Automating the detection of disturbances to aquatic resources

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U.S. Department of the Interior
U.S. Geological Survey

Wetland Mapping Consortium webinar (October 7, 2020)

Project Motivation

- Global trends in wetland degradation and loss have created an urgency to:
    1. Monitor wetland extent and,
    2. Track the distribution and causes of wetland loss.
- Satellite imagery can be used to monitor wetlands over time.
- Few efforts have attempted to distinguish anthropogenic wetland loss from climate-driven variability in wetland extent.

Approach

- Tracked inundation extent and land cover disturbance across the Mid-Atlantic region using the Landsat archive in Google Earth Engine.

- How to best remotely detect anthropogenic wetland loss (due to land cover change)?
  - Decrease in inundation extent?
  - Disturbance extent?
  - Co-location of inundation decline and disturbance?

remote sensing

MDPI

Article

Isolating Anthropogenic Wetland Loss by Concurrently Tracking Inundation and Land Cover Disturbance across the Mid-Atlantic Region, U.S.

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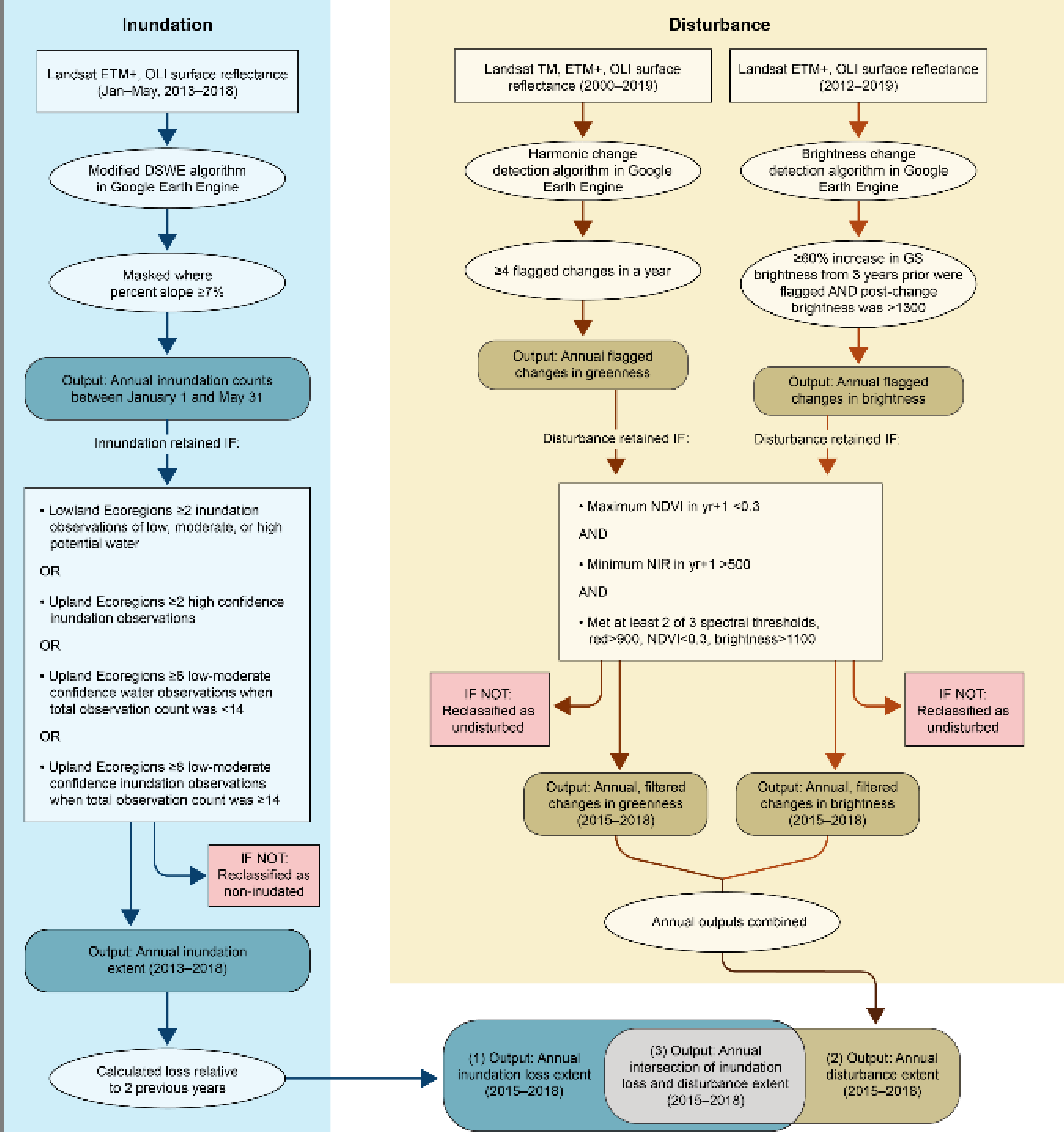
Abstract: Global trends in wetland degradation and loss have created an urgency to monitor wetland extent, as well as track the distribution and causes of wetland loss. Satellite imagery can be used to monitor wetlands over time, but few efforts have attempted to distinguish anthropogenic wetland loss from climate-driven variability in wetland extent. We present an approach to concurrently track land cover disturbance and inundation extent across the Mid-Atlantic region, United States, using the Landsat archive in Google Earth Engine. Disturbance was identified as a change in greenness, using a harmonic linear regression approach, or as a change in growing season brightness. Inundation extent was mapped using a modified version of the U.S. Geological Survey's Dynamic Surface Water Extent (DSWE) algorithm. Annual (2015–2018) disturbance averaged 0.32% (1095 km^2 $year^{-1}$) of the study area per year and was most common in forested areas. While inundation extent showed substantial interannual variability, the co-occurrence of disturbance and declines in inundation extent represented a minority of both change types, totaling 109 km^2 over the four-year period, and 186 km^2, using the National Wetland Inventory dataset in place of the Landsat-derived inundation extent. When the annual products were evaluated with permitted wetland and stream fill points, 95% of the fill points were detected, with most found by the disturbance product (89%) and fewer found by the inundation decline product (25%). The results suggest that mapping inundation alone is unlikely to be adequate to find and track anthropogenic wetland loss. Alternatively, remotely tracking both disturbance and inundation can potentially focus efforts to protect, manage, and restore wetlands.

Keywords: Chesapeake Bay; wetland fill; harmonic regression; Landsat; permit; surface water

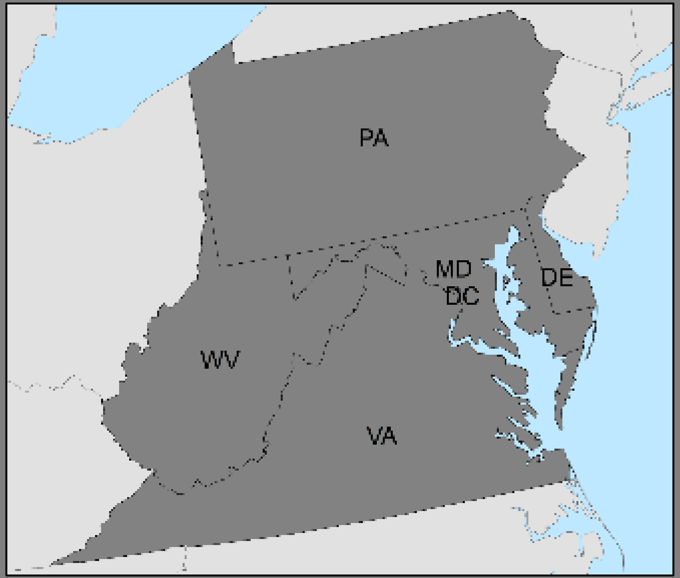
1



2

Temporal Extent:
2015-2018

Spatial Extent:



Annual Inundation (2013-2018)

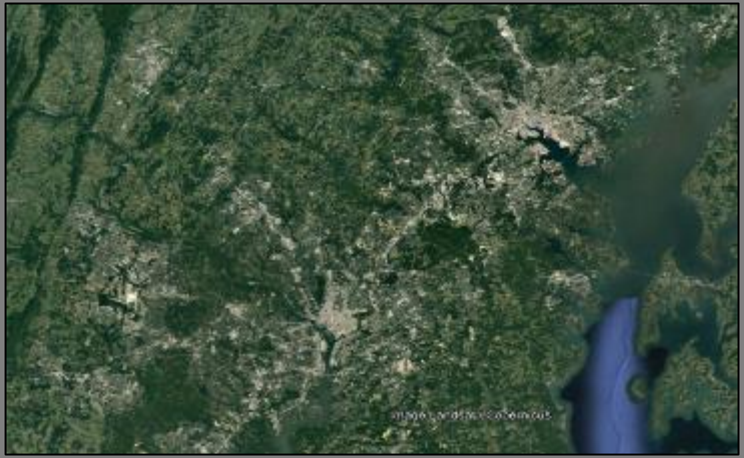
- Uses Landsat ETM+ (n=1036), OLI (n=1086) images across study area.
- Applied USGS Dynamic Surface Water Extent (DSWE) algorithm to ETM+
- Advantage: unsupervised algorithm
- Modified DSWE algorithm for OLI
  - Additional test for forested wetlands
  - Reduced commission error for suburban areas

Test	Landsat ETM+	Landsat OLI
Test 1	mNDWI > 123	mNDWI > 123
Test 2	MBSRV > 0	MBSRV > 0
Test 3	AWESH > 0	AWESH > 0
Test 4	mNDWI > −400, SWIR1 < 900, NIR < 1500, NDVI < 6000	mNDWI > −4400, SWIR1 < 900, NIR < 1500, NDVI < 6500
Test 5	mNDWI > −5000, SWIR1 < 3000, SWIR2 < 1000, NIR < 2500, NDVI < 4000, B < 1000	mNDWI > −5000, SWIR1 < 3000, SWIR2 < 1000, NIR < 2500, NDVI < 5500, B < 1000, BU3 < 1600
Test 6		G < 480, NIR < 2500, NDVI < 5500, BU3 < 1600

DSWE Classes
Not Water
Water - High Confidence
Water - Moderate Confidence
Partial Surface Water Pixel
Water or wetland, low confidence

Regional surface water mapping challenges

Lots of forest (60%) – limited surface visibility

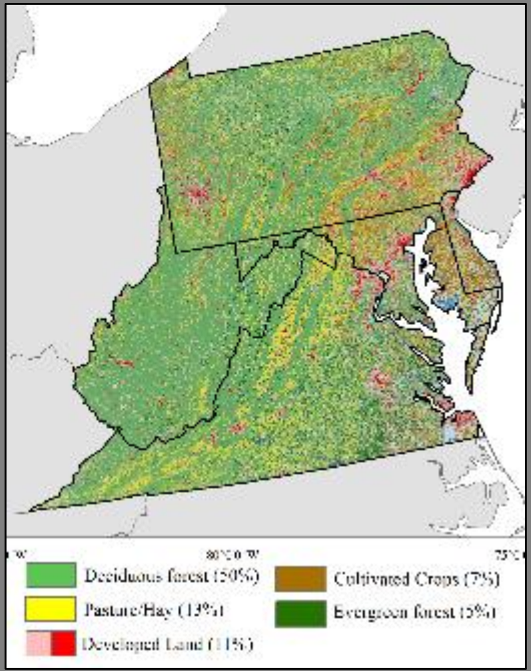


Multiple urban areas – D.C., Baltimore, Philadelphia, Pittsburgh, Virginia Beach, Richmond

