Image Manipulation: Bands, Arithmetic, Thresholds, and Masks (F2.0)

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Overview
Once images have been identified in Earth Engine, they can be viewed in a wide array of band combinations for targeted purposes. For users who are already versed in remote sensing concepts, this chapter shows how to do familiar tasks on this platform; for those who are entirely new to such concepts, it introduces the idea of band combinations.

Learning Outcomes
- Understanding what spectral indices are and why they are useful.
- Being introduced to a range of example spectral indices used for a variety of purposes.

Assumes you know how to:
- Import images and image collections, filter, and visualize (Part F1).

Introduction to Theory

Spectral indices are based on the fact that different objects and land covers on the Earth's surface reflect different amounts of light from the Sun at different wavelengths. In the visible part of the spectrum, for example, a healthy green plant reflects a large amount of green light while absorbing blue and red light—which is why it appears green to our eyes. Light also arrives from the Sun at wavelengths outside what the human eye can see, and there are large differences in reflectances between living and nonliving land covers, and between different types of vegetation, both in the visible and outside the visible wavelengths. We visualized this earlier, in Chaps. F1.1 and F1.3 when we mapped color-infrared images (Fig. F2.0.1).

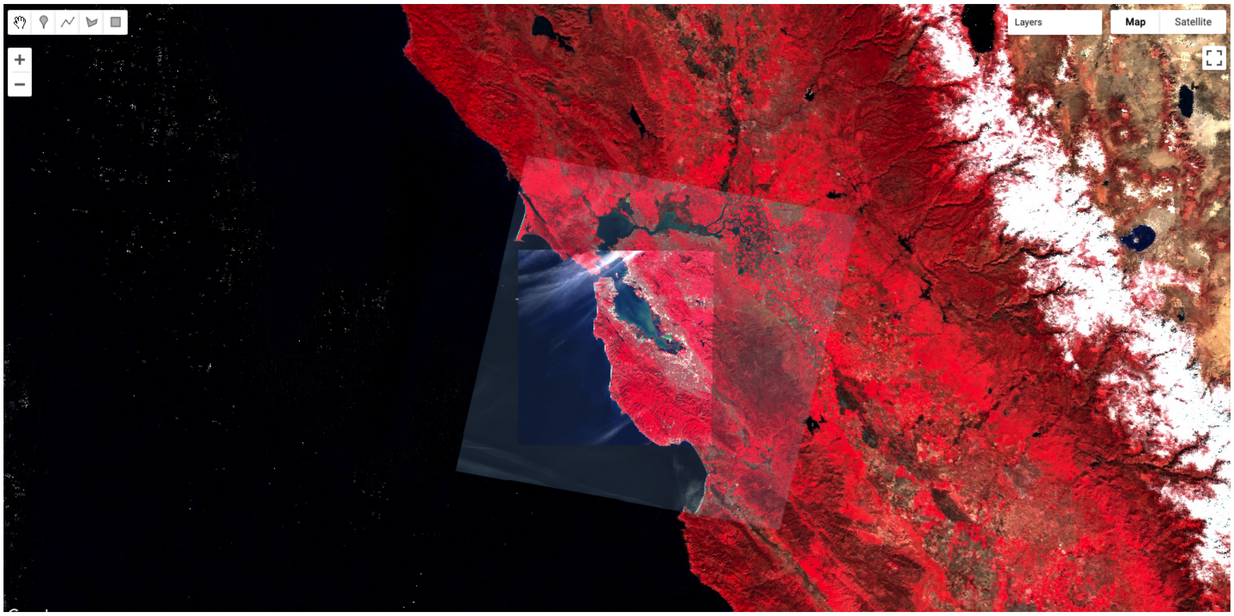

Fig. F2.0.1 Mapped color-IR images from multiple satellite sensors that we mapped in Chap. F1.3. The near infrared spectrum is mapped as red, showing where there are high amounts of healthy vegetation.

If we graph the amount of light (reflectance) at different wavelengths that an object or land cover reflects, we can visualize this more easily (Fig. F2.0.2). For example, look at the reflectance curves for soil and water in the graph below. Soil and water both have relatively low reflectance at wavelengths around 300 nm (ultraviolet and violet light). Conversely, at wavelengths above 700 nm (red and infrared light) soil has relatively high reflectance, while water has very low reflectance. Vegetation, meanwhile, generally reflects large amounts of near infrared light, relative to other land covers.

