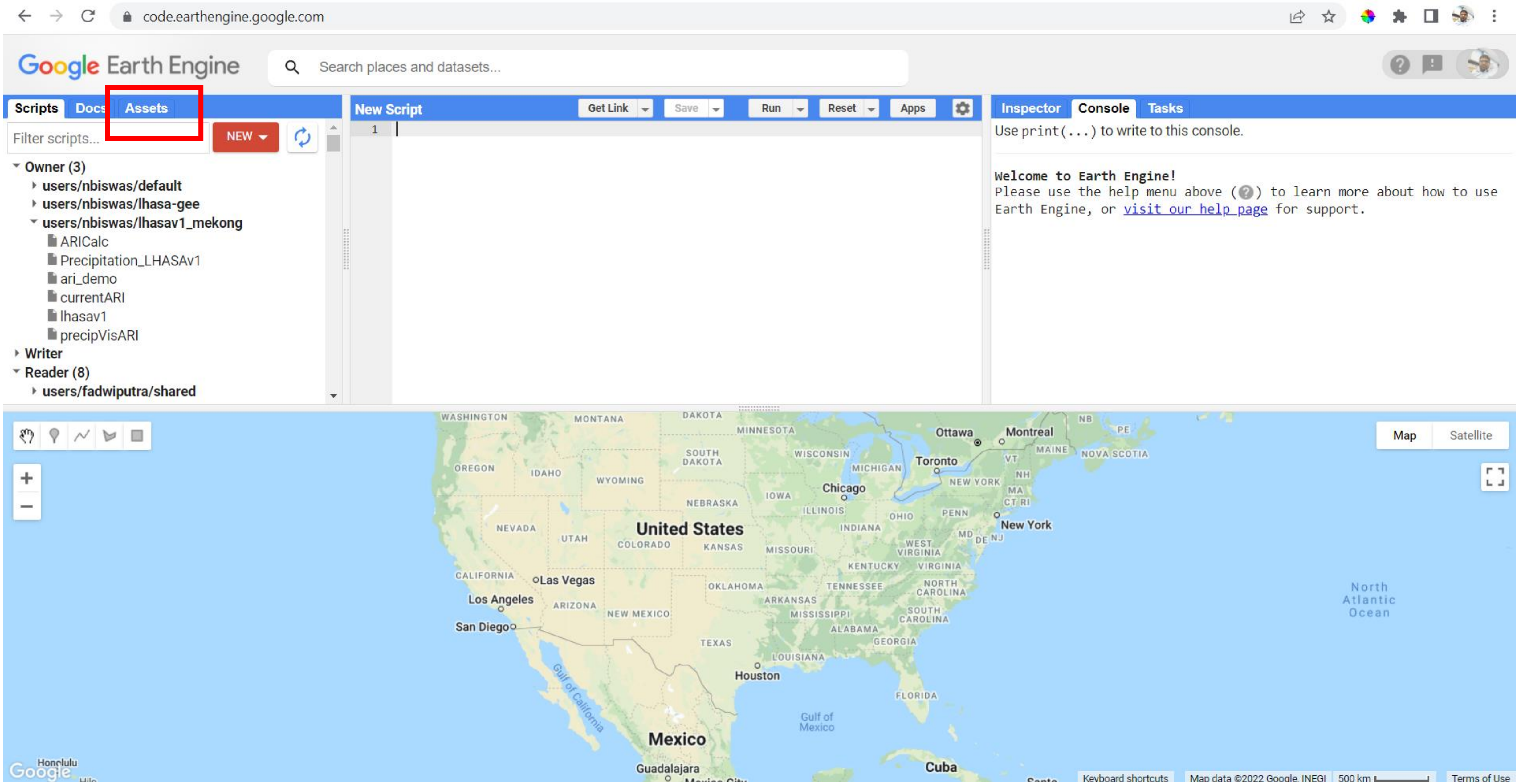




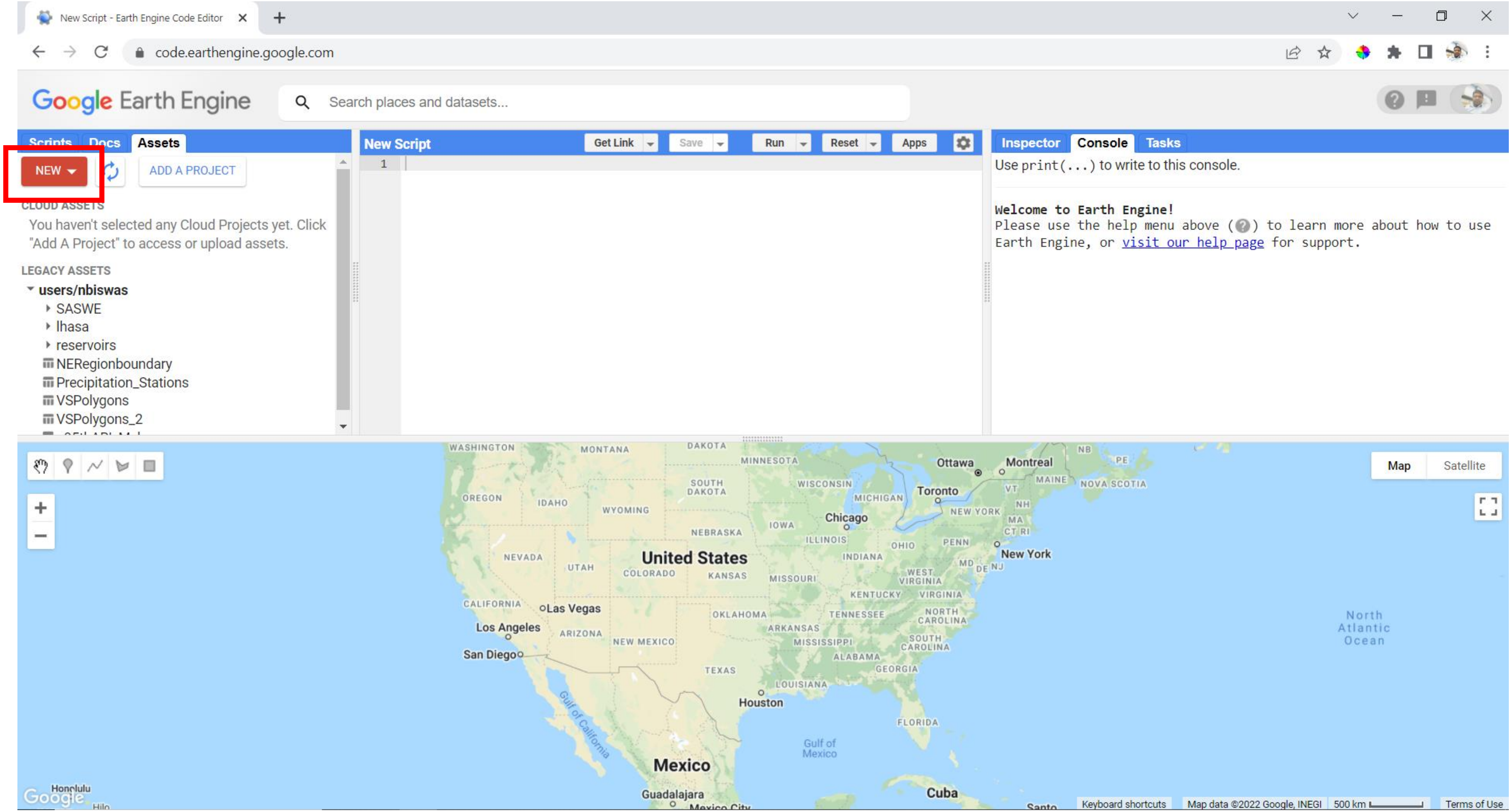
Importing susceptibility map in GEE

1. Download the NASA Landslide Susceptibility map, and clip to your region of interest.
2. Import the Susceptibility Map your current GEE project