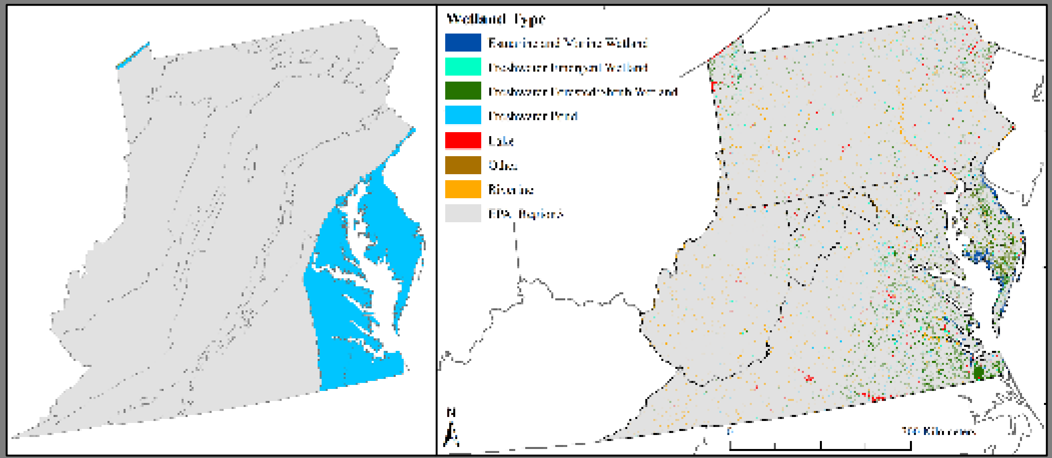
Lots of dynamic tidal wetlands

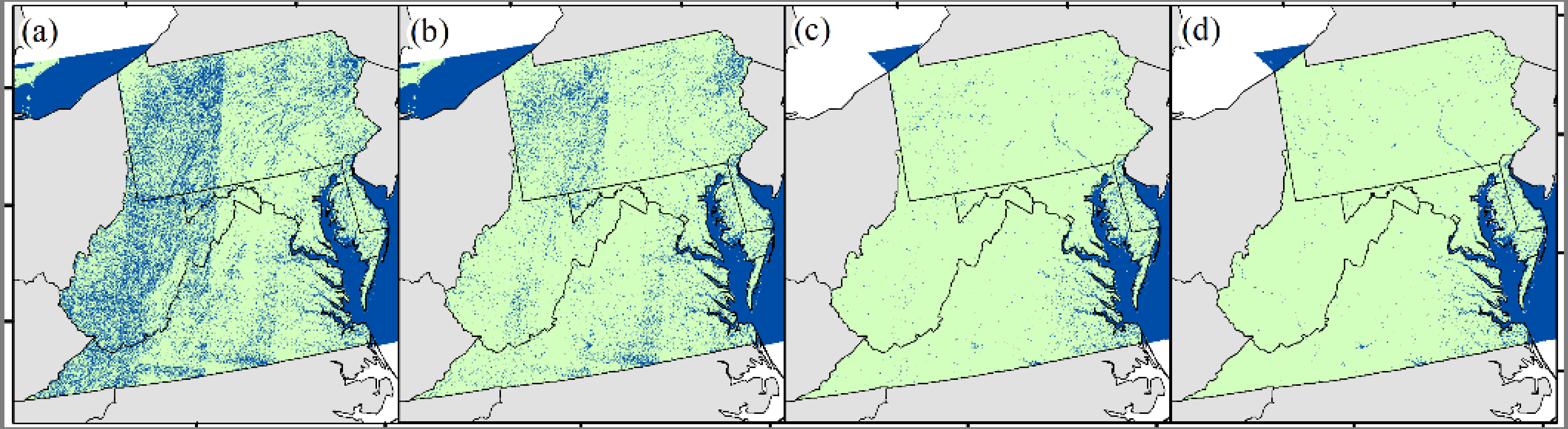
Appalachian Mts create severe topographical shadowing

Delmarva Peninsula – high frequency of ephemeral wetlands



Response to regional challenges and big data challenges





(a) January 1 – May 31
- ≥2 observations of inundation
- All DSWE confidence classes

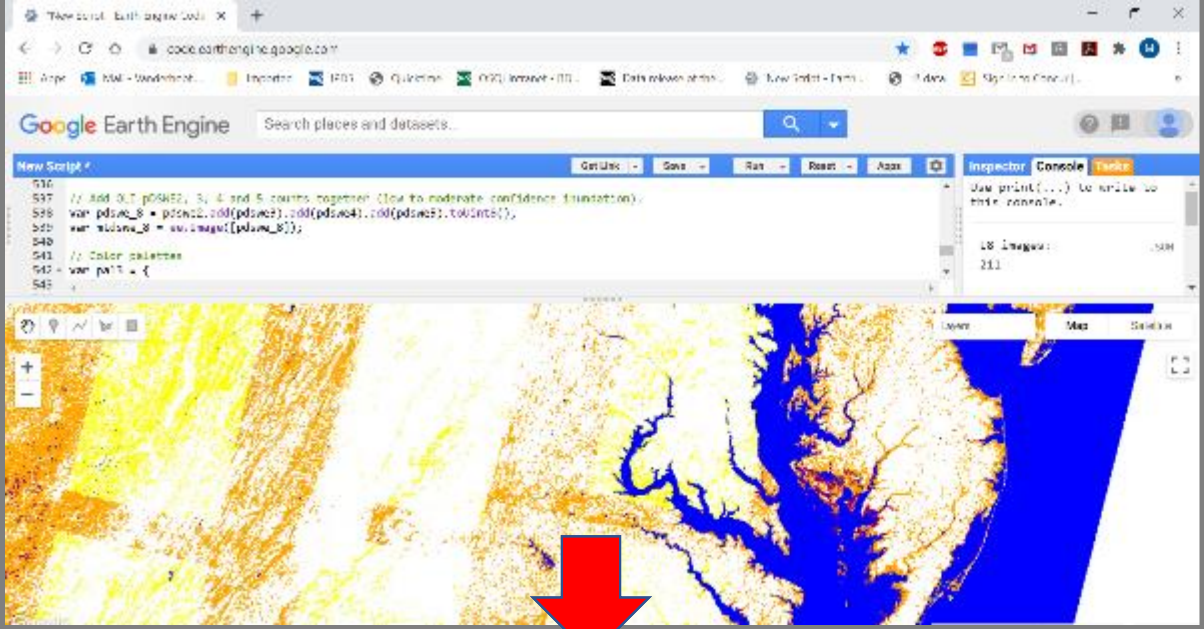
(b) Mask out slopes >7%.

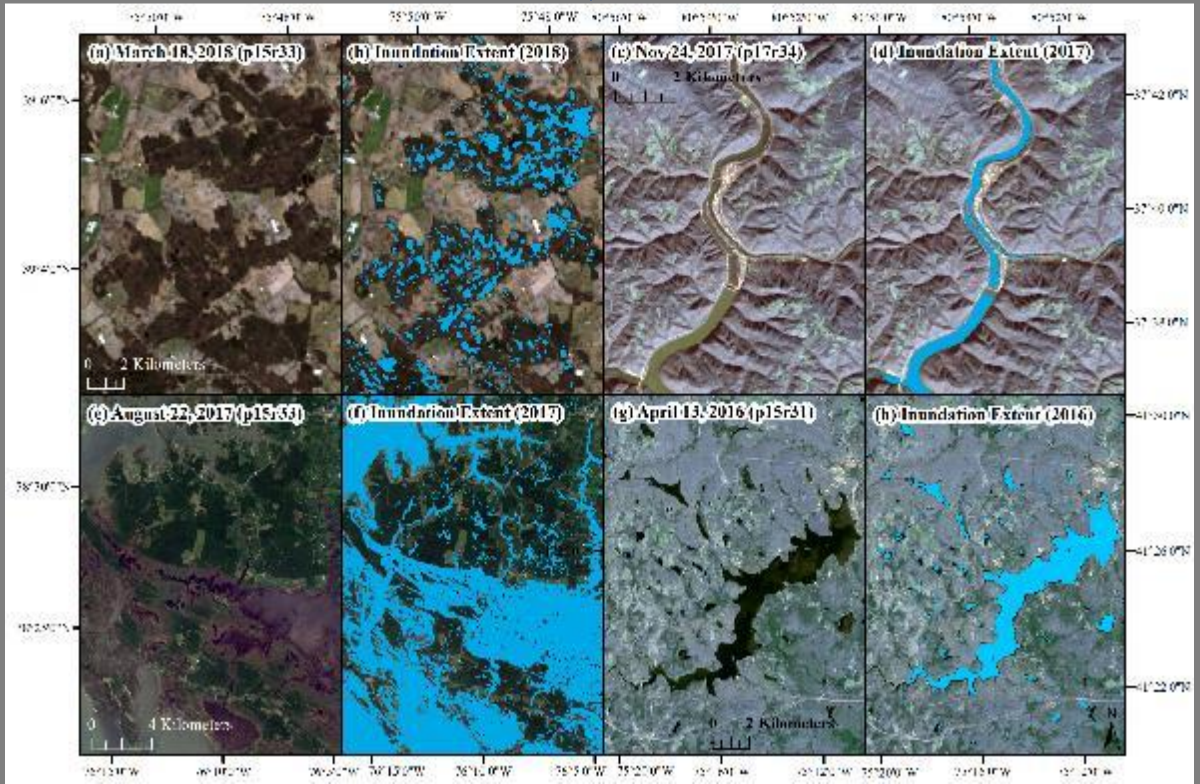
(c) If high-confidence DSWE water class → retain everywhere, otherwise, require more observations in uplands.

(d) Intersect a NWI polygon

Algorithm maps sub-pixel inundation

- Surface water depends on:
    1. DSWE water confidence class
    2. Number of inundation observations per year
    3. Ecoregion (lowland, upland)



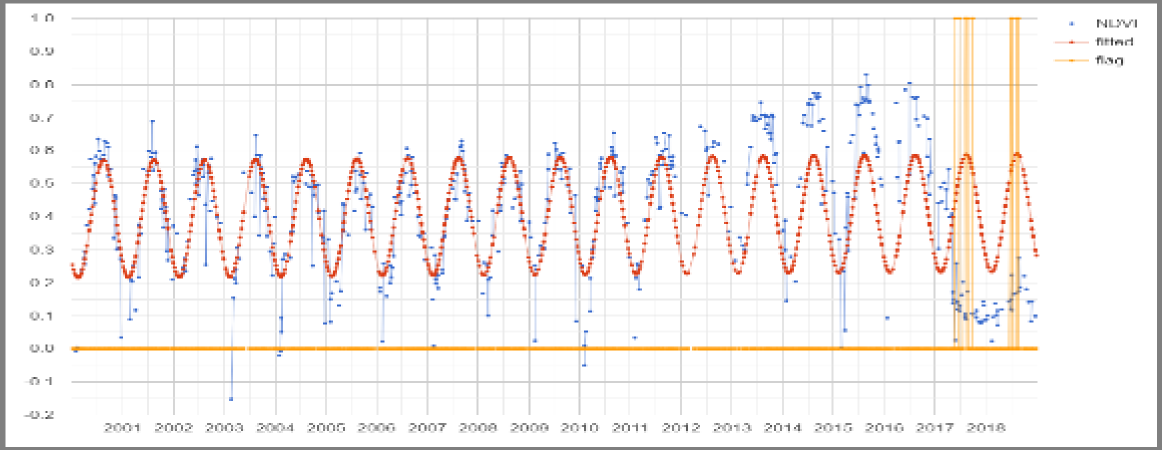


Mapping Disturbance

1a

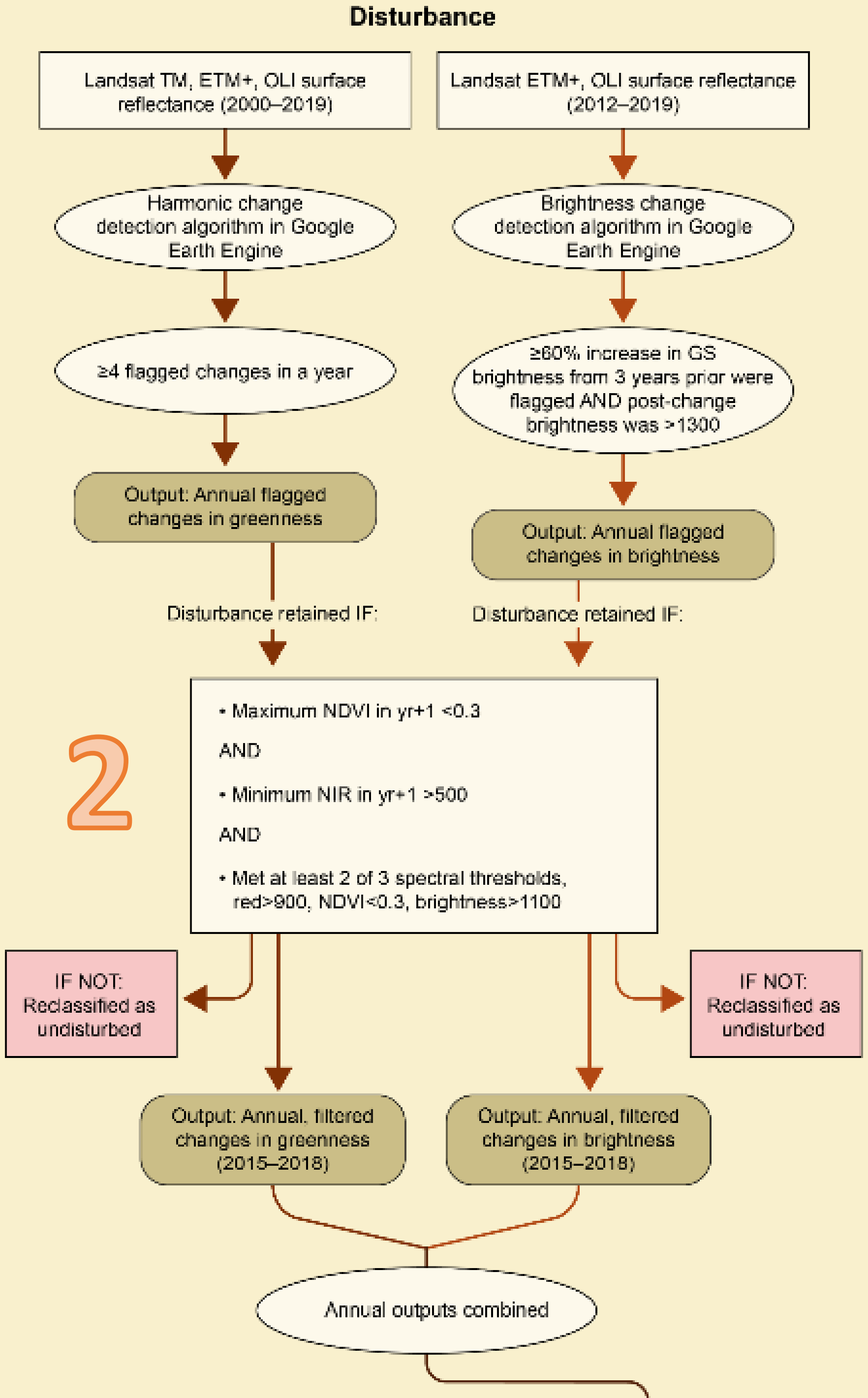
1a. Harmonic NDVI change analysis (17,956 images)