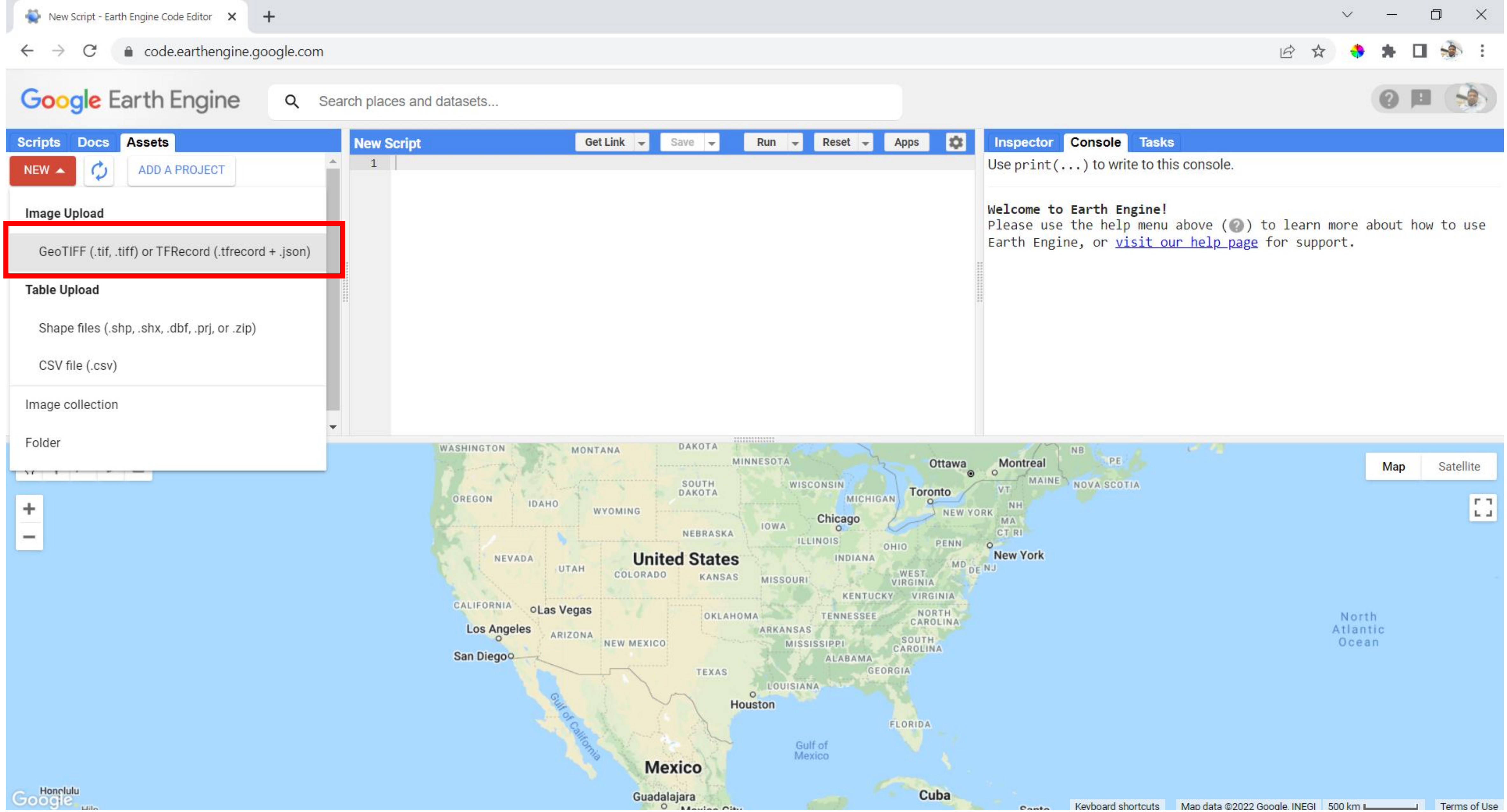
Importing susceptibility map in GEE



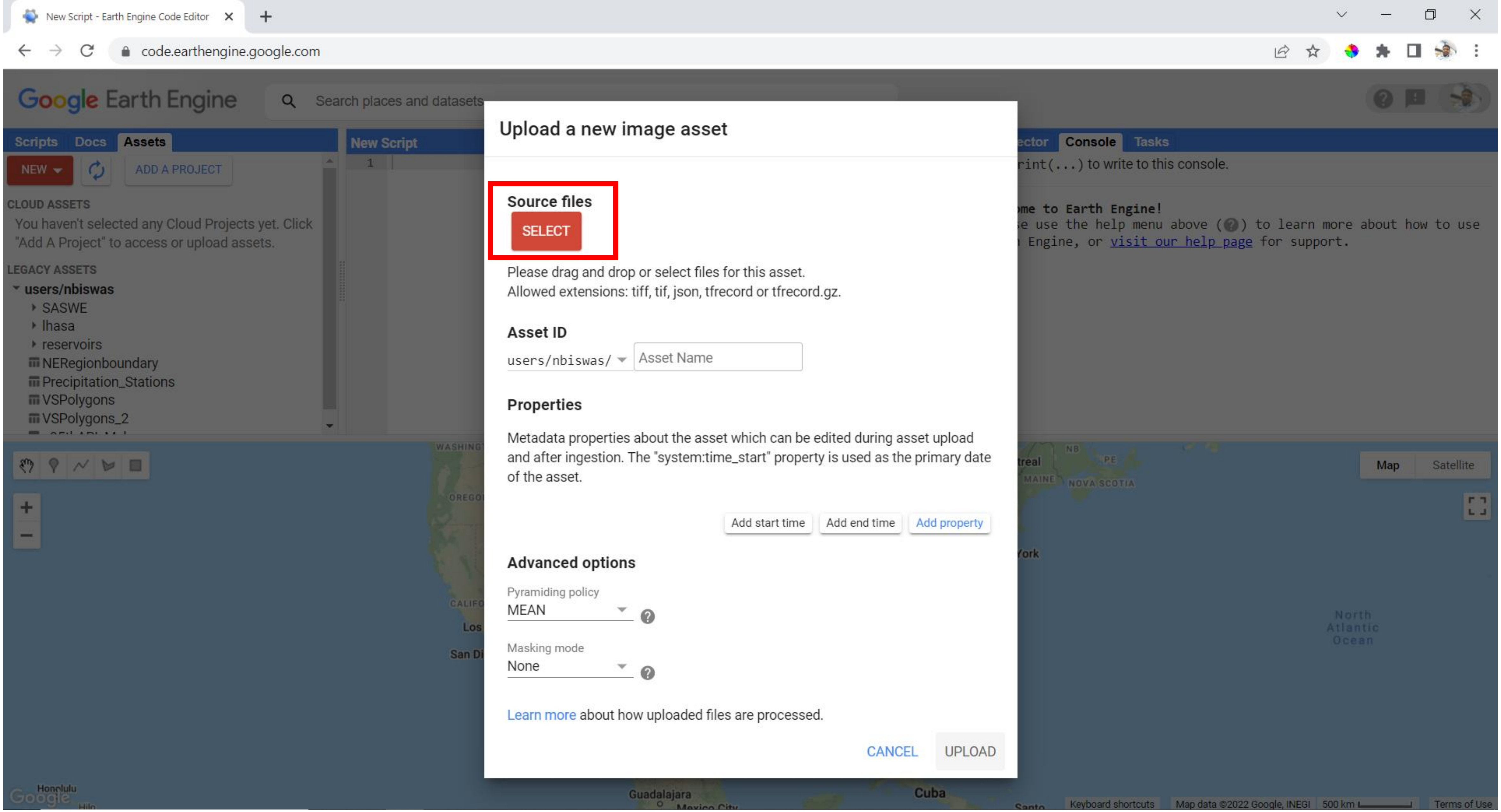
Importing susceptibility map in GEE



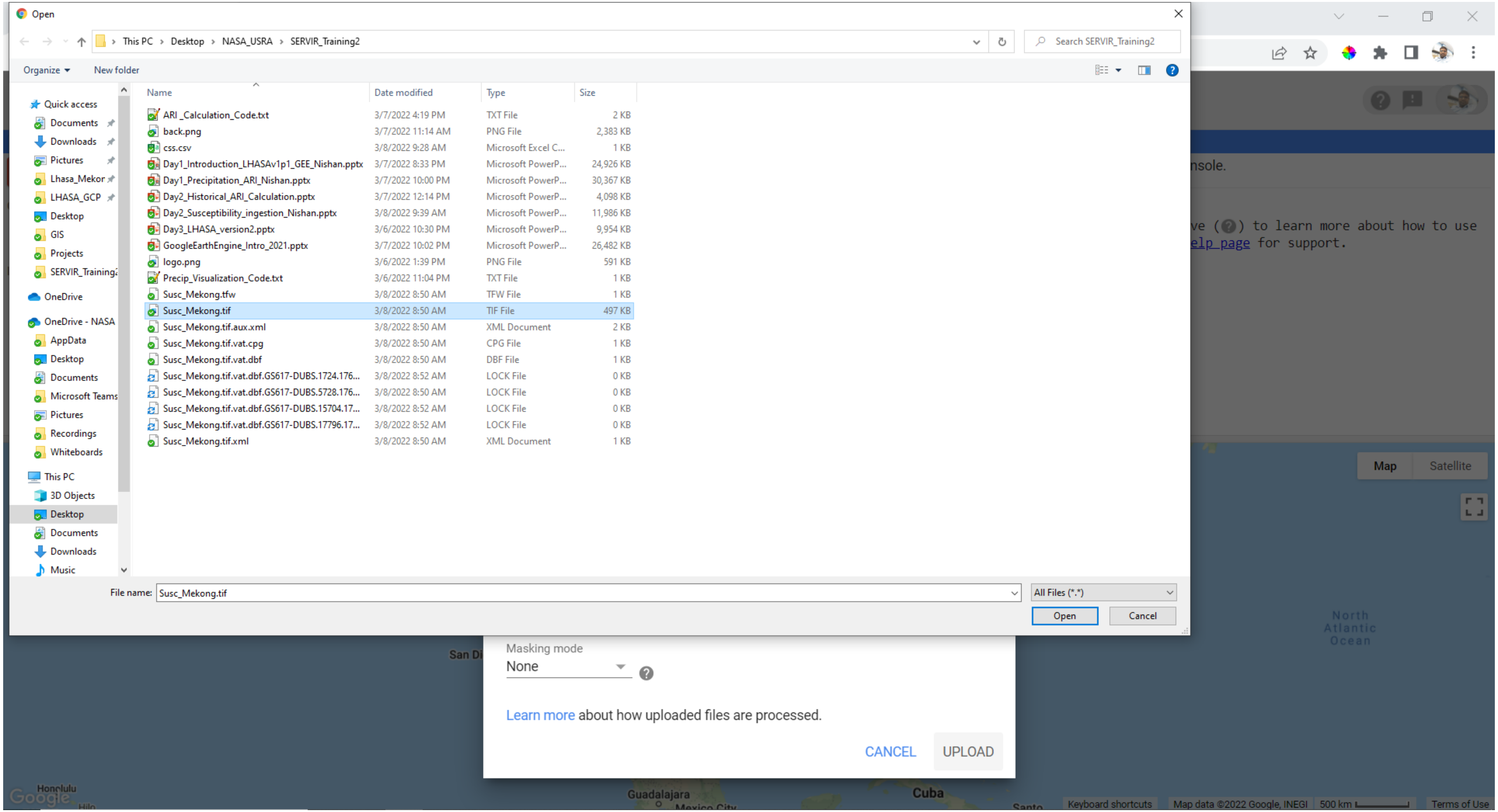
Importing susceptibility map in GEE



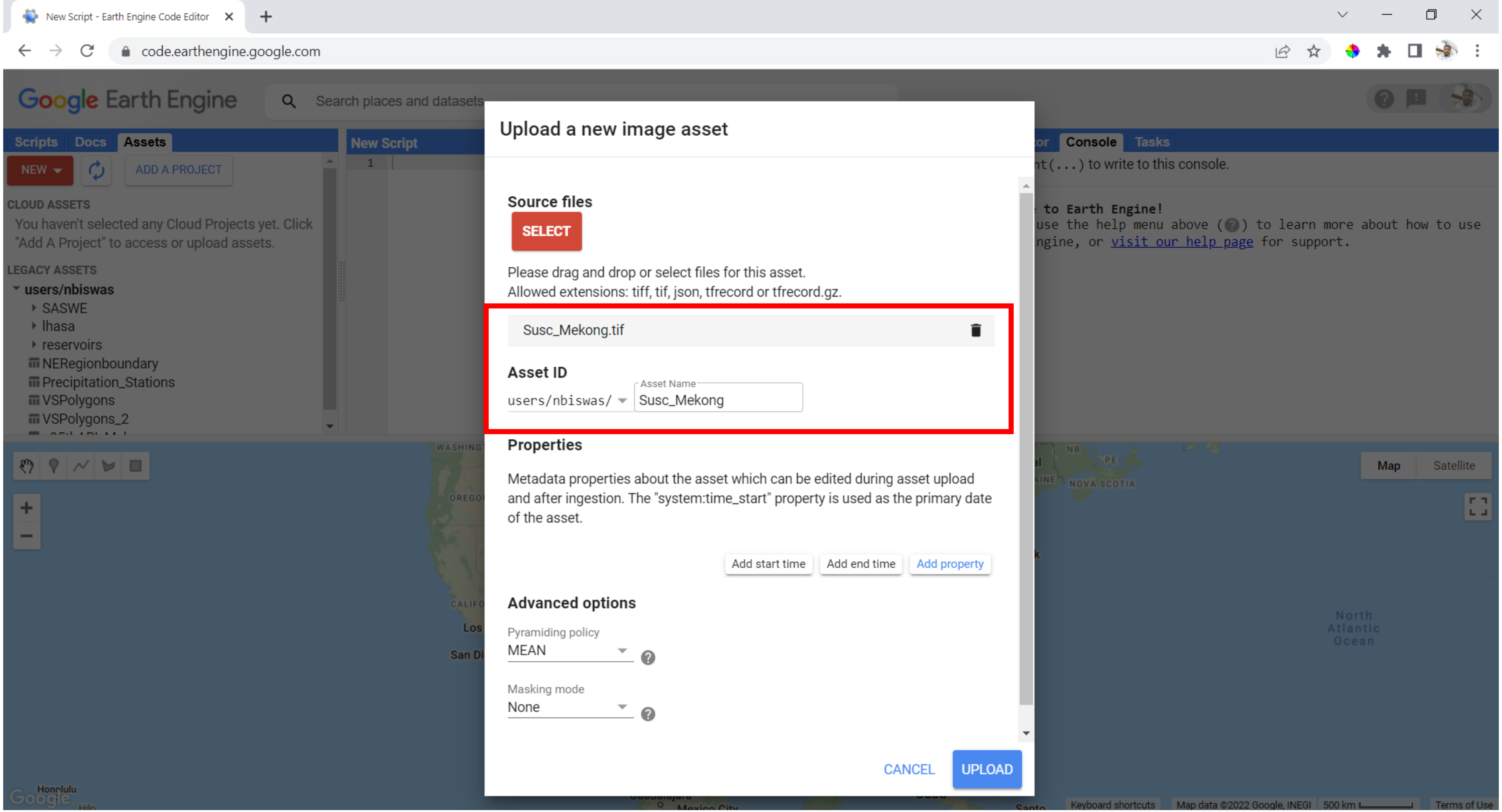
Importing susceptibility map in GEE



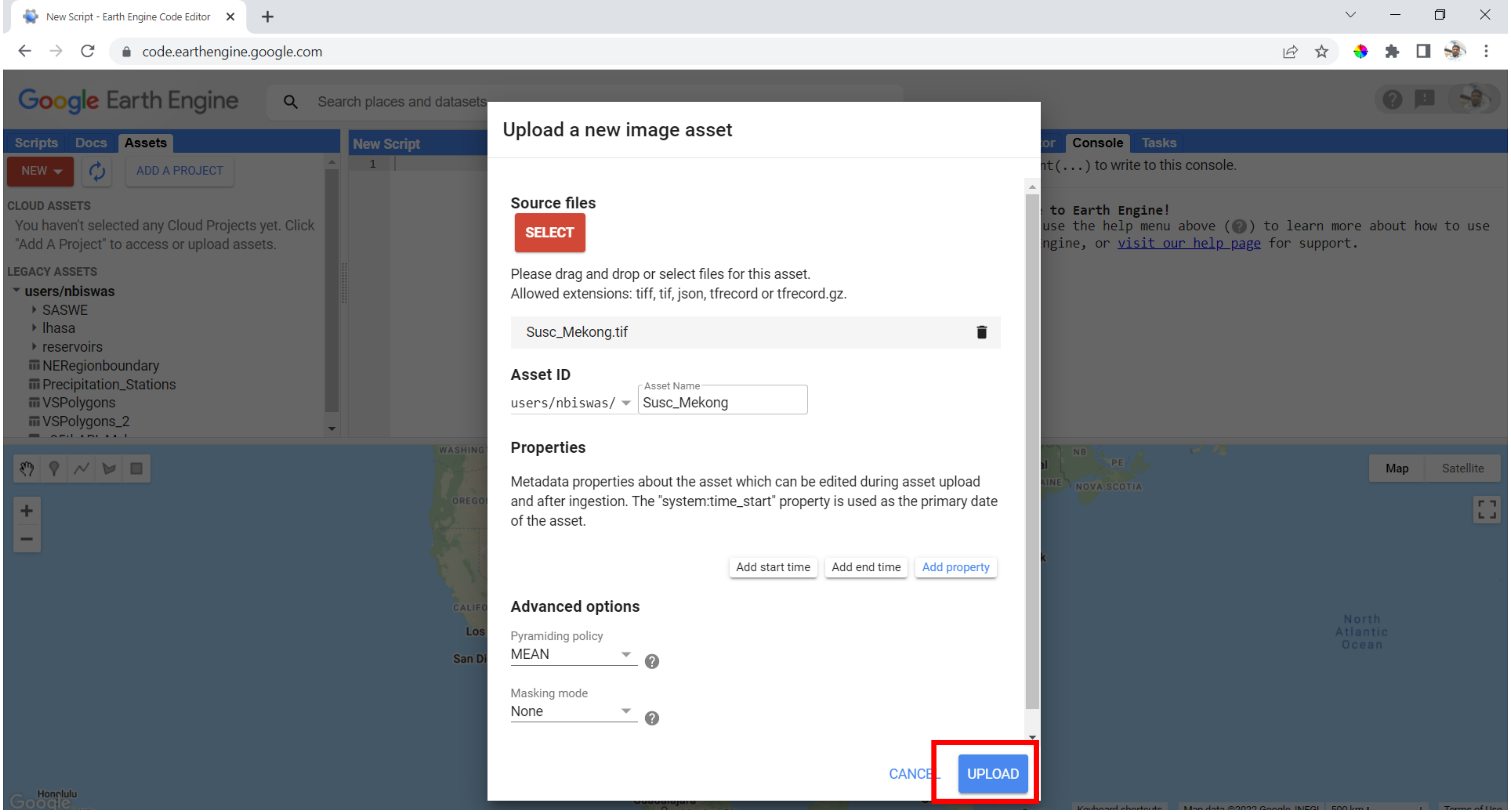
Importing susceptibility map in GEE



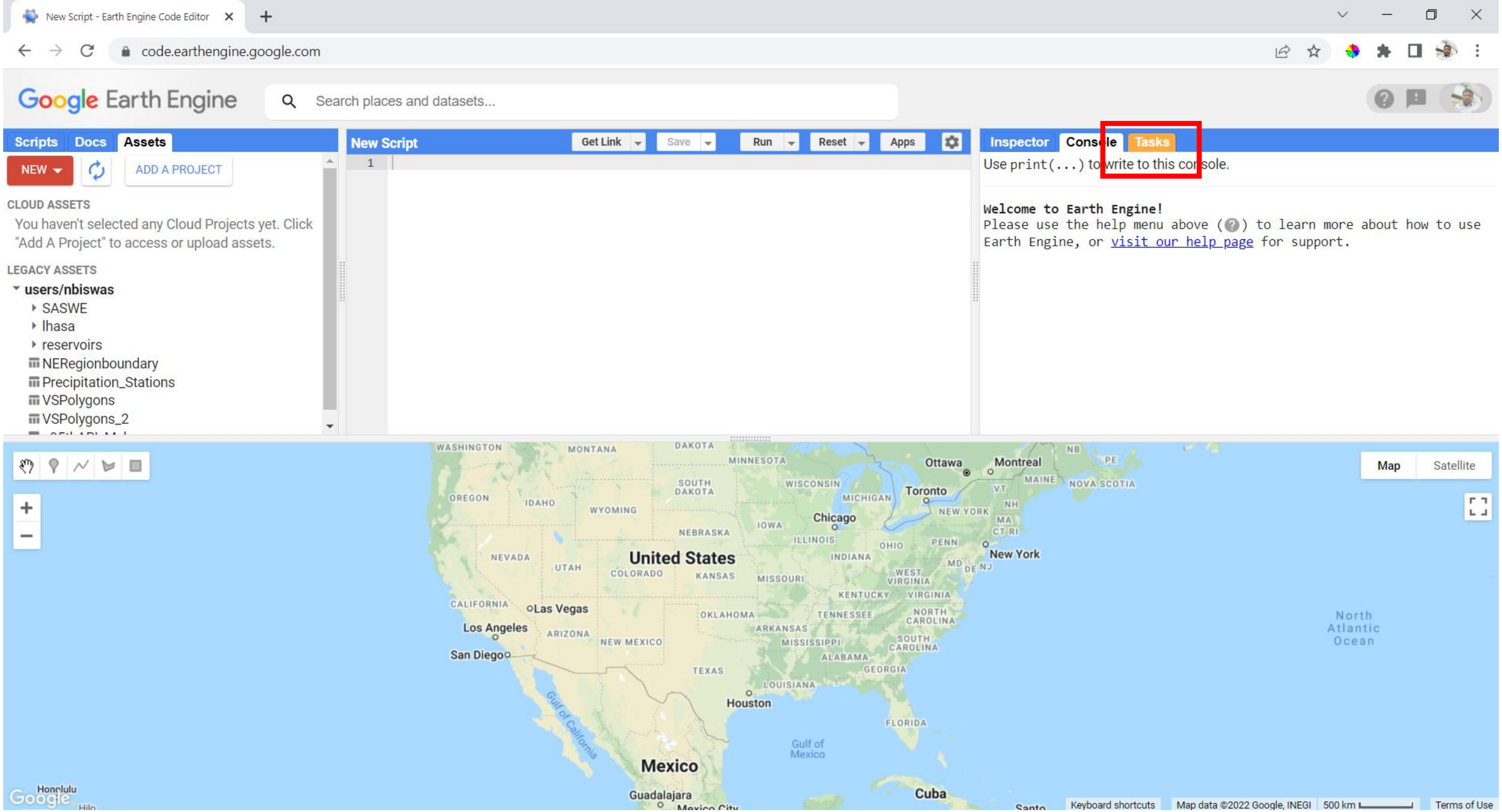
Importing susceptibility map in GEE



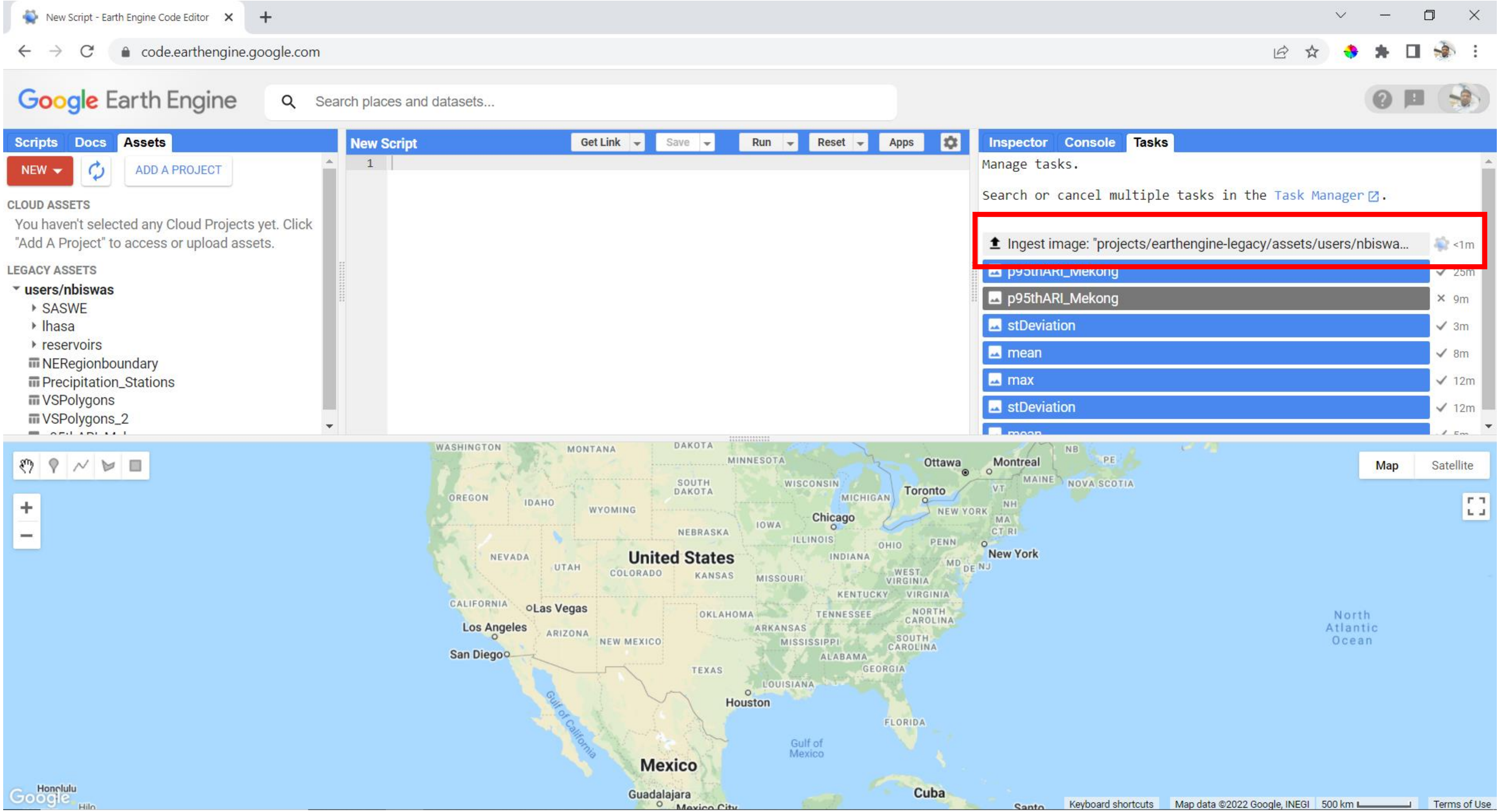
Importing susceptibility map in GEE



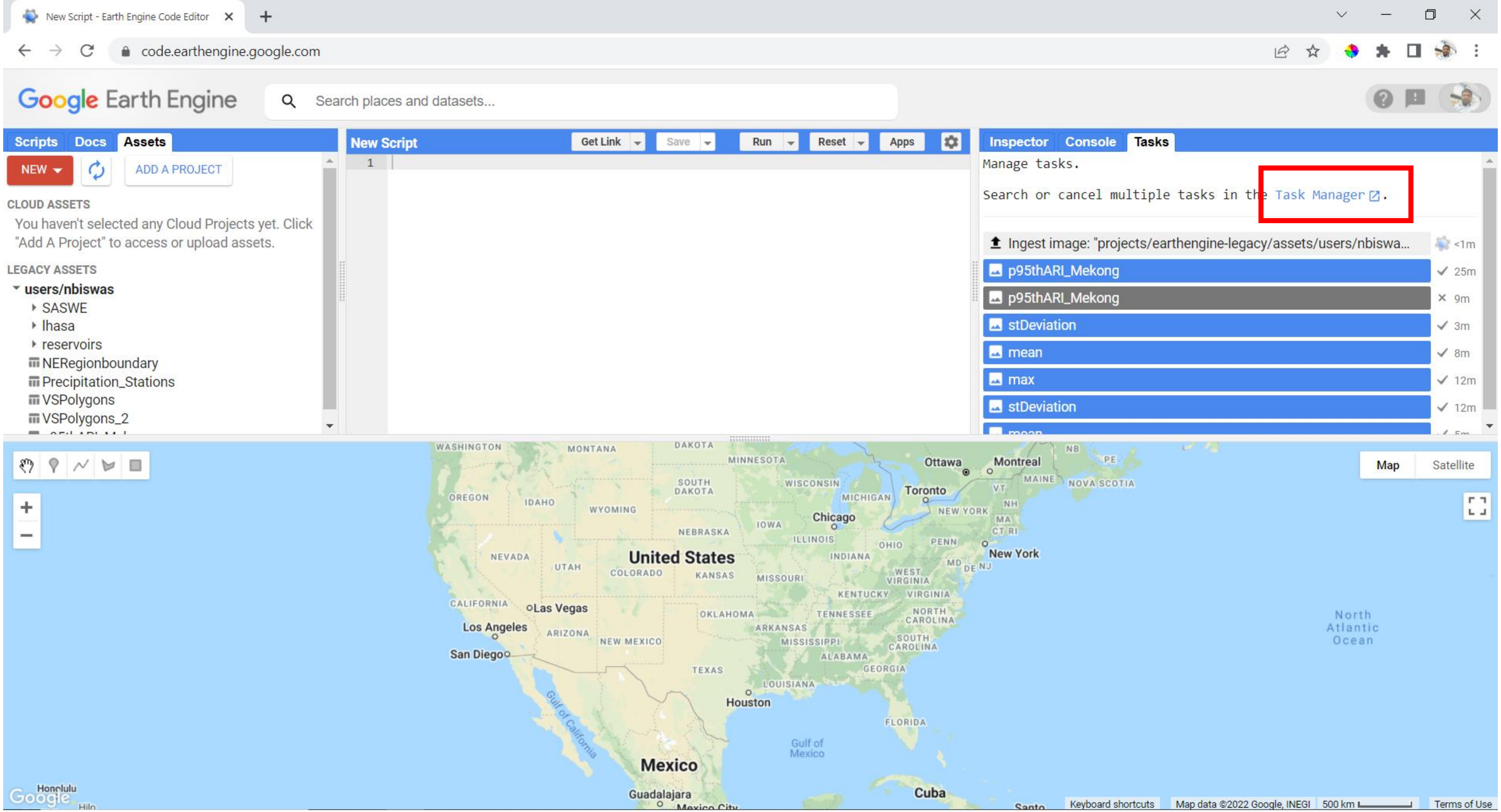
Importing susceptibility map in GEE



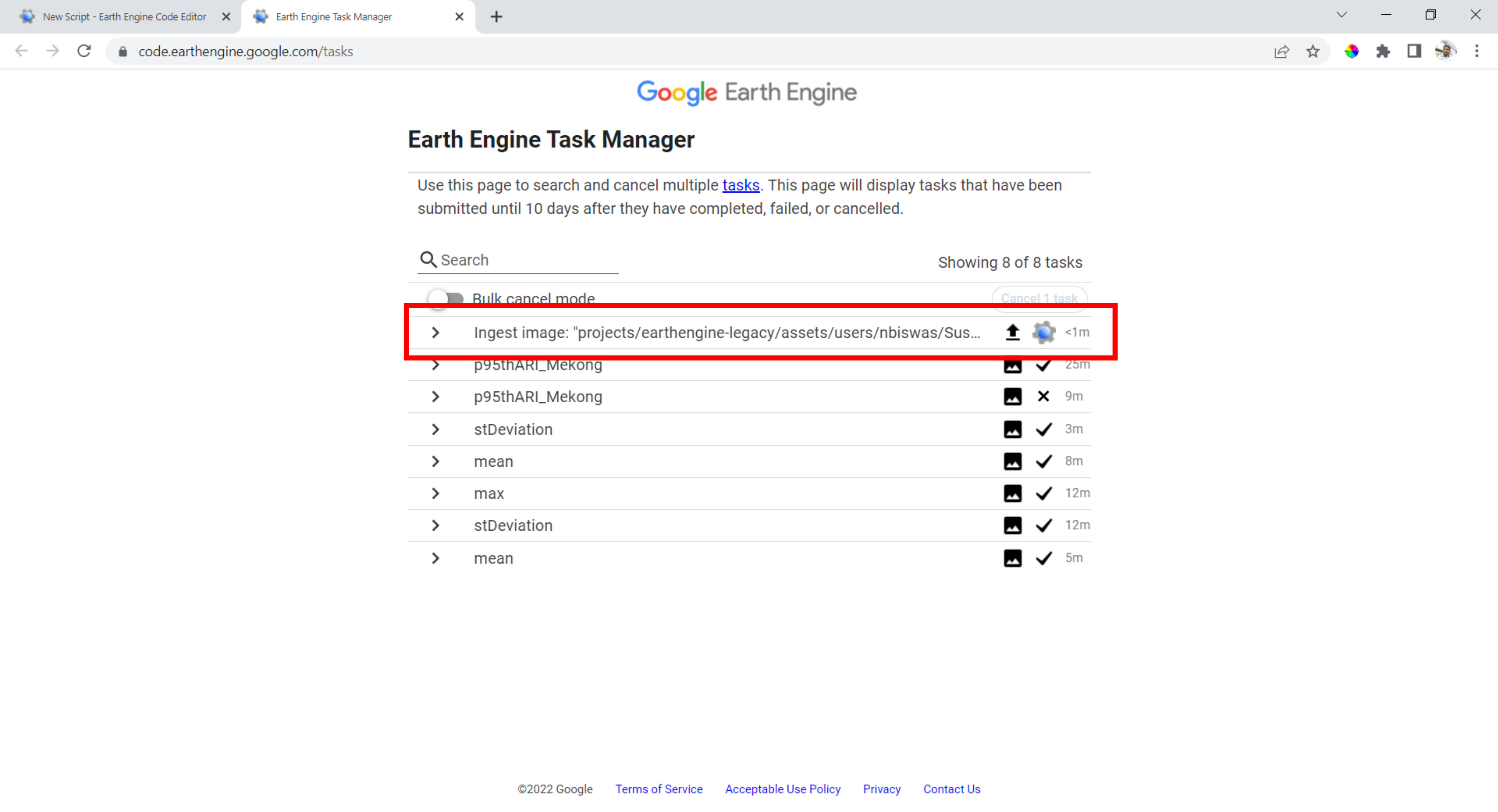
Importing susceptibility map in GEE