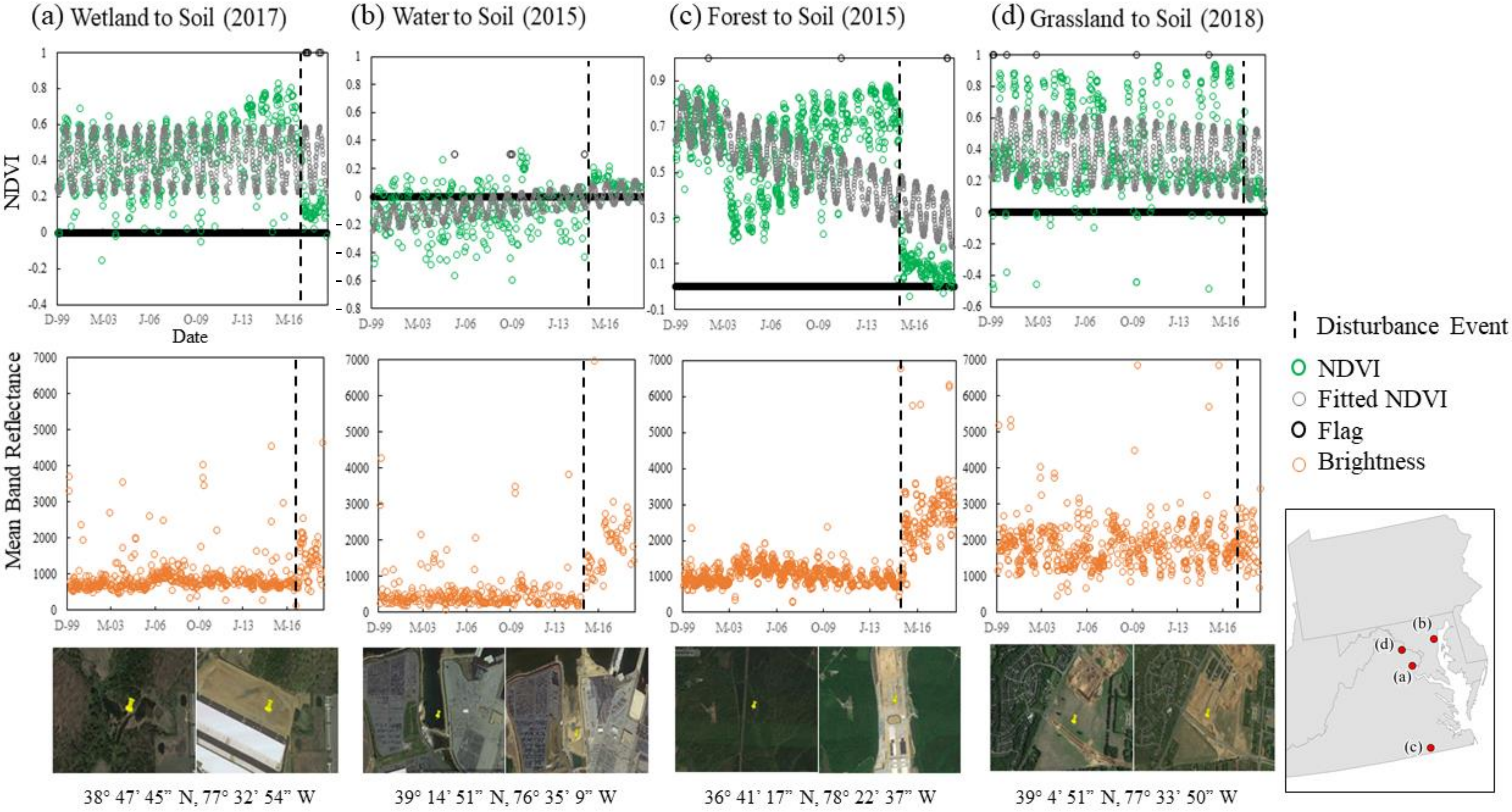
1b. Increase in brightness (7,213 images)



1b

2

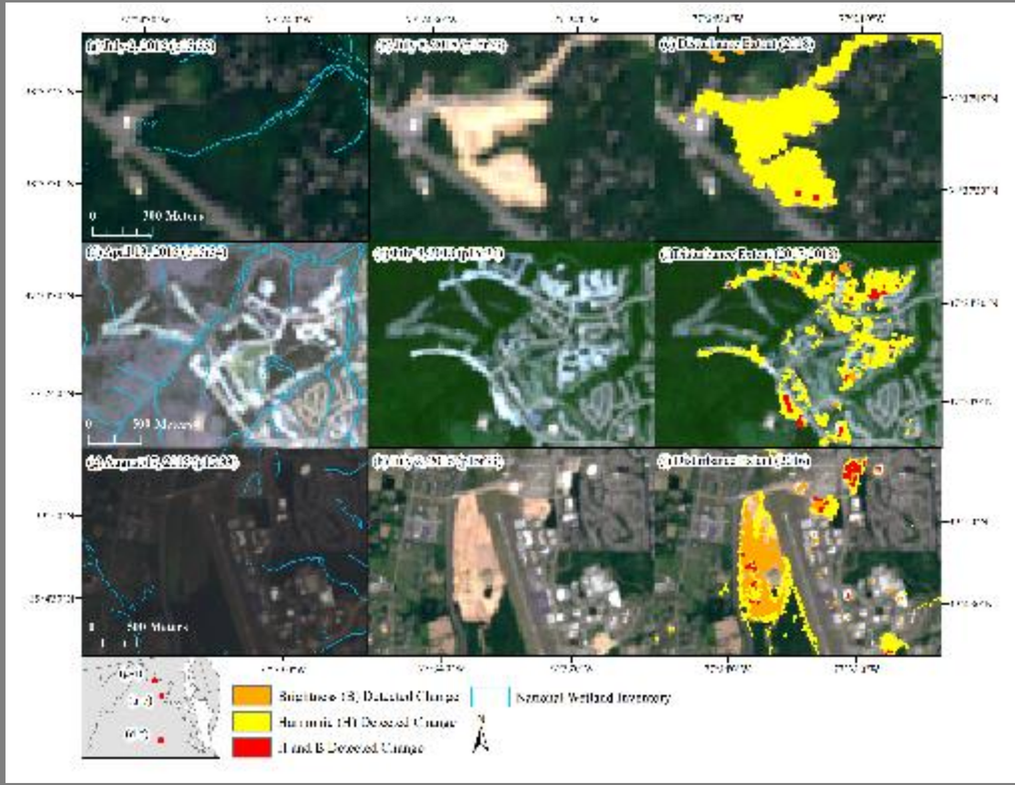


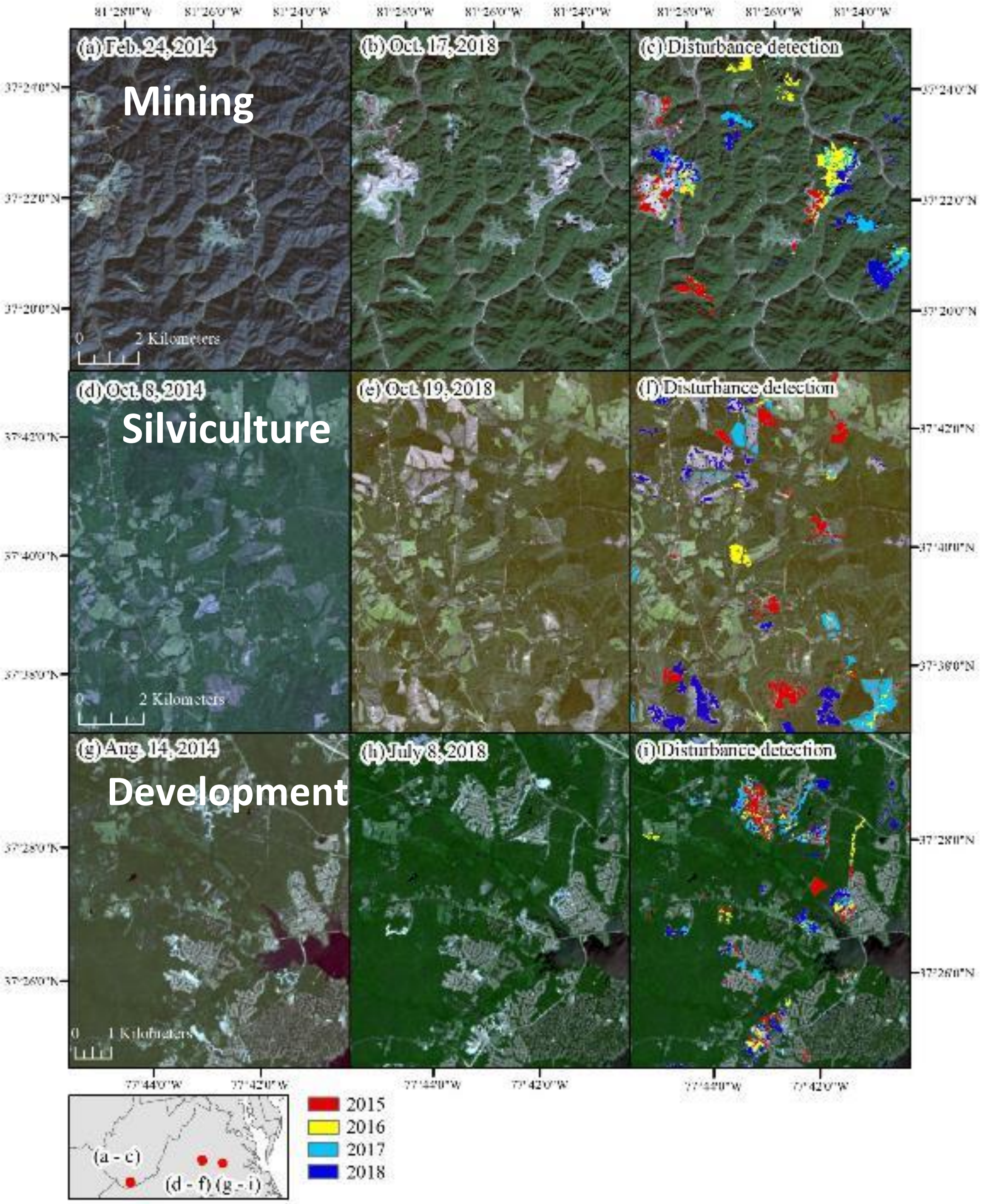


(a) Wetland to Soil (2017)
(b) Water to Soil (2015)
(c) Forest to Soil (2015)
(d) Grassland to Soil (2018)
NDVI
Date
Mean Band Reflectance
D-99
M-03
J-06
O-09
J-13
M-16
Disturbance Event
NDVI
Fitted NDVI
Flag
Brightness
38° 47' 45" N, 77° 32' 54" W
39° 14' 51" N, 76° 35' 9" W
36° 41' 17" N, 78° 22' 37" W
39° 4' 51" N, 77° 33' 50" W
(a)
(b)
(c)
(d)

Disturbance Output Examples

- 60% in NLCD forest (e.g., silviculture, development)
- 14% in NLCD developed classes – intensification of development
- 15% in NLCD agriculture (conversion from ag to development, or error)