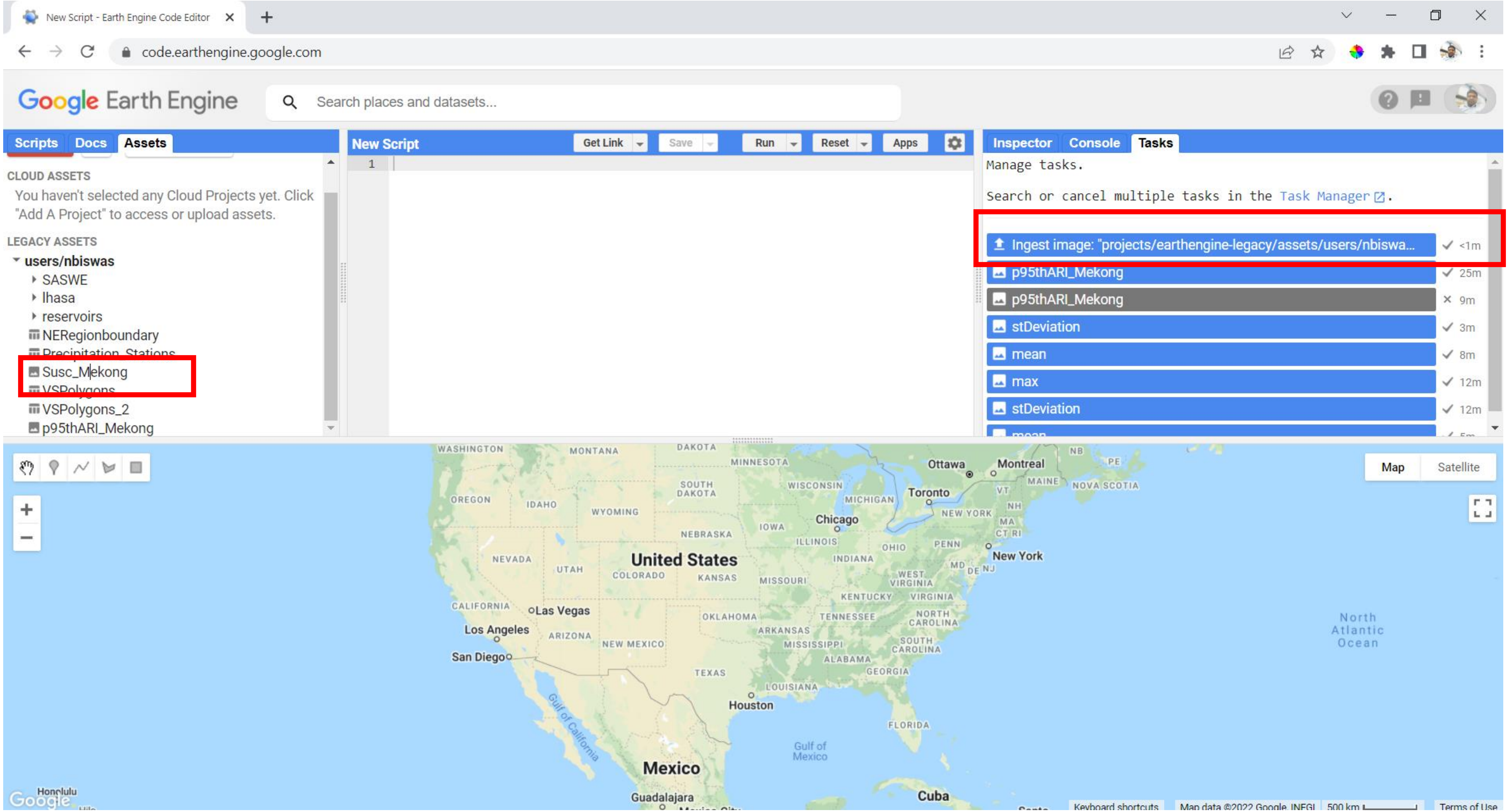
Importing susceptibility map in GEE



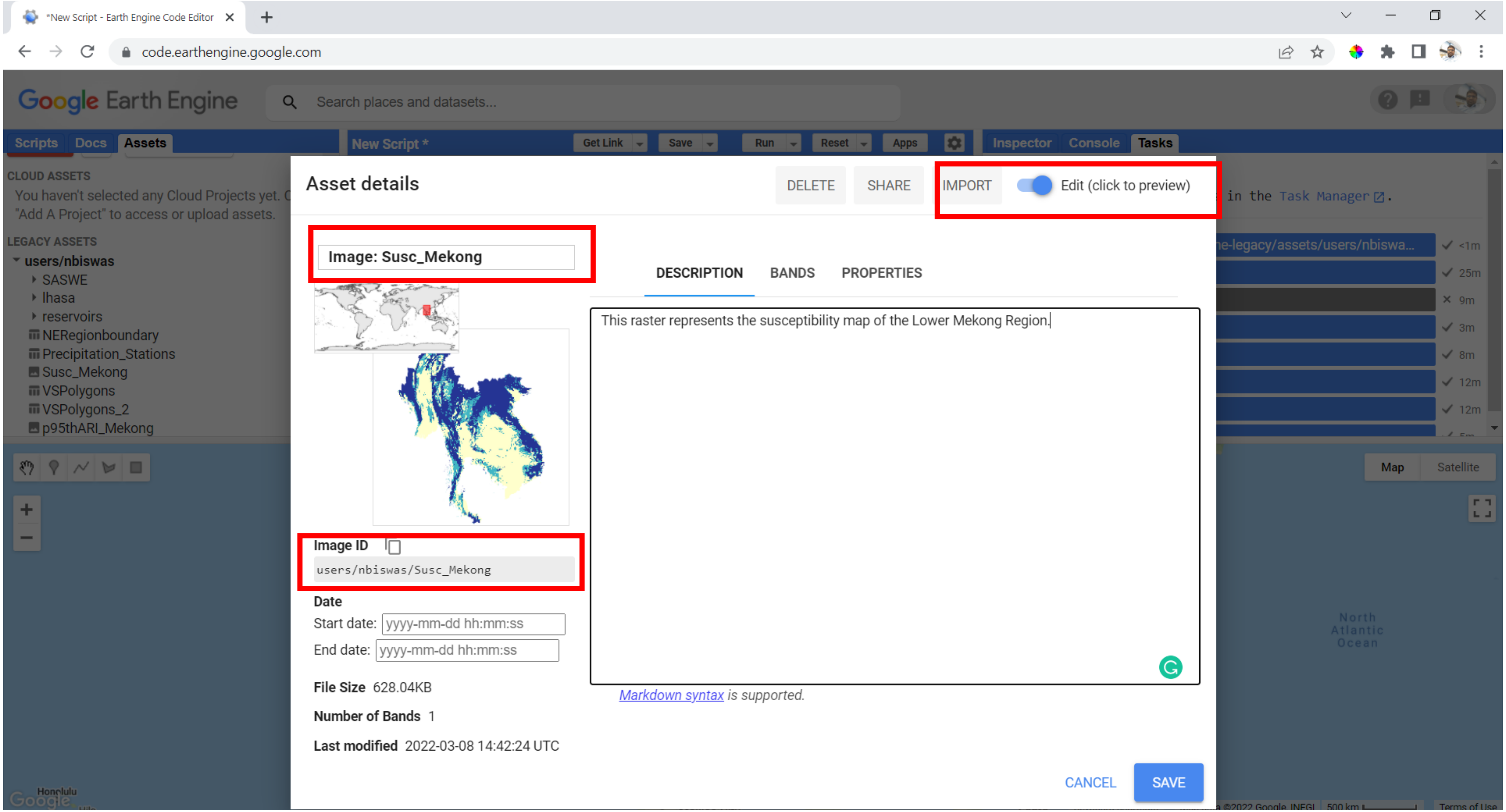
Importing susceptibility map in GEE



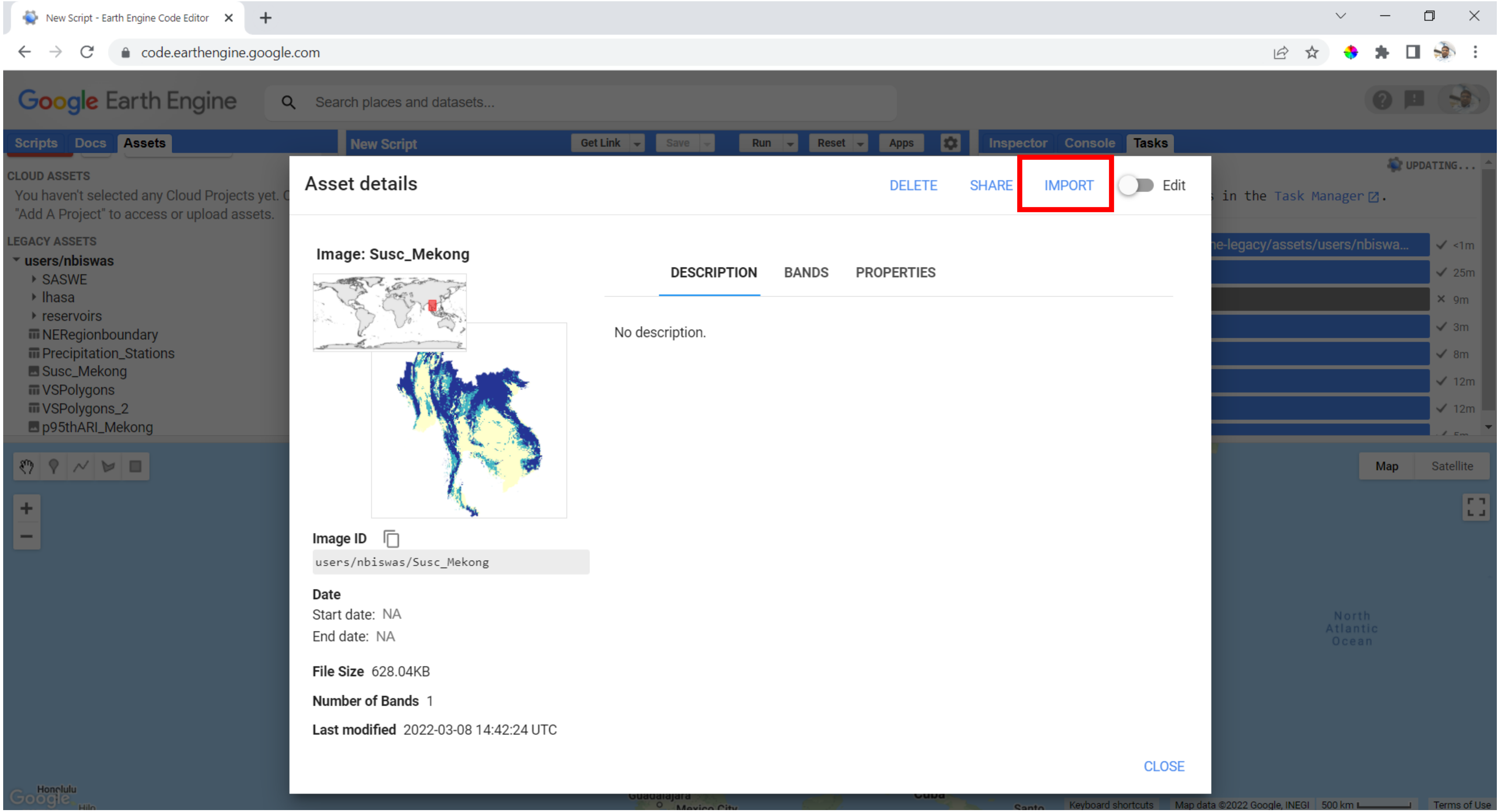
Importing susceptibility map in GEE



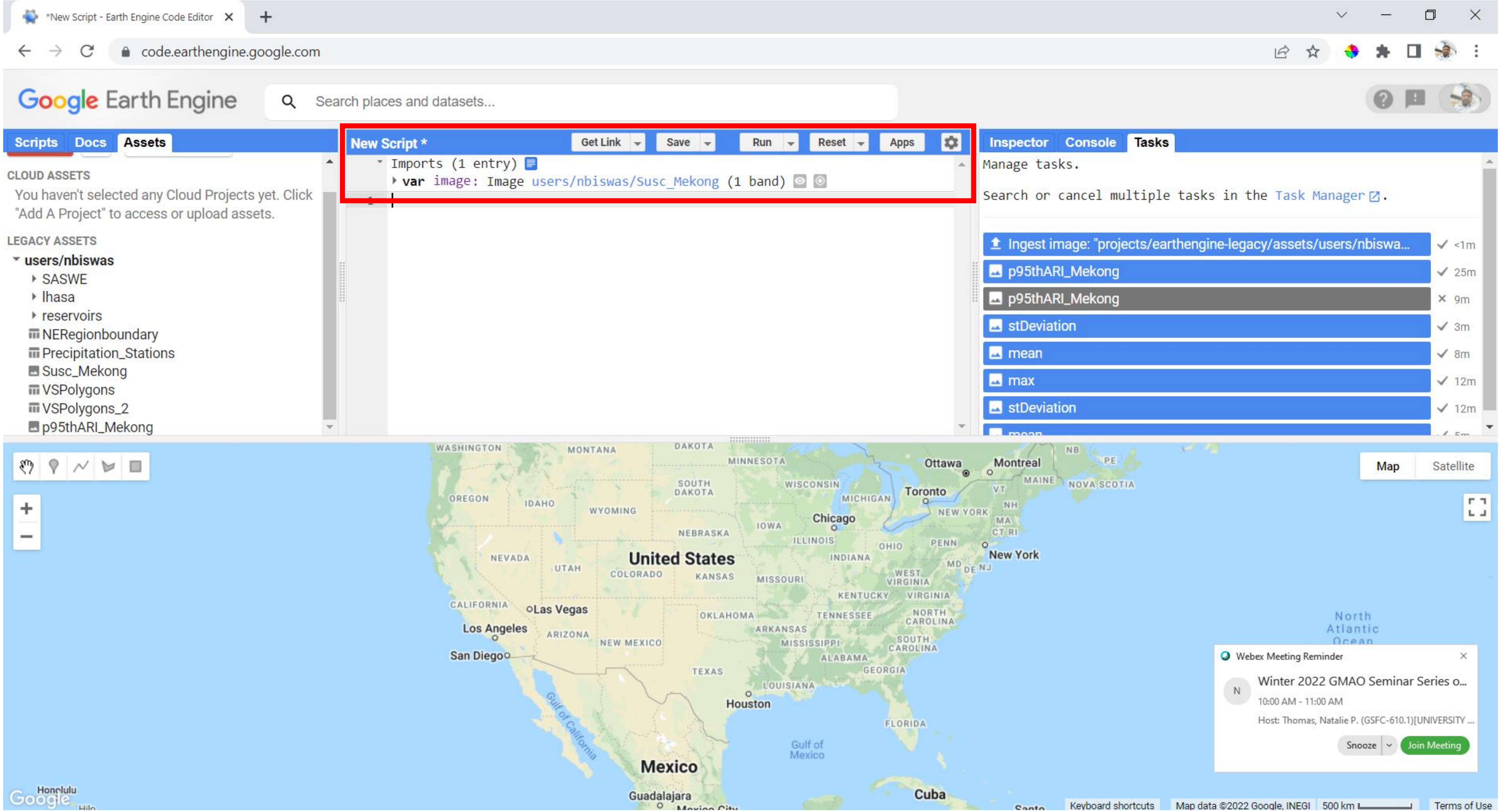
Importing susceptibility map in GEE



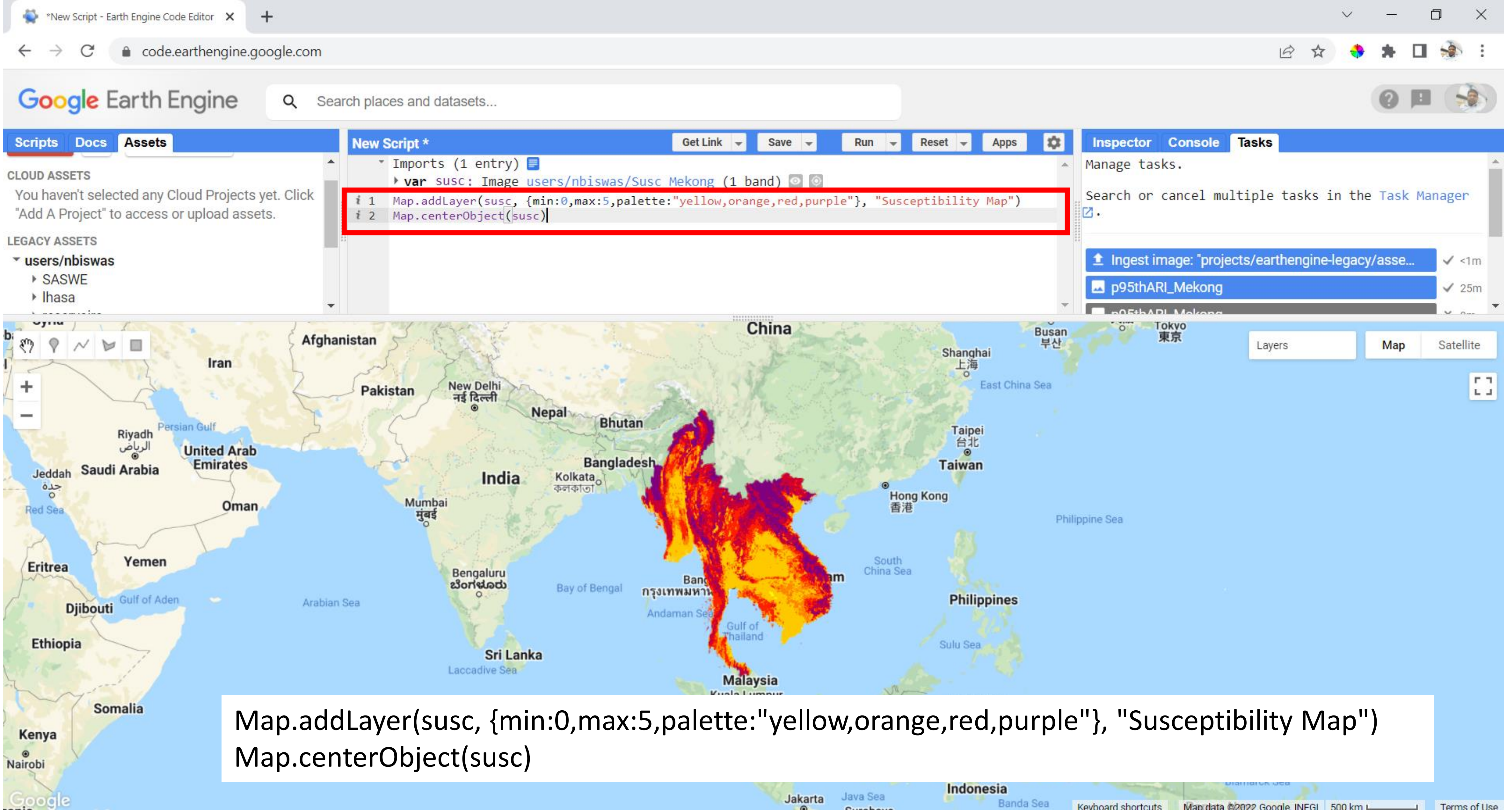
Importing susceptibility map in GEE



Importing susceptibility map in GEE

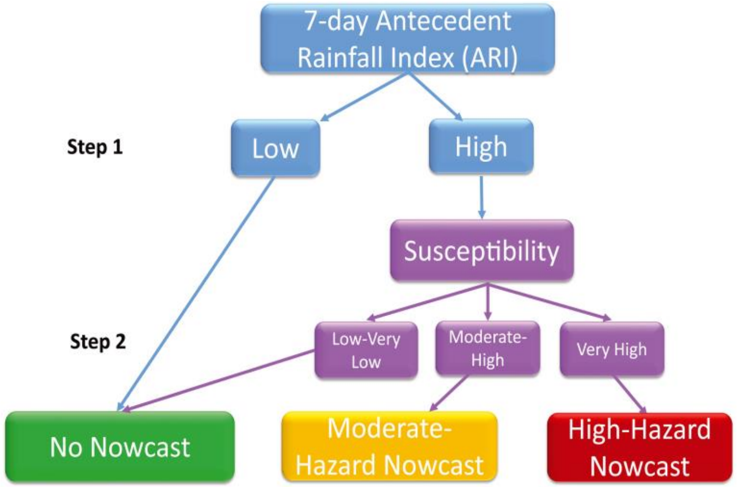


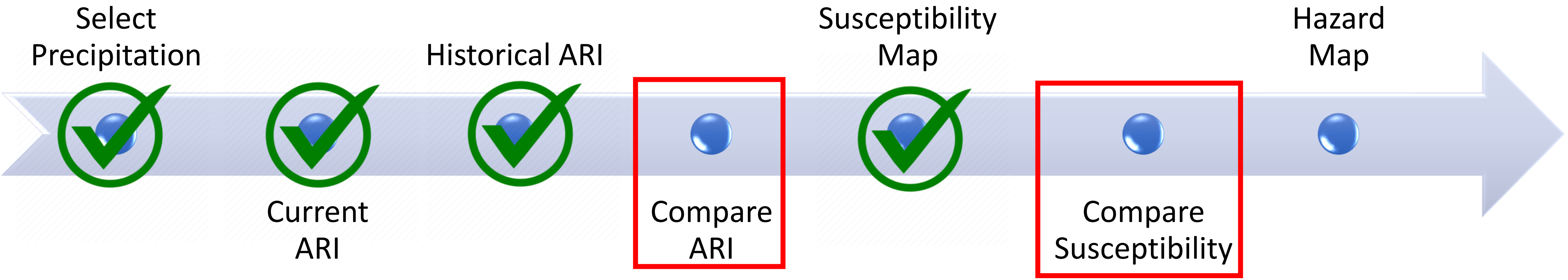
Importing susceptibility map in GEE




```
Map.addLayer(susc, {min:0,max:5,palette:"yellow,orange,red,purple"}, "Susceptibility Map")
Map.centerObject(susc)
```