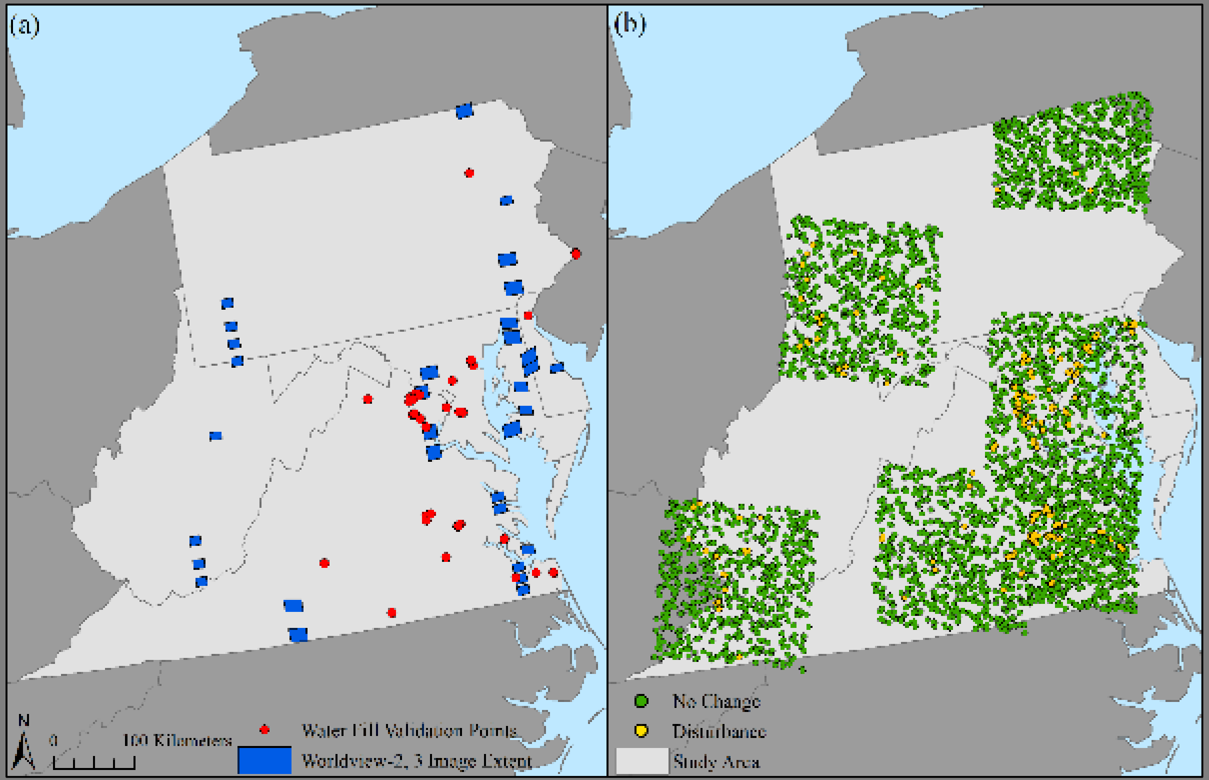
Product Validation

Inundation Extent:

- Landsat ETM+ inundation: 18% OE, 1% CE
- Landsat OLI inundation: 19% OE, 4% CE
- **ETM-OLI combined inundation: 13% OE, 4% CE**
- **MMU** (1176 wetlands in WorldView imagery):
    - 61% wetlands (0.4 – 1.0 ha)
    - 84% wetlands (1.0 – 1.5 ha)

Disturbance Extent:

- Disturbance (Harmonic): 27% OE, 2% CE
- Disturbance (Brightness): 56% OE, 1% CE
- **Disturbance (B-H combined): 15% OE, 2% CE**

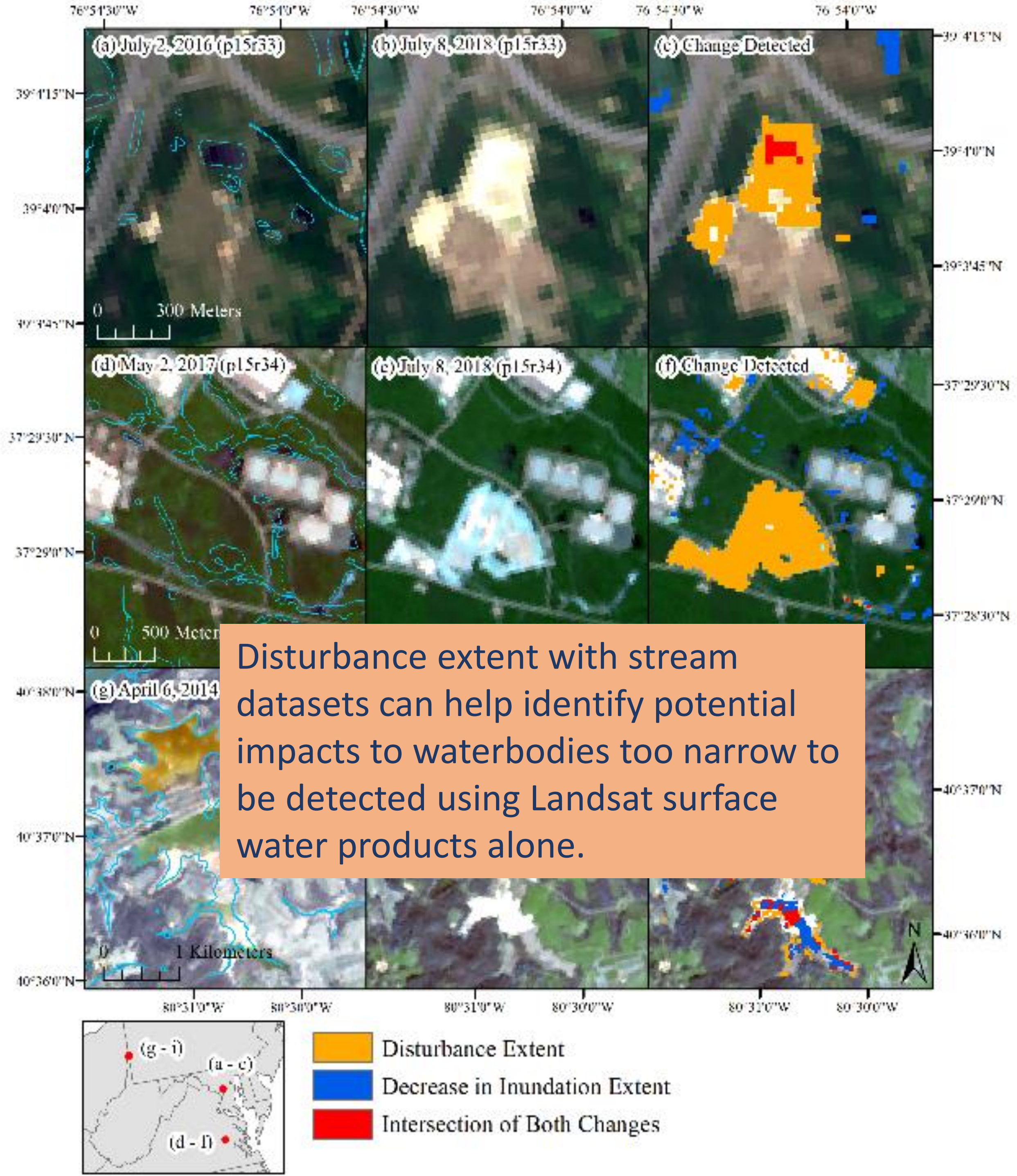


USACE Section 404 Permits (permitted aquatic resource loss (n=263))

- **Detected 95% of USACE water fill points** (71% disturbance only, 6% inundation loss only, 18%, disturbance and inundation loss)

Products applied to examine aquatic resource loss

- Inundation loss (decline relative to previous 2 years) represented 7-11% of total inundation.
- Disturbance extent represented 0.25% (2016) to 0.35% (2015) of the study area.
- 99% of annual “inundation loss” occurred without a disturbance event (i.e., climate variability).

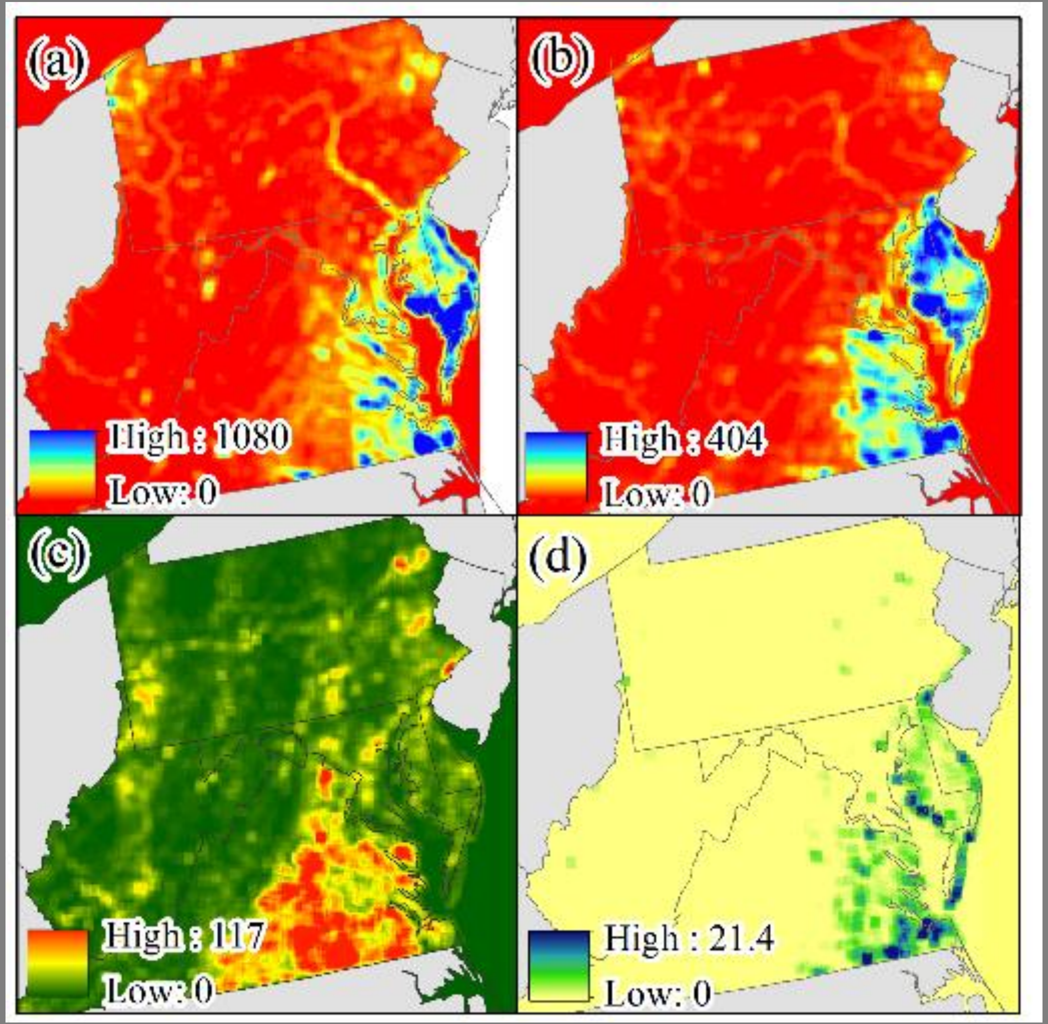


Disturbance extent with stream datasets can help identify potential impacts to waterbodies too narrow to be detected using Landsat surface water products alone.

Patterns of disturbance and potential aquatic resource loss were uneven across the SA.

- A total of 108.6 km^2 (2015-2018) showed both disturbance and inundation loss.
- A total of 186 km^2 (2015-2018) intersected NWI polygons and disturbance.

NWI density **Inun. loss density**



Disturbance density **Inun. Loss-Disturb.**

So what can we do with this information?

- **Goal:** Enable stakeholders to make informed, strategic decisions in a cost-efficient manner.
- **Inundation:** where is the water? What water is relatively stable? What water is most dynamic and most susceptible to changes in climate (e.g., droughts, floods)
- **Disturbance:** where are changes in vegetation actively occurring? Where are changes minimal? Can this help us identify at risk regions or aquatic resource types?
- **Disturbance – NWI wetlands:** what aquatic resources are potentially at-risk? Where can we prioritize restoration needs?

Tracking disturbance and inunda ×

sciencebase.gov/catalog/item/5e430b15e4b0edb47be845ce

Tracking disturbance and inundation to identify wetland loss

View

Dates

Start Date : 2015-01-01
End Date : 2018-12-31
Publication Date : 2020-06-16

Citation

Vanderhoof, M.K., Christensen, J., Beal, Y.J.G. DeVries, B., Lang, M.W., Hwang, N., Mazzarella, C., and Jones, J.W., Tracking disturbance and inundation to identify wetland loss: U.S. Geological Survey data release, https://doi.org/10.5066/P9ODILGN.

Summary

Global trends in wetland degradation and loss have created an urgency to monitor wetland extent, as well as track the distribution and causes of wetland loss. Satellite imagery can be used to monitor wetlands over time, but few efforts have attempted to distinguish anthropogenic wetland loss from climate-driven variability in wetland extent. We present

Map »

Communities

Tracking disturbance and inundat ×

sciencebase.gov/catalog/item/5e430b15e4b0edb47be845ce

Tracking disturbance and inundation to identify w...