Step 4 and 6: ARI and Susceptibility Comparison

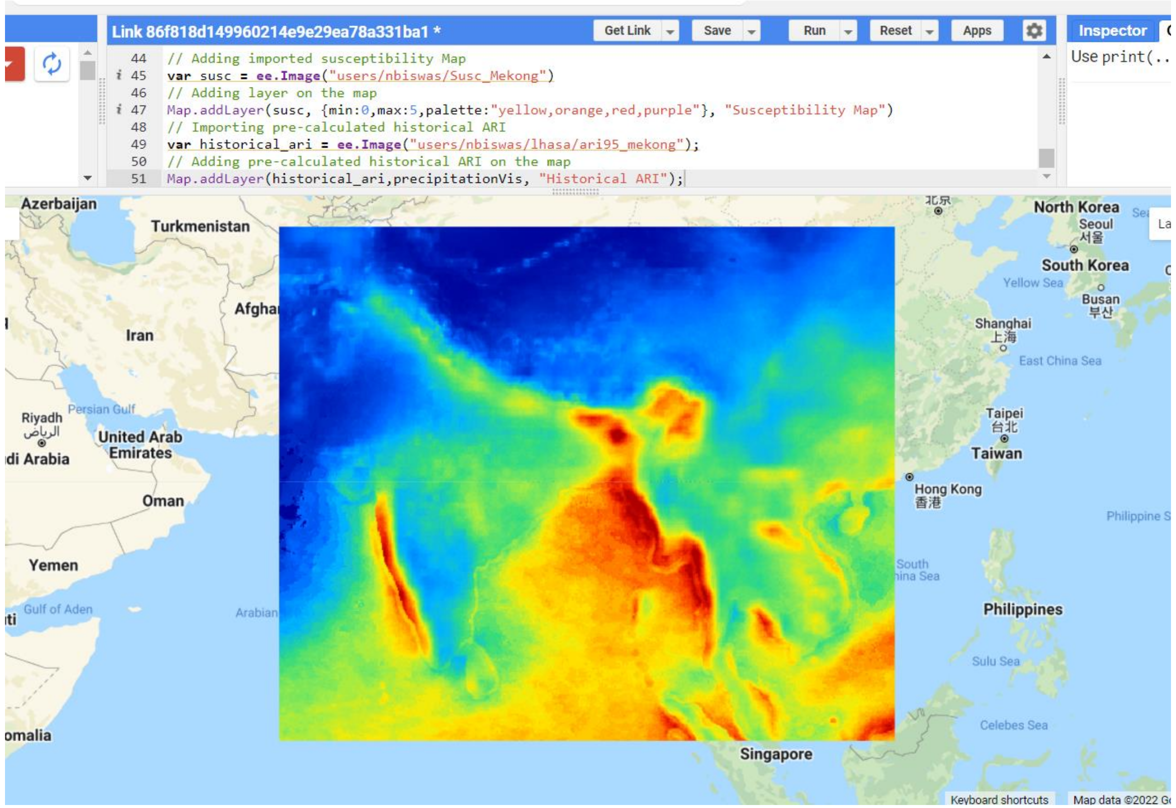




Sharing pre-calculated ARI in GEE

Add these lines below the earlier code:

```
// Adding pre-calculated historical ARI
var historical_ari = ee.Image("users/nbiswas/lhasa/ari95_mekong");
// Adding pre-calculated historical ARI on the map
Map.addLayer(historical_ari,precipitationVis, "Historical ARI");
```



Comparison of ARI and Susceptibility

```
///////**************** Applying decision tree algorithm ***************
// Checking the area where current ARI is greater than historical ARI
var heavy_rain = ari.gt(historical_ari).rename('Heavy Rainfall');
```

ARI> 95th Percentile of Historical Precip

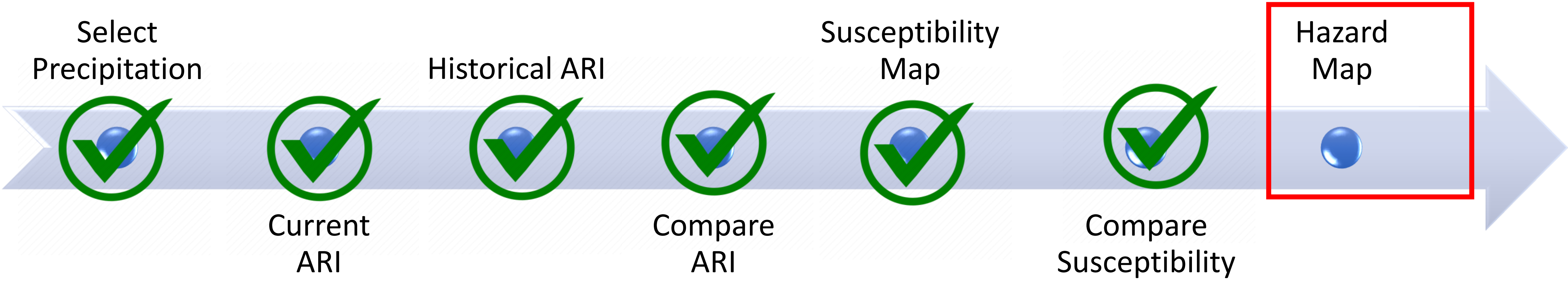
```
// Current ARI>historical ARI and Susceptibility value greater than 2 is moderate hazard zone
var moderate = heavy_rain.and(susc.gt(2)).rename('Moderate_Nowcast');
```

Comparing with Susceptibility map

```
// Current ARI>historical ARI and Susceptibility value greater than 4 is high hazard zone
var high = moderate.and(susc.gt(4)).rename('High_Nowcast');
```

Comparing with Susceptibility map

Step 7: Hazard Map Visualization



Hazard Map Visualization: Adding layers on the Map

```
// Adding layer on the map
Map.addLayer(prcp1day.clip(geometry), precipitationVis, "Precipitation")
```

Adding precipitation layer

```
// Adding current ARI Layer
Map.addLayer(ari, precipitationVis, "Current ARI of " + date)
```

Adding current ARI layer

```
// Adding historical ARI Map
Map.addLayer(historical_ari,precipitationVis, "Historical ARI");
```

Adding historical ARI layer

```
// Adding Susceptibility Map layer on the map
Map.addLayer(susc, {min:0,max:5,palette:"yellow,orange,red,purple"}, "Susceptibility Map")
```

Adding susceptibility map

```
// Adding heavy_rain on the map
Map.addLayer(heavy_rain,{min: 0.0, max: 1.0, palette: ['red','blue']}, "Heavy Rain");
```

Adding heavy rain map

```
// Adding moderate hazard map layer on the map
Map.addLayer(moderate,{min:0, max:1, palette:'yellow'},'moderate-hazard’);
```

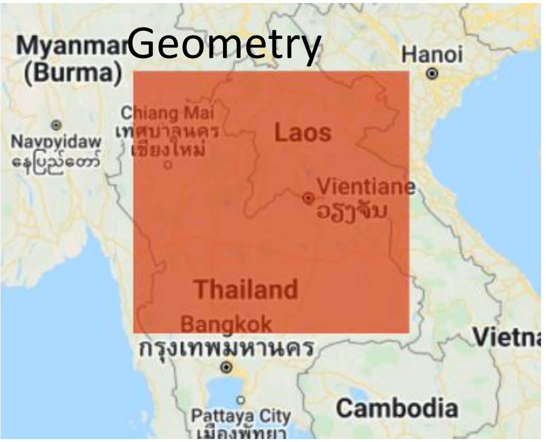
Adding moderate hazard map

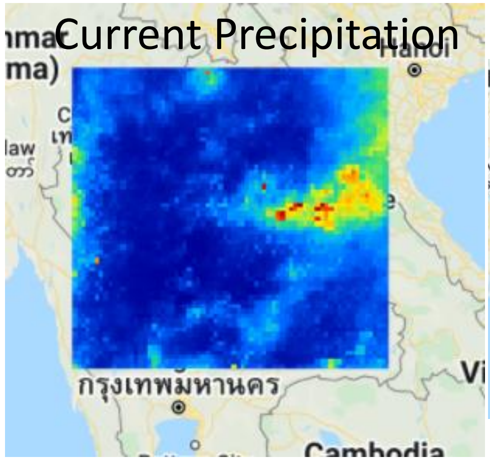
```
// Adding high hazard map layer on the map
Map.addLayer(high,{min:0, max:1, palette:'red'},'high-hazard');
```

Adding high hazard map

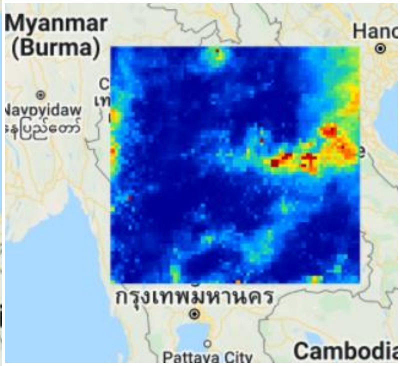
Complete code and Map

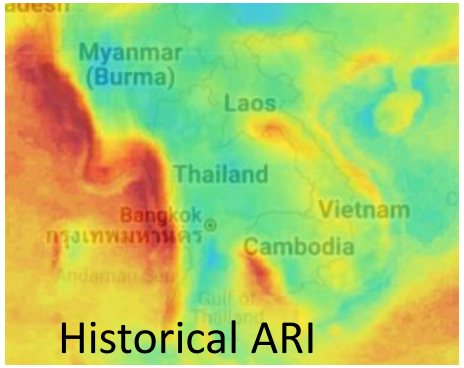
```
Imports (2 entries)
 var imerg: ImageCollection "GPM: Global Precipitation Measurement (GPM) v6"
 var geometry: Polygon, 4 vertices
// Selecting appropriate variable
var precip = imerg.select('precipitationCal');
// Selecting a date to visualize precipitation
var date = '2015-07-30';
// Converting date string into a ee formatted date
var precipDate = ee.Date(date).getRange('day');
//Filtering, summing, and dividing precipitation
var prcp1day = precip.filterDate(precipDate).sum().divide(2);
// Using color palette to make visualization better
var palette = [
  '000096','0064ff', '00b4ff', '33db80', '9beb4a',
  'ffeb00', 'ffb300', 'ff6400', 'eb1e00', 'af0000'];
// Visualization parameter using the color palette mentioned above
var precipitationVis = {min: 0.0, max: 100.0, palette: palette};
// Adding layer on the map
Map.addLayer(prcp1day.clip(geometry), precipitationVis, "Precipitation")

var precipDate = ee.Date(date)
// Selecting days to consider for calculating ARI
var daysofWeek  = ee.List.sequence(0,6,1);
   // Declaring list of weightage for those days
  var weight = ee.List([1.0,0.25,0.111,0.0625, 0.04, 0.02778, 0.02040816]);
 // Summing up weightage
  var ws = 1.511797;
  // calculate the daily precipitation in this case we just use the immerg data
  var ari = ee.ImageCollection(daysofWeek.map(function(m){
      // parse M to a number
      m = ee.Number.parse(m);
      // set the date range
      var startDay = precipDate.advance(m.multiply(-1),"day");
      // Offsetting one day to make a 24 hour span
      var endDay = startDay.advance(1,"day");
      // get the weight
      var w = ee.Number.parse(weight.get(m));
      // get the rainfall of day x
      var dayPrecip = ee.Image(precip.filterDate(startDay,endDay).sum()).divide(2);
      // multiply with weight factor
      var riDay = dayPrecip.multiply(ee.Image(w));
      return riDay;
  })).sum().divide(ws).rename('api').clip(geometry);
Map.addLayer(ari, {}, "Current ARI of " + date)

// Adding pre-calculated historical ARI
var historical_ari = ee.Image("users/nbiswas/lhasa/ari95_mekong");
// Adding pre-calculated historical ARI on the map
Map.addLayer(historical_ari,precipitationVis, "Historical ARI");

// importing susceptibility Map
var susc = ee.Image("users/nbiswas/Susc_Mekong")
// Adding layer on the map
Map.addLayer(susc, {min:0,max:5,palette:"yellow,orange,red,purple"}, "Susceptibility Map")
//////***************** Applying decision tree algorithm ***************
// Chacking the area where current ARI is greater than historical ARI
var heavy_rain = ari.gt(historical_ari).rename('Heavy Rainfall');
// Adding heavy_rain on the map
Map.addLayer(heavy_rain,{min: 0.0, max: 1.0, palette: ['red','blue']}, "Heavy Rain");
// Current ARI>historical ARI and Susceptibility value greater than 2 is moderate hazard zone
var moderate = heavy_rain.and(susc.gt(2)).rename('Moderate_Nowcast');
// Adding moderate hazard map layer on the map
Map.addLayer(moderate,{min:0, max:1, palette:'yellow'},'moderate-hazard');
// Current ARI>historical ARI and Susceptibility value greater than 4 is high hazard zone
var high = moderate.and(susc.gt(4)).rename('High_Nowcast');
// Adding high hazard map layer on the map
Map.addLayer(high,{min:0, max:1, palette:'red'},'high-hazard');
```

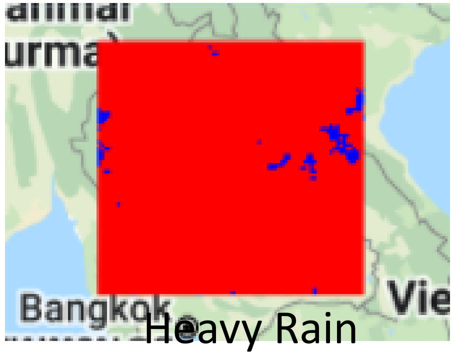


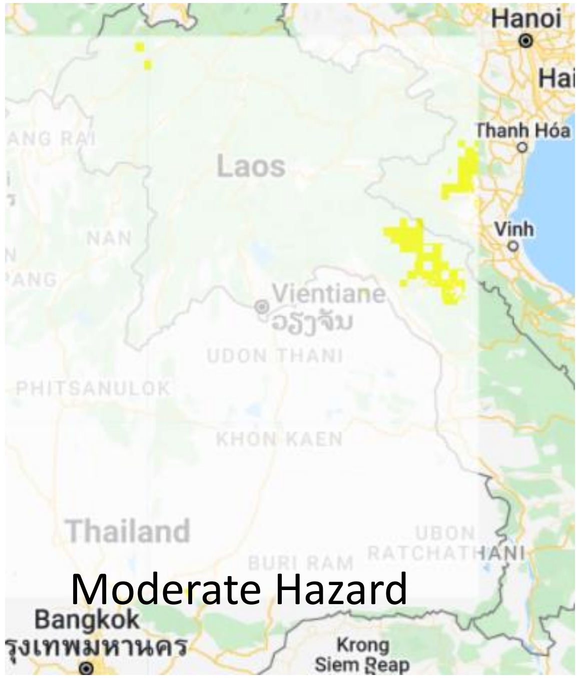


Current ARI





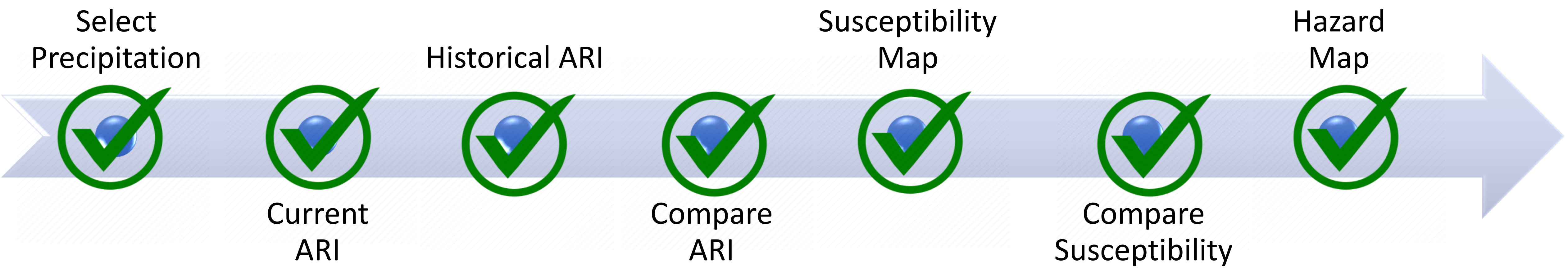




High Hazard

Summary

- Imported susceptibility data in GEE
- Imported precalculated ARI in GEE
- Compared ARI and susceptibility
- Prepared LHASA hazard map and Visualized in GEE Map



LHASA version 1

Optional add-on: Exposure Analysis

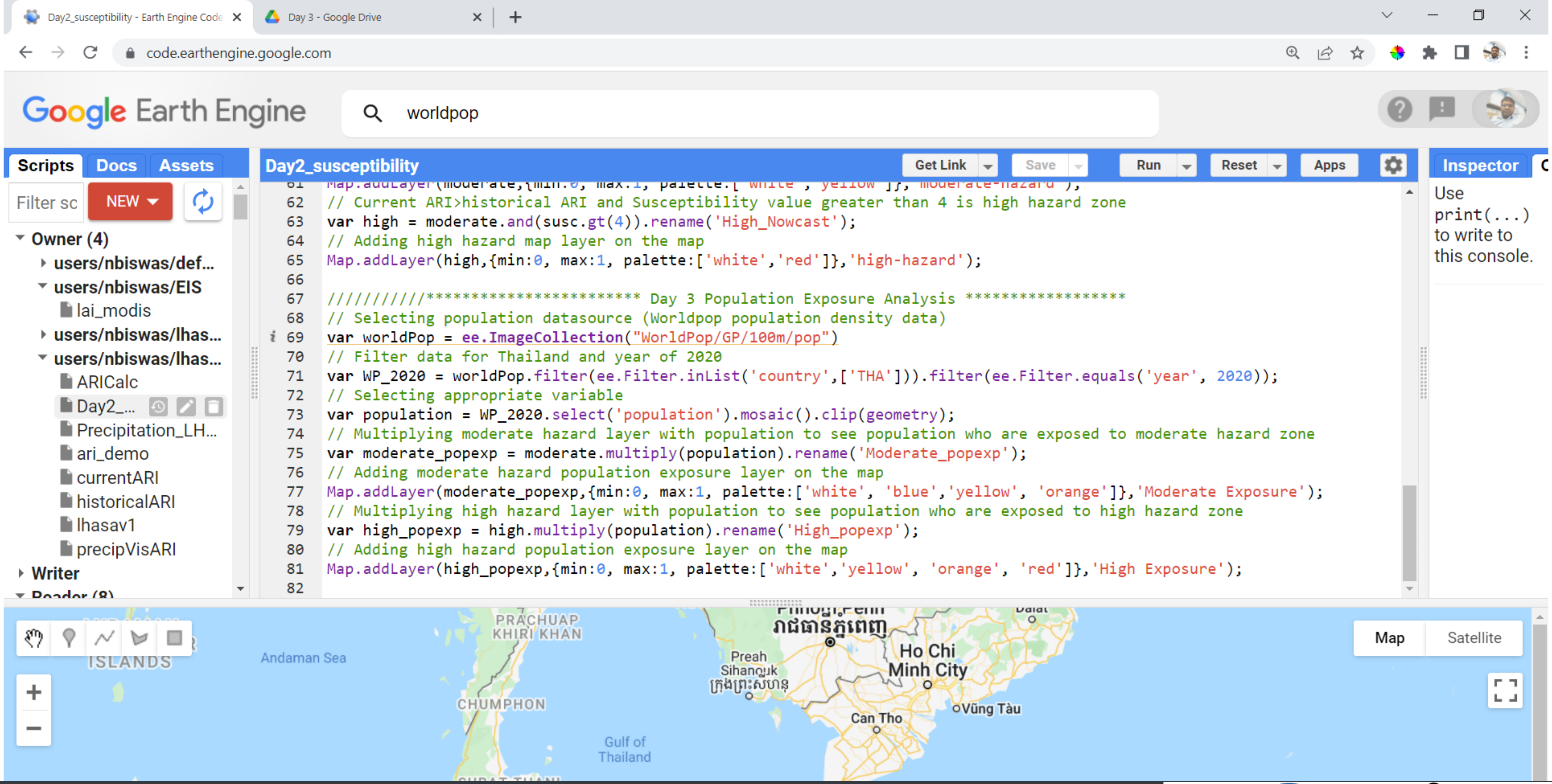
Steps:

1. Open code window of GEE
2. Import study area in GEE (need to have a polygon shapefile)
3. Open complete model code
4. Import study area inside code
5. Select a date
6. Run LHASA Model
7. Visualize hazard map
8. Exposure analysis
9. Visualize exposure layers

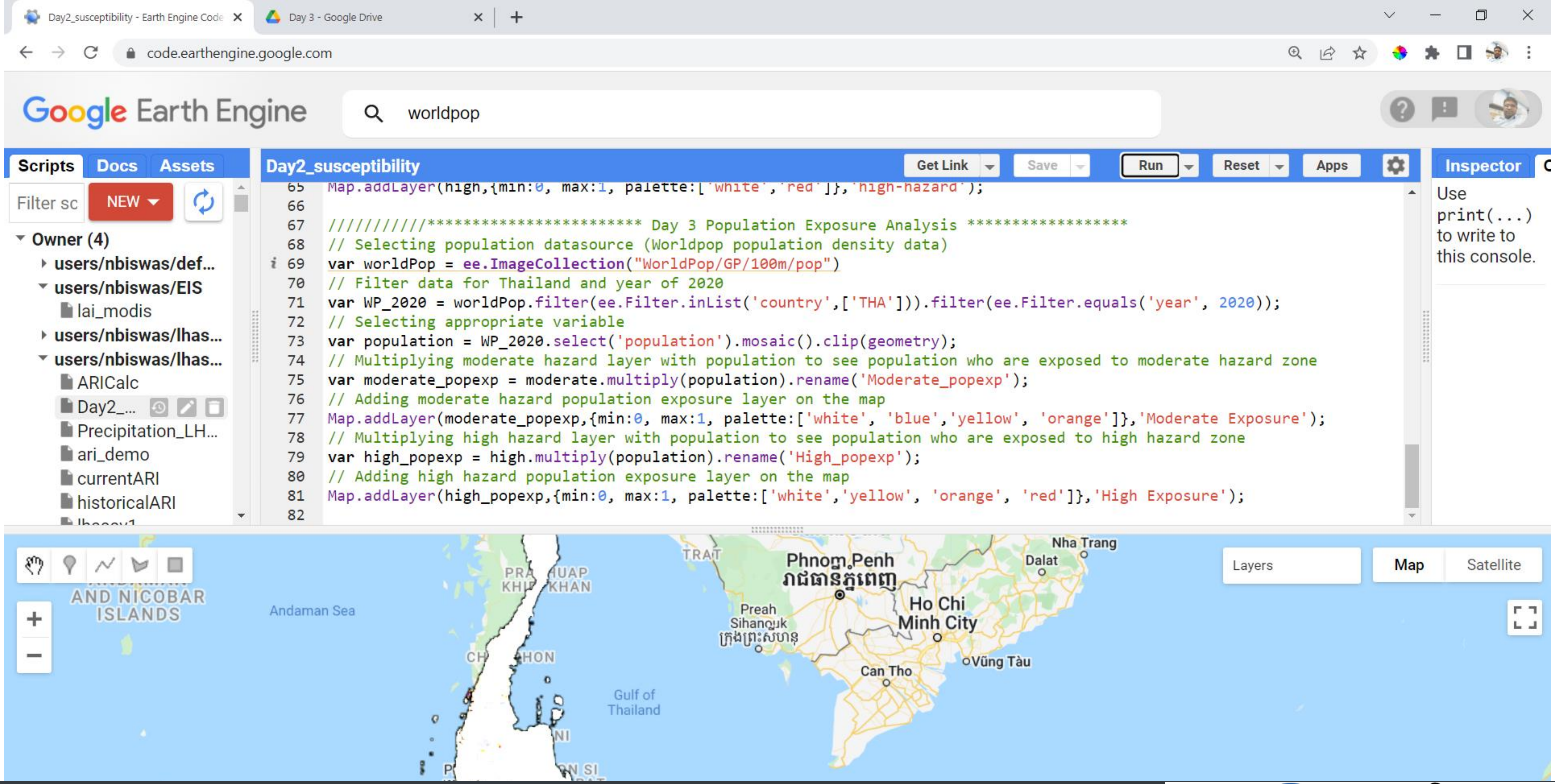
Step 8: Exposure analysis

```
///////////************************ Population Exposure Analysis ******************
// Selecting population data source (WorldPop population density data)
var worldPop = ee.ImageCollection("WorldPop/GP/100m/pop")
// Filter data for Thailand and year of 2020
var WP_2020 = worldPop.filter(ee.Filter.inList('country',['THA'])).filter(ee.Filter.equals('year', 2020));
// Selecting appropriate variable
var population = WP_2020.select('population').mosaic().clip(geometry);
// Multiplying moderate hazard layer with population to see population who are exposed to moderate hazard zone
var moderate_popexp = moderate.multiply(population).rename('Moderate_popexp');
// Adding moderate hazard population exposure layer on the map
Map.addLayer(moderate_popexp,{min:0, max:1, palette:['white', 'blue','yellow', 'orange']},'Moderate Exposure');
// Multiplying high hazard layer with population to see population who are exposed to high hazard zone
var high_popexp = high.multiply(population).rename('High_popexp');
// Adding high hazard population exposure layer on the map
Map.addLayer(high_popexp,{min:0, max:1, palette:['white','yellow', 'orange', 'red']},'High Exposure');
```