View

Distributor : U.S. Geological Survey - ScienceBase
SDC Data Owner : Geosciences and Environmental Change Science Center
USGS Mission Area : Land Resources

(2015-2018)

Attached Files

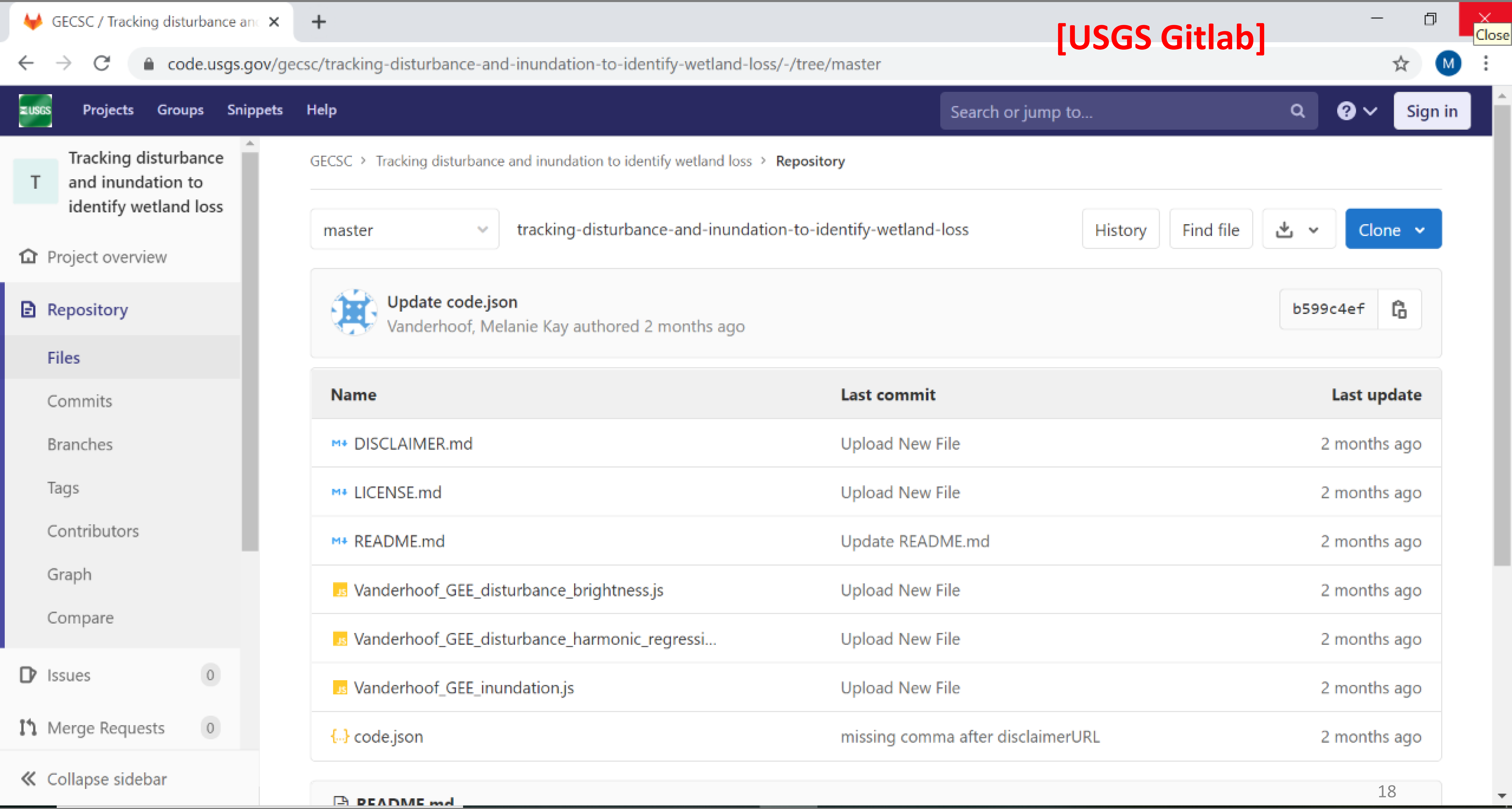
Click on title to download individual files attached to this item or download all files listed below as a compressed file.

Tracking_disturbance_and_inundation_to identify_wetland_loss_metadata.xml *Original FGDC Metadata*	View	19.82 KB
AppendixTables.zip		1.34 KB
decline_inundation_annual.zip		18.85 MB
disturbance_extent_annual.zip		10.5 MB
inundation_extent_annual.zip		20.8 MB
potential_wetland_loss.zip		17.61 MB

Related External Resources

Type: Related Primary Publication

Vanderhoof, M.K.; Christensen, J.; Beal, Y.-J.G.; DeVries, B.; Lang, M.W.; Hwang, N.; Mazzarella, C.; Jones, J.W. Isolating Anthropogenic Wetland Loss by Concurrently Tracking Inundation and Land Cover Disturbance across the Mid-Atlantic Region, U.S.. Remote Sens. 2020, 12, 1464	https://www.mdpi.com/2072-4292/12/9/1464


[USGS Gitlab]
GECSC / Tracking disturbance an
code.usgs.gov/gecsc/tracking-disturbance-and-inundation-to-identify-wetland-loss/-/tree/master
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Update code.json
Vanderhoof, Melanie Kay authored 2 months ago
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Tracking disturbance and inundation to identify wetland loss

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Maintenance scheduled for Thursday, September 24th at 15:00 MDT. Expected downtime <1 hour.

GECSC > Tracking disturbance and inundation to identify wetland loss > Repository

master | tracking-disturbance-and-inundation-to-identify-wetland-loss / **Vanderhoof_GEE_disturbance_harmonic_r...** | Find file | Blame | History | Permalink

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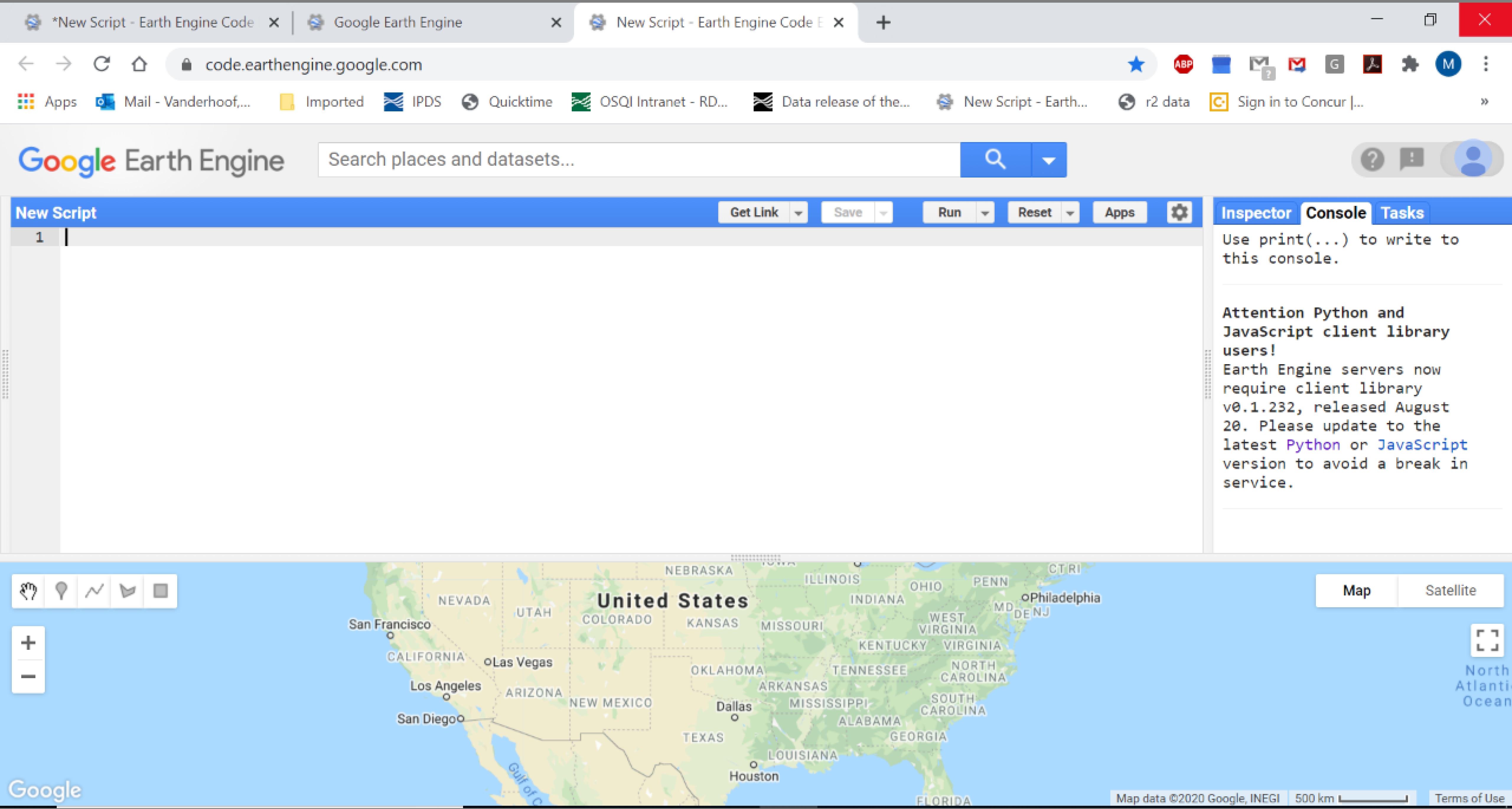
Vanderhoof, Melanie Kay authored 3 months ago | f10294e9

Vanderhoof_GEE_disturbance_harmonic_regression.js 13.4 KB | Edit | Web IDE

```
// Title: Producing annual disturbance extent using a harmonic Normalized Difference Vegetation Index (NDVI) linear regression appro
// Authors: Melanie Vanderhoof (mvanderhoof@usgs.gov), Yen-Ju G. Beal
// Date: June 12, 2020

// Javascript code to be run in Google Earth Engine (GEE, code.earthengine.google.com).
// This code requires no input imagery from the user, all images and image collections used are provided by the Google Earth Engine
// To run the code for a unique study area extent and date range modify the specific variable section, export extent (i.e., studyAre
// Output is the number of times a pixel was mapped as disturbance in each year.
// Export output in batches using single Landsat rows ("WRS_ROW").


// Set a point of interest.
```


*New Script - Earth Engine Code
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Use print(...) to write to this console.
Attention Python and JavaScript client library users!
Earth Engine servers now require client library v0.1.232, released August 20. Please update to the latest Python or JavaScript version to avoid a break in service.
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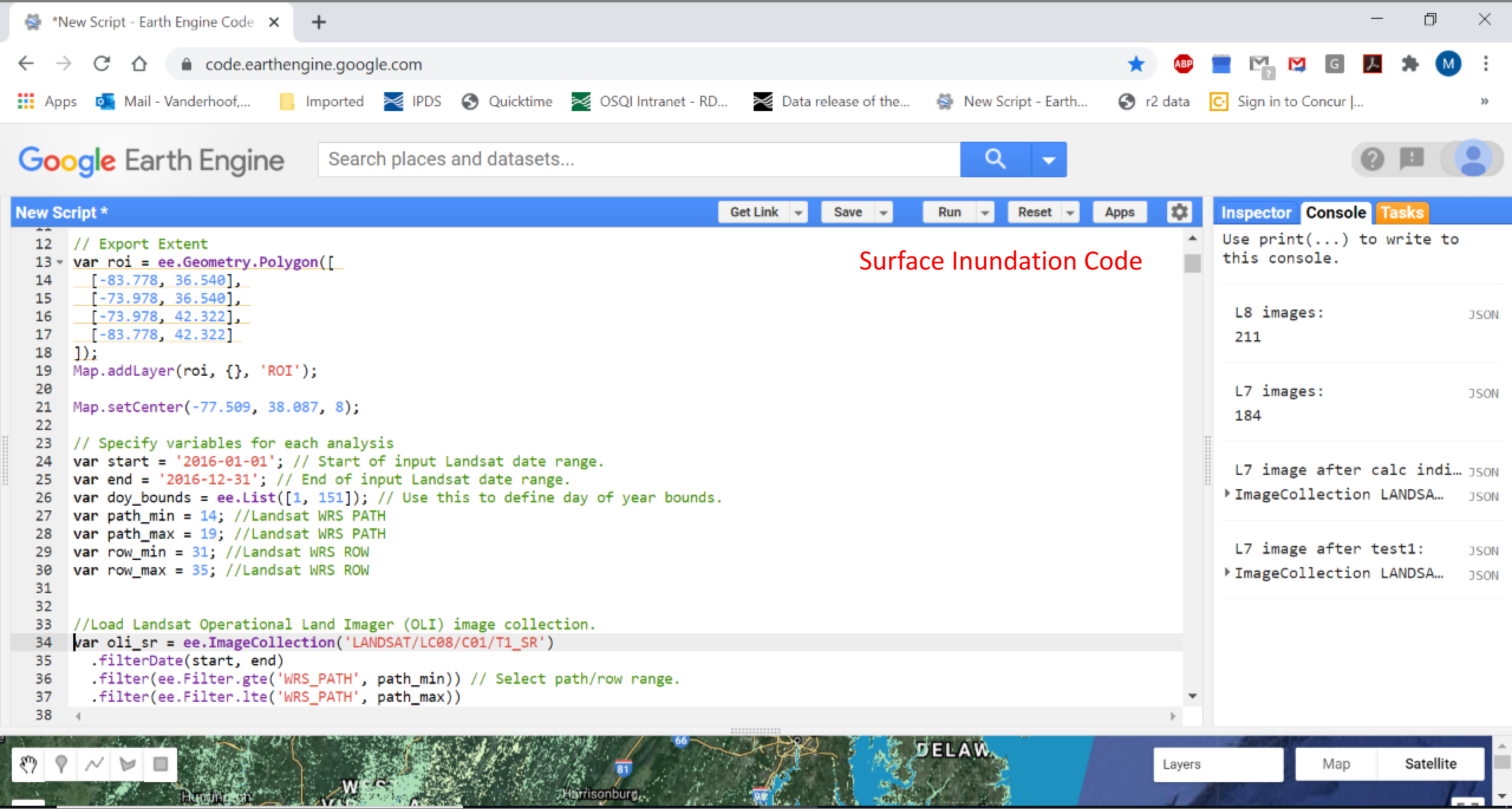

*New Script - Earth Engine Code
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New Script *
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Reset
Apps
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Console
Tasks
Surface Inundation Code
// Export Extent
var roi = ee.Geometry.Polygon([
[-83.778, 36.540],
[-73.978, 36.540],
[-73.978, 42.322],
[-83.778, 42.322]
]);
Map.addLayer(roi, {}, 'ROI');
Map.setCenter(-77.509, 38.087, 8);
// Specify variables for each analysis
var start = '2016-01-01'; // Start of input Landsat date range.
var end = '2016-12-31'; // End of input Landsat date range.
var doy_bounds = ee.List([1, 151]); // Use this to define day of year bounds.
var path_min = 14; //Landsat WRS PATH
var path_max = 19; //Landsat WRS PATH
var row_min = 31; //Landsat WRS ROW
var row_max = 35; //Landsat WRS ROW
//Load Landsat Operational Land Imager (OLI) image collection.
var oli_sr = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR')
.filterDate(start, end)
.filter(ee.Filter.gte('WRS_PATH', path_min)) // Select path/row range.
.filter(ee.Filter.lte('WRS_PATH', path_max))
Use print(...) to write to this console.
L8 images: JSON
211
L7 images: JSON
184
L7 image after calc indi... JSON
ImageCollection LANDSA... JSON
L7 image after test1: JSON
ImageCollection LANDSA... JSON
Layers
Map
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Vanderhoof_GEE_disturbance_ha | *New Script - Earth Engine Code

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Google Earth Engine

Search places and datasets...

New Script *   Get Link | Save | Run | Reset | Apps

NDVI Harmonic Change Code

```
// Set a point of interest.
var roi = ee.Geometry.Point([-77.45, 37.218]);

// Center map over the roi.
Map.setCenter(-77.45, 37.218, 15);

// Specify variables for each analysis
var start = '2000-01-01'; //start of Landsat image acquisition range
var end = '2019-12-31'; //end of Landsat image acquisition range
var path_min = 14; //Landsat WRS PATH
var path_max = 16; //Landsat WRS PATH
var row_min = 33; //Landsat WRS ROW
var row_max = 34; //Landsat WRS ROW
var export_start = 2015; //Start of annual products
var export_end = 2019; //End of annual products

// Export Extent
var studyArea = ee.Geometry.Polygon([
  [-83.778, 36.540],
  [-73.978, 36.540],
  [-73.978, 42.322],
  [-83.778, 42.322]
]);
Map.addLayer(studyArea, {}, 'Study area');

// Load Landsat Operational Land Imager (OLI) surface reflectance image collection.
var oli = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR')
  .filterDate(start, end) // Filter image acquisition dates.
```

Inspector | Console | Tasks

```
Use print(...) to write to
this console.

L8 images:                JSON
748

L5 images:                JSON
1110

L7 images:                JSON
2029

Count:                    JSON
3887

1.0                       JSON
ImageCollection (Computin...

fitted                    JSON
ImageCollection (Computin...
```

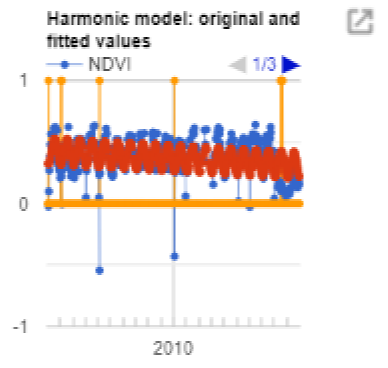
North Dr | Layers | Map | Satellite

NDVI Harmonic Change Code

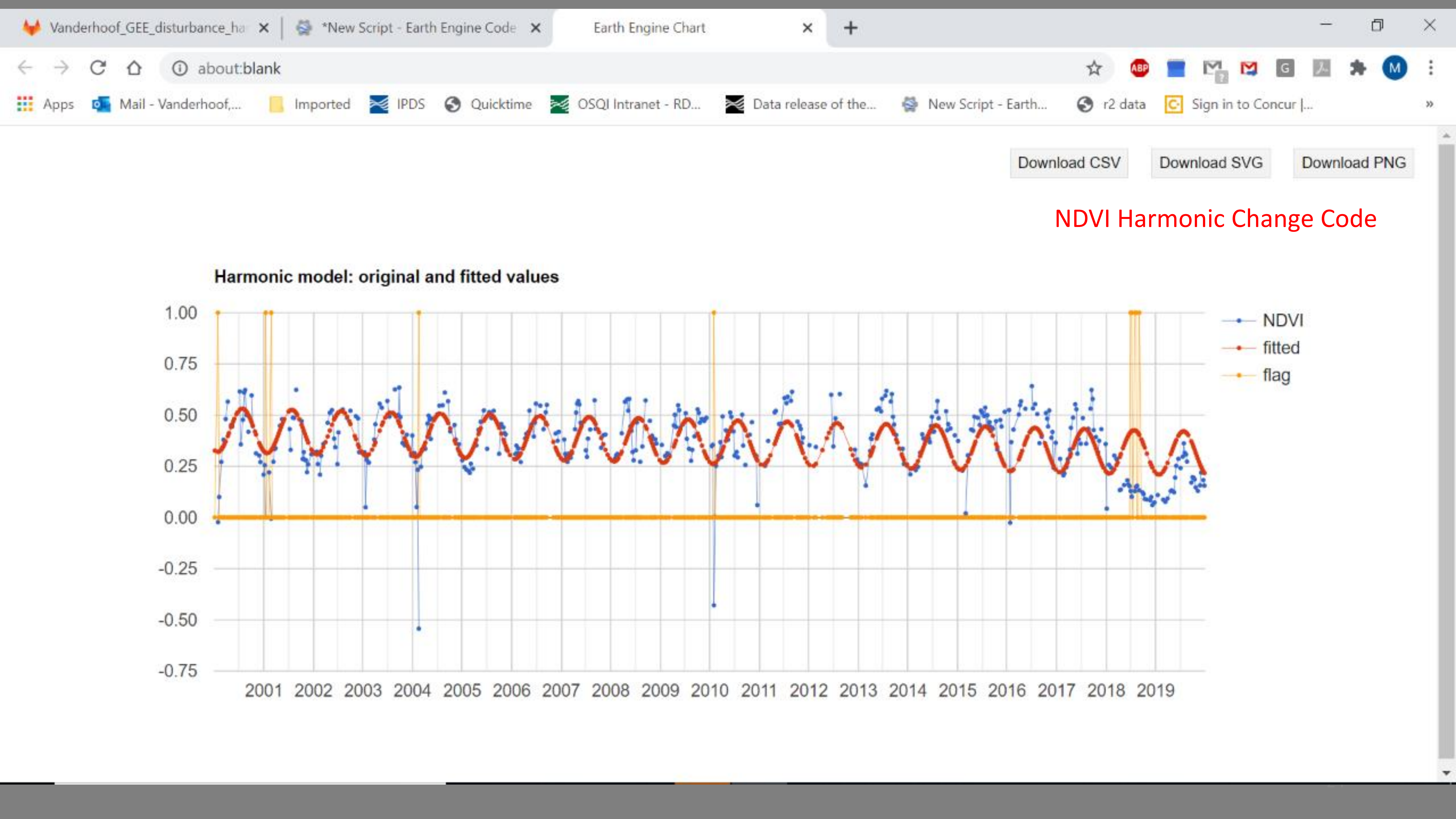
```
    var cloudShadowBitMask = 1 << 3;
    var cloudsBitMask = 1 << 5;
    // Get the pixel QA band.
    var qa = image.select('pixel_qa');
    // Both flags should be set to zero, indicating clear conditions.
    var mask = qa.bitwiseAnd(cloudShadowBitMask).eq(0)
      .and(qa.bitwiseAnd(cloudsBitMask).eq(0));
    // Return the masked image.
    return image.updateMask(mask);
  });

print('L8 images:', oli.size());

// Load Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) image collections.
var tm = ee.ImageCollection('LANDSAT/LT05/C01/T1_SR')
  .filterMetadata('IMAGE_QUALITY', 'equals', 9)
  .filterDate(start, end) // Filter image acquisition dates.
  .filter(ee.Filter.gte('WRS_PATH', path_min)) // Define path/row range.
  .filter(ee.Filter.lte('WRS_PATH', path_max))
  .filter(ee.Filter.gte('WRS_ROW', row_min))
  .filter(ee.Filter.lte('WRS_ROW', row_max));
var etm = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
  .filterMetadata('IMAGE_QUALITY', 'equals', 9)
  .filterDate(start, end) // Filter image acquisition dates.
  .filter(ee.Filter.gte('WRS_PATH', path_min)) // Define path/row range.
  .filter(ee.Filter.lte('WRS_PATH', path_max))
  .filter(ee.Filter.gte('WRS_ROW', row_min))
  .filter(ee.Filter.lte('WRS_ROW', row_max));
```

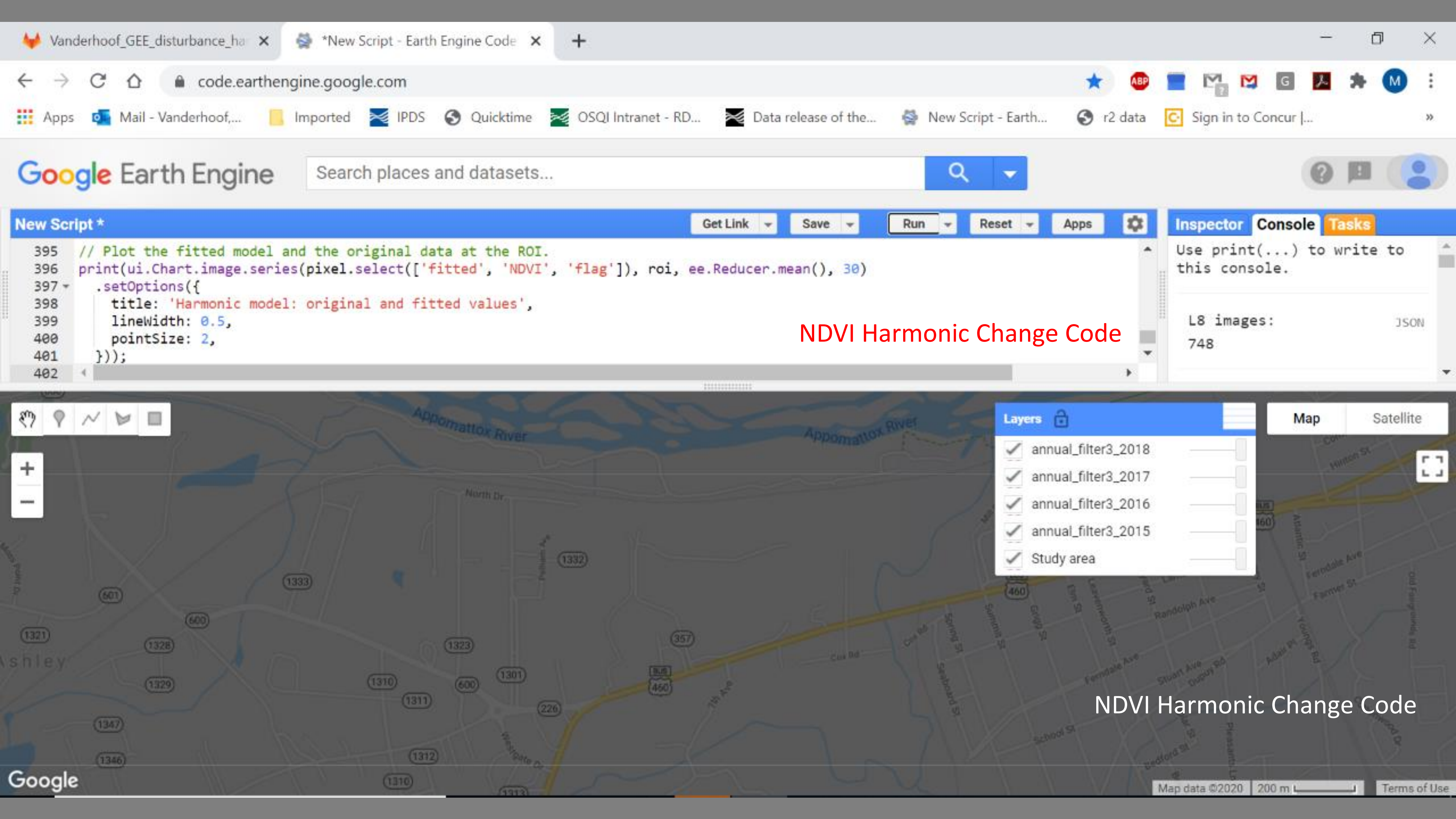
Console:

```
annual_filter_2018
Image (1 band)

annual_filter2_2018
Image (1 band)

annual_filter3_2018
Image (Computing)
```