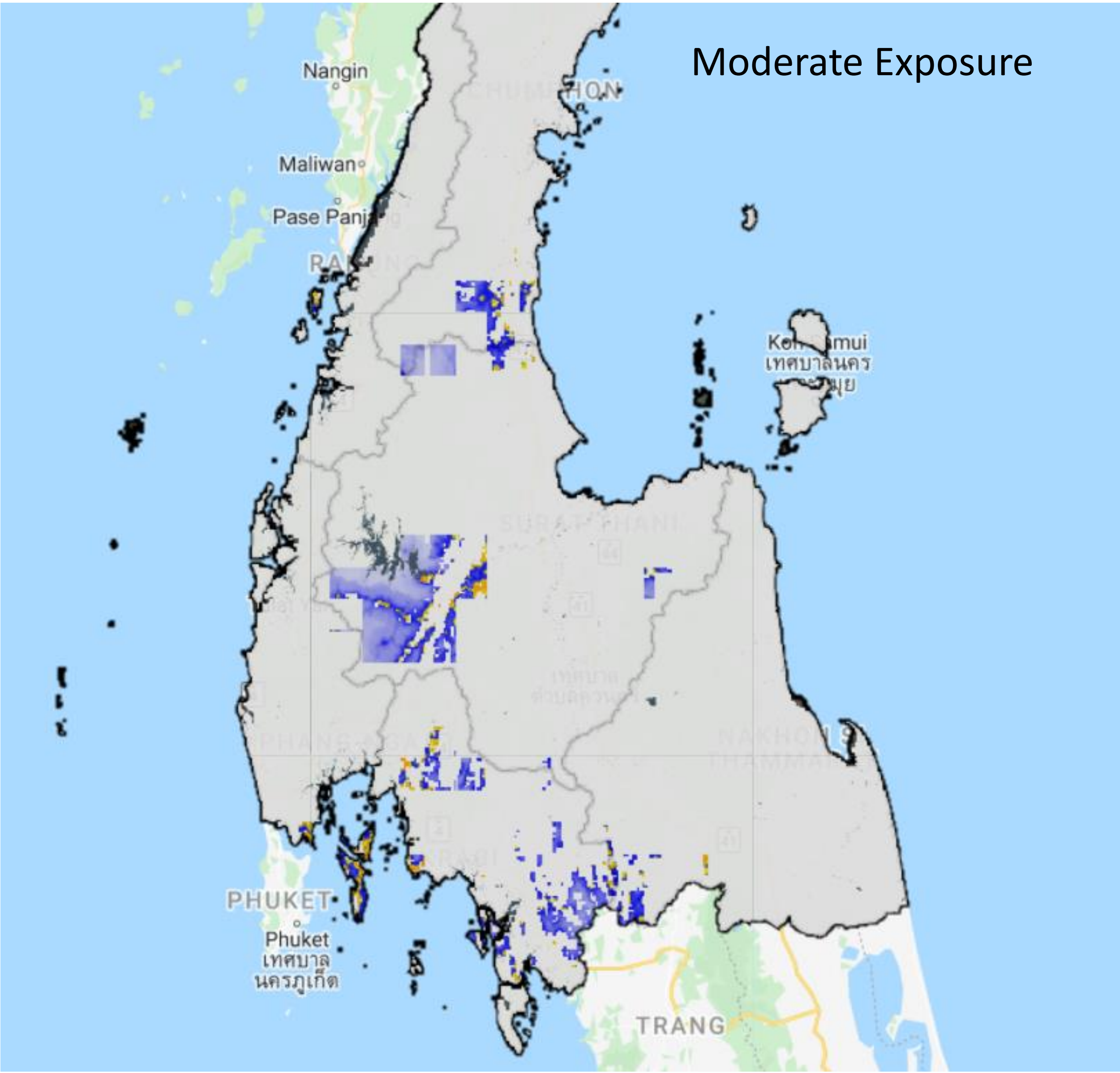
Step 8: Exposure analysis

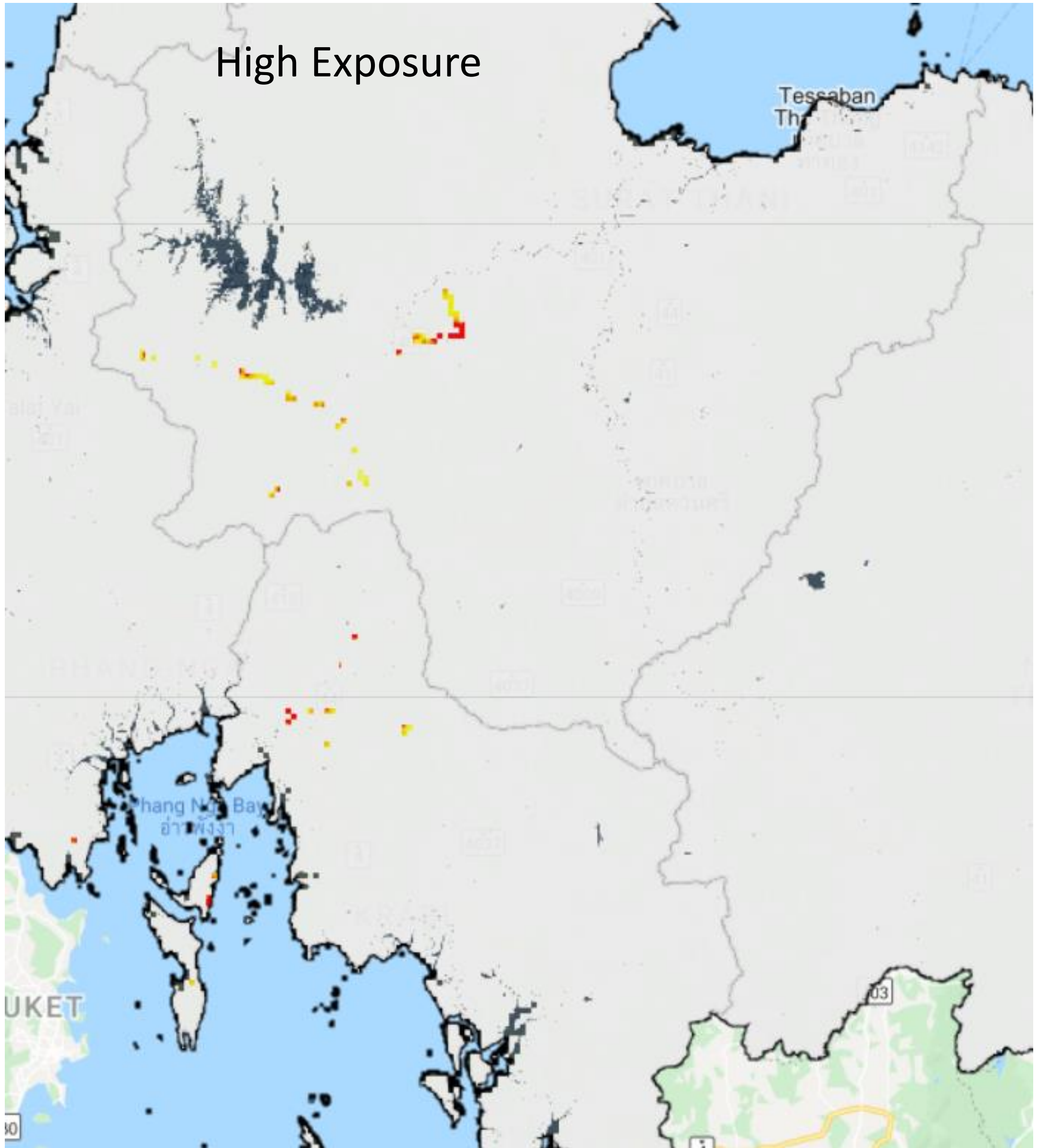


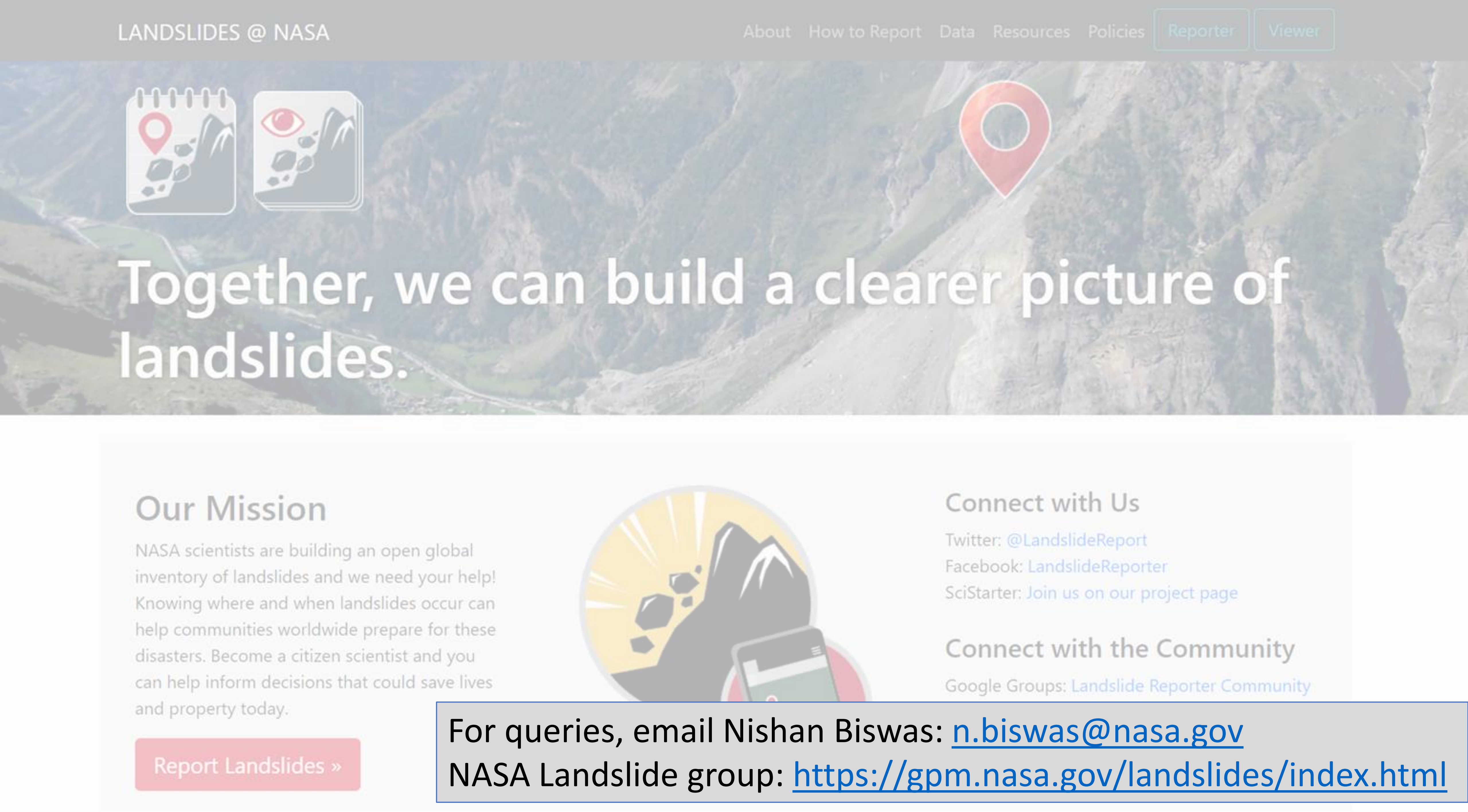
Step 8: Exposure analysis



Step 9: Visualize exposure layers







For queries, email Nishan Biswas: n.biswas@nasa.gov
NASA Landslide group: https://gpm.nasa.gov/landslides/index.html

References

- Stanley, T., & Kirschbaum, D. B. (2017). A heuristic approach to global landslide susceptibility mapping. *Natural hazards*, *87*(1), 145-164. Link
- Kirschbaum, D., & Stanley, T. (2018). Satellite-based assessment of rainfall-triggered landslide hazard for situational awareness. *Earth's future*, *6*(3), 505-523. Link
- Emberson, R., Kirschbaum, D., & Stanley, T. (2020). New global characterisation of landslide exposure. Natural Hazards and Earth System Sciences, 20(12), 3413-3424. Link
- Emberson, R., Kirschbaum, D., & Stanley, T. (2021). Global connections between El Nino and landslide impacts. Nature communications, 12(1), 1-11. Link