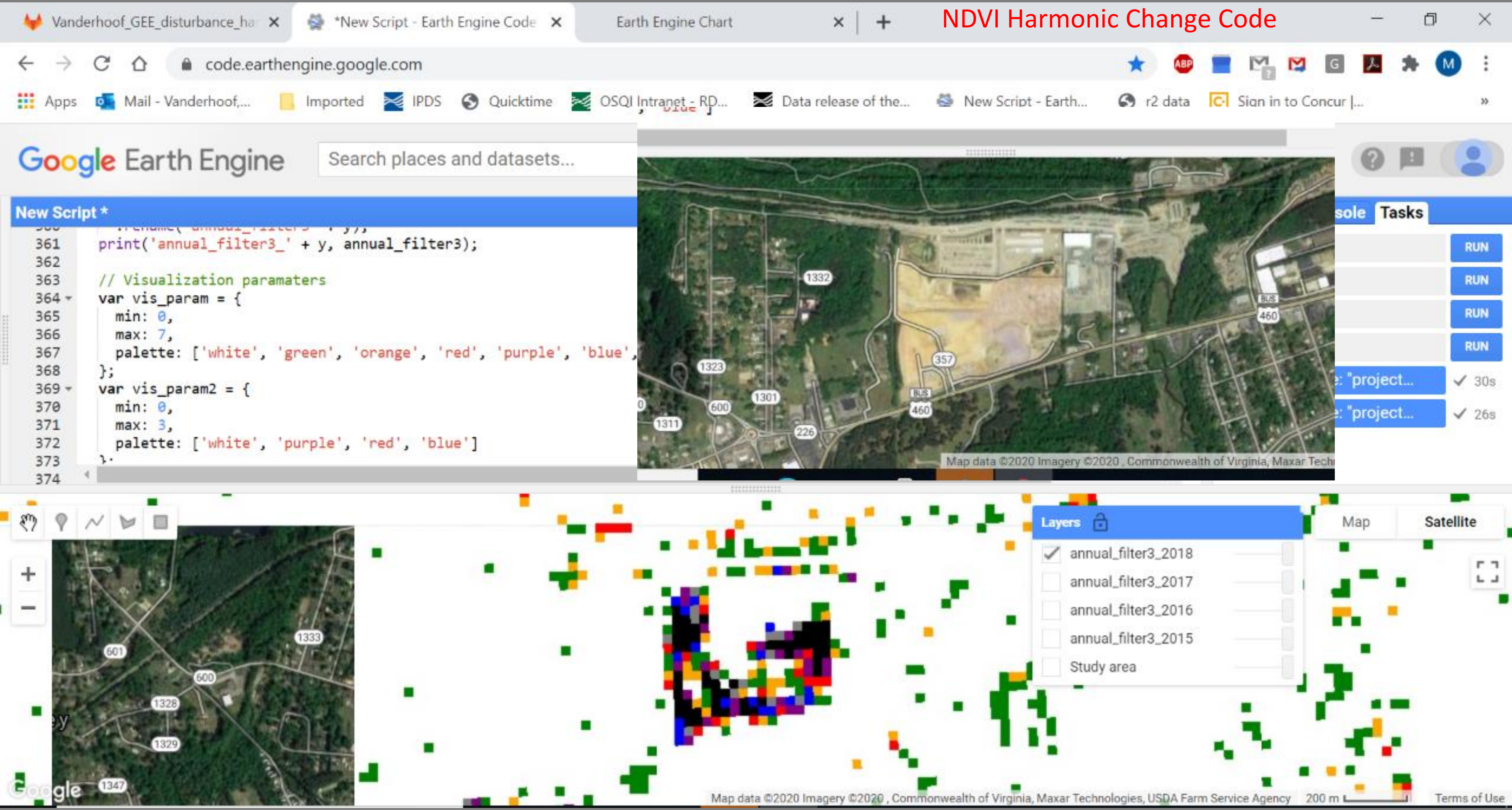


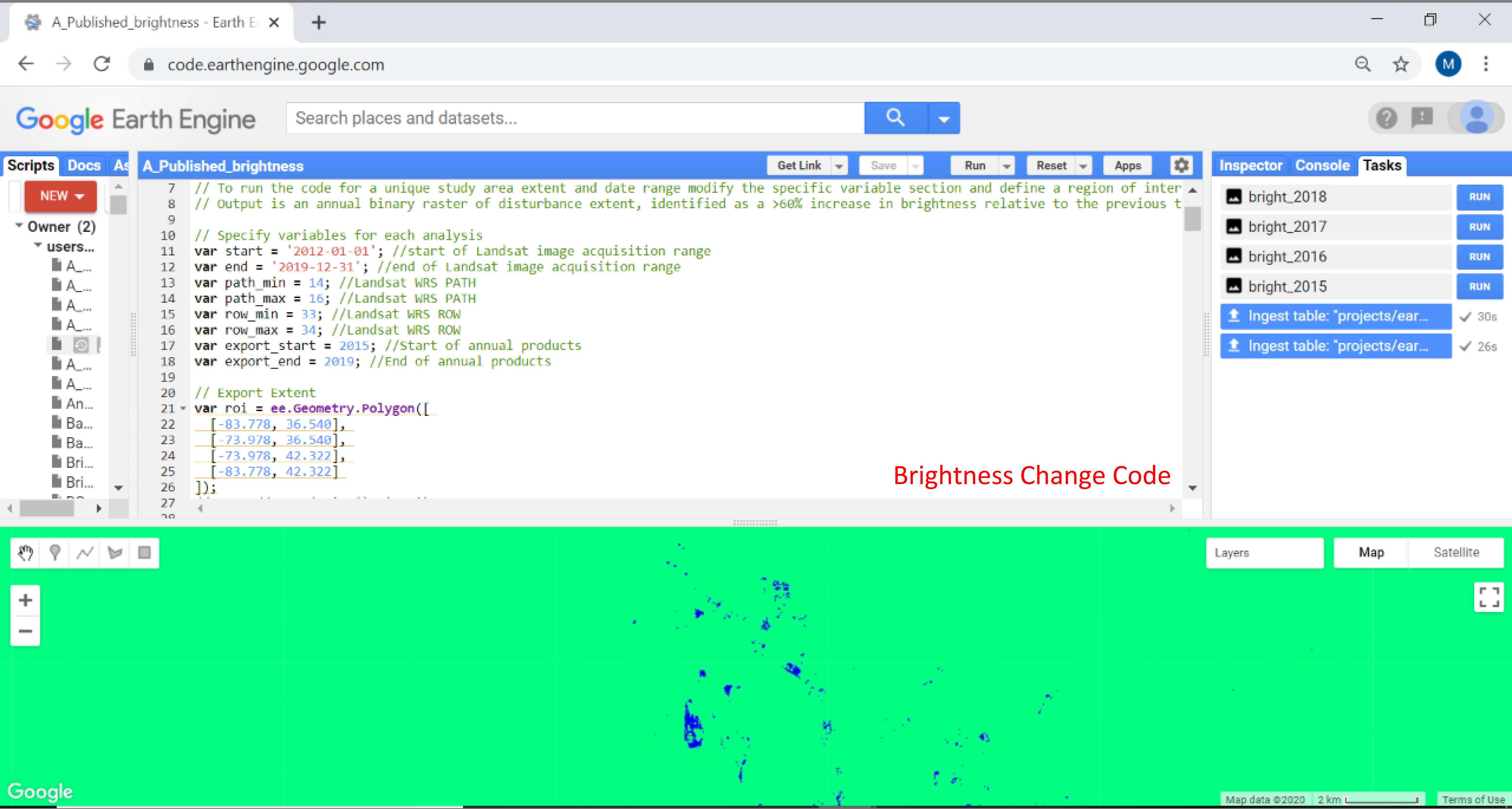
NDVI Harmonic Change Code




Vanderhoof_GEE_disturbance_ha
*New Script - Earth Engine Code
code.earthengine.google.com
Apps
Mail - Vanderhoof,...
Imported
IPDS
Quicktime
OSQI Intranet - RD...
Data release of the...
New Script - Earth...
r2 data
Sign in to Concur |...
Google Earth Engine
Search places and datasets...
New Script *
Get Link
Save
Run
Reset
Apps
// Plot the fitted model and the original data at the ROI.
print(ui.Chart.image.series(pixel.select(['fitted', 'NDVI', 'flag']), roi, ee.Reducer.mean(), 30)
.setOptions({
title: 'Harmonic model: original and fitted values',
lineWidth: 0.5,
pointSize: 2,
}));
NDVI Harmonic Change Code
Inspector
Console
Tasks
Use print(...) to write to this console.
L8 images:
JSON
748
Layers
annual_filter3_2018
annual_filter3_2017
annual_filter3_2016
annual_filter3_2015
Study area
Map
Satellite
Appomattox River
NDVI Harmonic Change Code
Google
Map data ©2020
200 m
Terms of Use

NDVI Harmonic Change Code





Brightness Change Code

Brightness Change Code

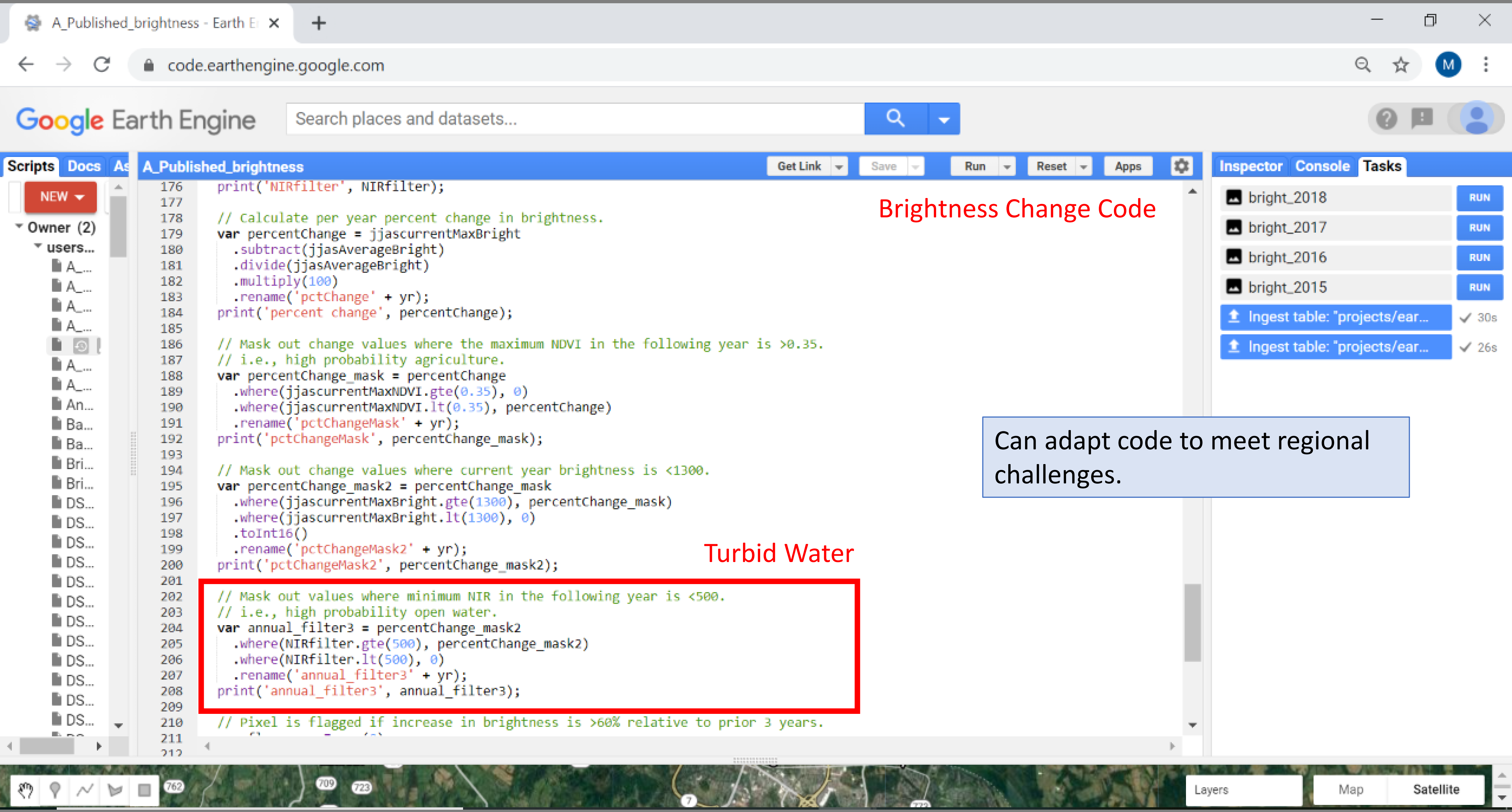
Fallow Ag, Crop Type Shift

Can adapt code to meet regional challenges.

A_Published_brightness

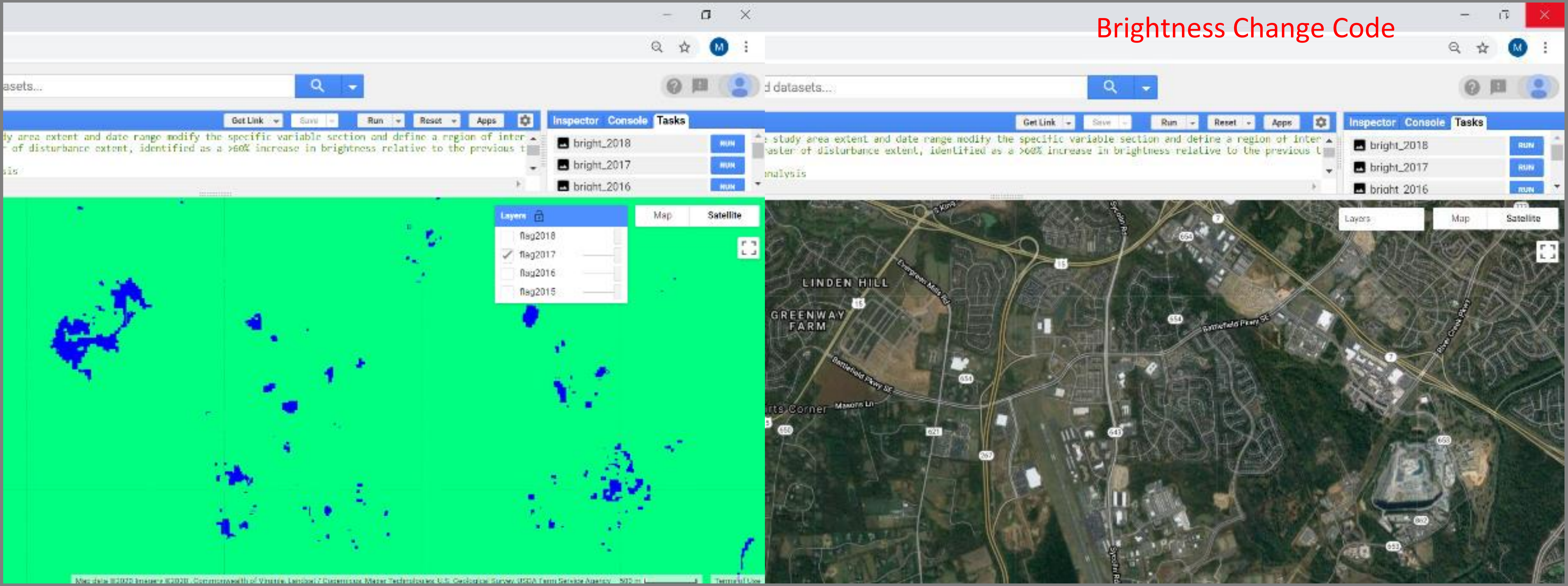
```
print('NIRfilter', NIRfilter);

// Calculate per year percent change in brightness.
var percentChange = jjascurrentMaxBright
  .subtract(jjasAverageBright)
  .divide(jjasAverageBright)
  .multiply(100)
  .rename('pctChange' + yr);
print('percent change', percentChange);

// Mask out change values where the maximum NDVI in the following year is >0.35.
// i.e., high probability agriculture.
var percentChange_mask = percentChange
  .where(jjascurrentMaxNDVI.gte(0.35), 0)
  .where(jjascurrentMaxNDVI.lt(0.35), percentChange)
  .rename('pctChangeMask' + yr);
print('pctChangeMask', percentChange_mask);

// Mask out change values where current year brightness is <1300.
var percentChange_mask2 = percentChange_mask
  .where(jjascurrentMaxBright.gte(1300), percentChange_mask)
  .where(jjascurrentMaxBright.lt(1300), 0)
  .toInt16()
  .rename('pctChangeMask2' + yr);
print('pctChangeMask2', percentChange_mask2);

// Mask out values where minimum NIR in the following year is <500.
// i.e., high probability open water.
var annual_filter3 = percentChange_mask2
  .where(NIRfilter.gte(500), percentChange_mask2)
  .where(NIRfilter.lt(500), 0)
  .rename('annual_filter3' + yr);
print('annual_filter3', annual_filter3);

// Pixel is flagged if increase in brightness is >60% relative to prior 3 years.
```

Tasks:
- bright_2018 RUN
- bright_2017 RUN
- bright_2016 RUN
- bright_2015 RUN
- Ingest table: "projects/ear... ✓ 30s
- Ingest table: "projects/ear... ✓ 26s



A_Published_brightness - Earth E
code.earthengine.google.com
Google Earth Engine
Search places and datasets...
Scripts
Docs
NEW
Owner (2)
users...
A_Published_brightness
Get Link
Save
Run
Reset
Apps
Inspector
Console
Tasks
bright_2018
bright_2017
bright_2016
bright_2015
RUN
Ingest table: "projects/ear...
30s
26s
Brightness Change Code
Turbid Water
Can adapt code to meet regional challenges.
print('NIRfilter', NIRfilter);
// Calculate per year percent change in brightness.
var percentChange = jjascurrentMaxBright
.subtract(jjasAverageBright)
.divide(jjasAverageBright)
.multiply(100)
.rename('pctChange' + yr);
print('percent change', percentChange);
// Mask out change values where the maximum NDVI in the following year is >0.35.
// i.e., high probability agriculture.
var percentChange_mask = percentChange
.where(jjascurrentMaxNDVI.gte(0.35), 0)
.where(jjascurrentMaxNDVI.lt(0.35), percentChange)
.rename('pctChangeMask' + yr);
print('pctChangeMask', percentChange_mask);
// Mask out change values where current year brightness is <1300.
var percentChange_mask2 = percentChange_mask
.where(jjascurrentMaxBright.gte(1300), percentChange_mask)
.where(jjascurrentMaxBright.lt(1300), 0)
.toInt16()
.rename('pctChangeMask2' + yr);
print('pctChangeMask2', percentChange_mask2);
// Mask out values where minimum NIR in the following year is <500.
// i.e., high probability open water.
var annual_filter3 = percentChange_mask2
.where(NIRfilter.gte(500), percentChange_mask2)
.where(NIRfilter.lt(500), 0)
.rename('annual_filter3' + yr);
print('annual_filter3', annual_filter3);
// Pixel is flagged if increase in brightness is >60% relative to prior 3 years.
Layers
Map
Satellite

Example from Leesburg, VA



Project and Product Summary

1. Disturbance, inundation extent, and the co-location of the 2 have applications for monitoring and managing wetland extent and condition.
2. Published products and code can be used as a jumping off point and adapted to work across different regions.

Thank You! Questions?

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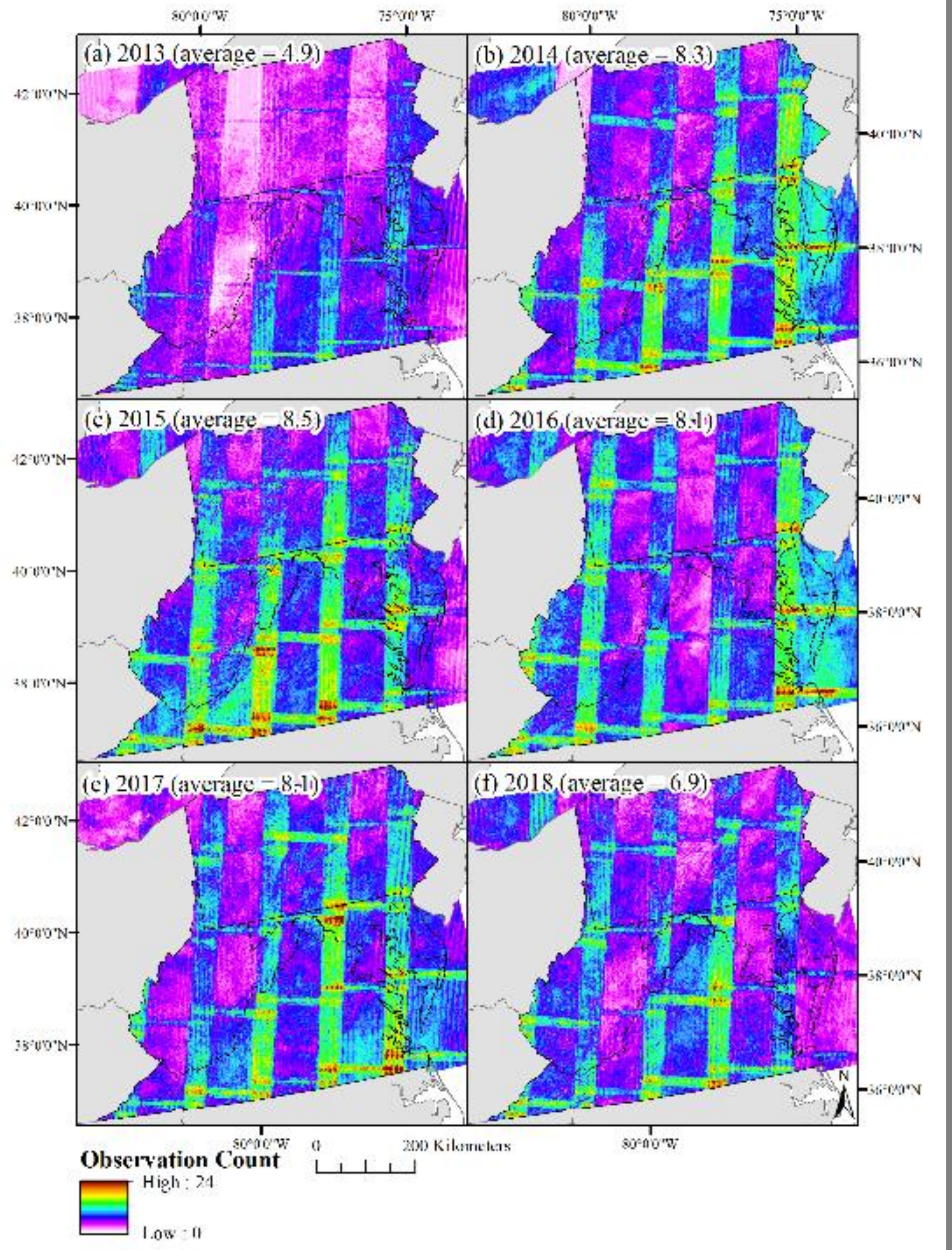
Products – ScienceBase:
https://www.sciencebase.gov/catalog/item/5e430b15e4b0edb47be845ce

Code – GitLab:
https://code.usgs.gov/gecsc/tracking-disturbance-and-inundation-to-identify-wetland-loss/-/tree/master

Research Presented Funded by:

EPA Region 3
EPA Region 3 RARE Program
USGS, Land Change Science Program

EPA USGS science for a changing world



(a) 2013 (average = 4.9)
(b) 2014 (average = 8.3)
(c) 2015 (average = 8.5)
(d) 2016 (average = 8.1)
(e) 2017 (average = 8.1)
(f) 2018 (average = 6.9)
80°0'0"W
75°0'0"W
42°0'0"N
40°0'0"N
38°0'0"N
36°0'0"N
0
200 Kilometers
Observation Count
High : 24
Low : 0
N