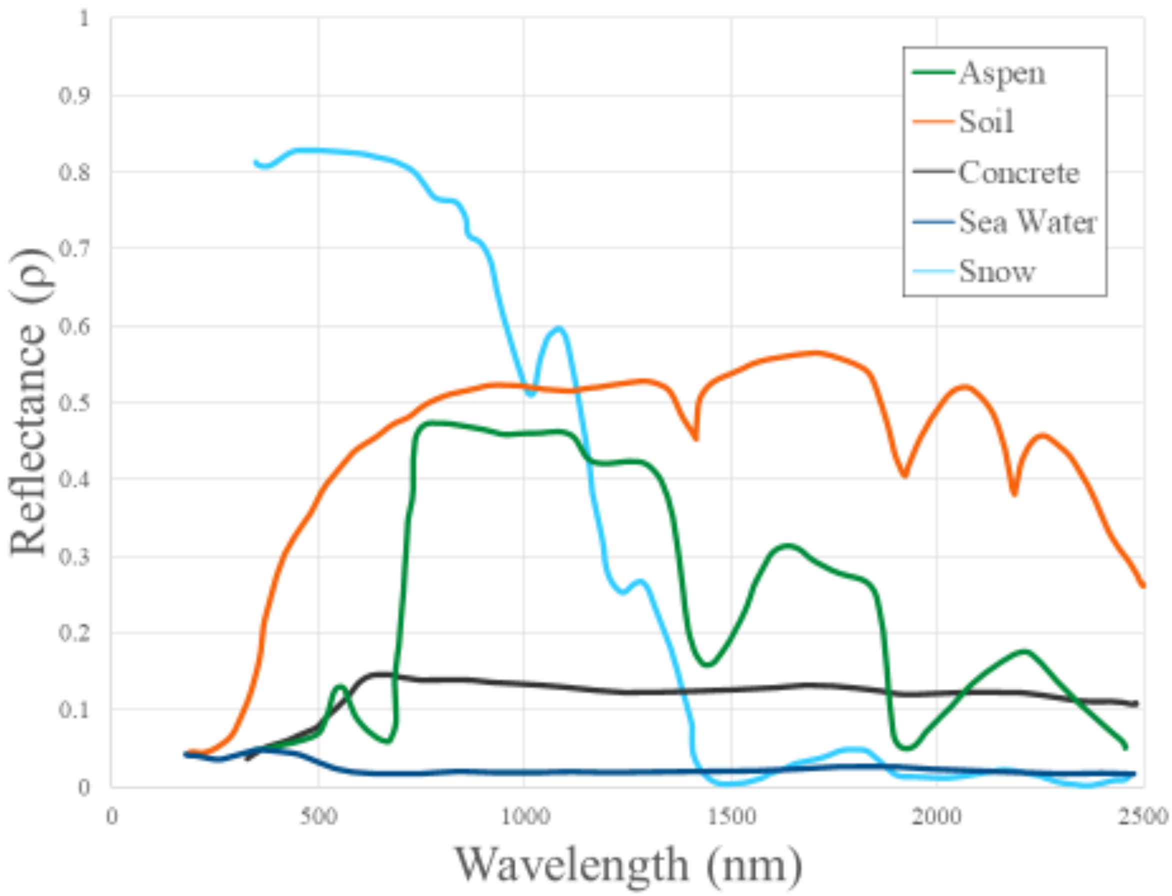

Fig. F2.0.2 A graph of the amount of reflectance for different objects on the Earth's surface at different wavelengths in the visible and infrared portions of the electromagnetic spectrum. 1 micrometer (μm) = 1,000 nanometers (nm).

Spectral indices use math to express how objects reflect light across multiple portions of the spectrum as a single number. Indices combine multiple bands, often with simple operations of subtraction and division, to create a single value across an image that is intended to help to distinguish particular land uses or land covers of interest. Using Fig. F2.0.2, you can imagine which wavelengths might be the most informative for distinguishing among a variety of land covers. We will explore a variety of calculations made from combinations of bands in the following sections.

Indices derived from satellite imagery are used as the basis of many remote-sensing analyses. Indices have been used in thousands of applications, from detecting anthropogenic deforestation to examining crop health. For example, the growth of economically important crops such as wheat and cotton can be monitored throughout the growing season: Bare soil reflects more red wavelengths, whereas growing crops reflect more of the near-infrared (NIR) wavelengths. Thus, calculating a ratio of these two bands can help monitor how well crops are growing (Jackson and Huete 1991).

Practicum

Section 1. Band Arithmetic in Earth Engine

If you have not already done so, you can add the book's code repository to the Code Editor by entering https://code.earthengine.google.com/?accept_repo=projects/gee-edu/book (or the short URL bit.ly/EEFA-repo) into your browser. The book's scripts will then be available in the script manager panel to view, run, or modify. If you have trouble finding the repo, you can visit bit.ly/EEFA-repo-help for help.

Many indices can be calculated using band arithmetic in Earth Engine. Band arithmetic is the process of adding, subtracting, multiplying, or dividing two or more bands from an image. Here we'll first do this manually, and then show you some more efficient ways to perform band arithmetic in Earth Engine.

Arithmetic Calculation of NDVI

The red and near-infrared bands provide a lot of information about vegetation due to vegetation's high reflectance in these wavelengths. Take a look at Fig. F2.0.2 and note, in particular, that vegetation curves (graphed in green) have relatively high reflectance in the NIR range (approximately 750–900 nm). Also note that vegetation has low reflectance in the red range (approximately 630–690 nm), where sunlight is absorbed by chlorophyll. This suggests that if the red and near-infrared bands could be combined, they would provide substantial information about vegetation.

Soon after the launch of Landsat 1 in 1972, analysts worked to devise a robust single value that would convey the health of vegetation along a scale of −1 to 1. This yielded the NDVI, using the formula:

$$NDVI = \frac{NIR - red}{NIR + red} \qquad \text{(F2.0.1)}$$

where *NIR* and *red* refer to the brightness of each of those two bands. As seen in Chaps. F1.1 and F1.2, this brightness might be conveyed in units of reflectance, radiance, or digital number (DN); the NDVI is intended to give nearly equivalent values across platforms that use these wavelengths. The general form of this equation is called a "normalized difference"—the numerator is the "difference" and the denominator “normalizes” the value. Outputs for NDVI vary between −1 and 1. High amounts of green vegetation have values around 0.8–0.9. Absence of green leaves gives values near 0, and water gives values near −1.

To compute the NDVI, we will introduce Earth Engine’s implementation of *band arithmetic.* Cloud-based band arithmetic is one of the most powerful aspects of Earth Engine, because the platform’s computers are optimized for this type of heavy processing. Arithmetic on bands can be done even at planetary scale very quickly—an idea that was out of reach before the advent of cloud-based remote sensing. Earth Engine automatically partitions calculations across a large number of computers as needed, and assembles the answer for display.

As an example, let’s examine an image of San Francisco (Fig. F2.0.3).

```
/////
// Band Arithmetic
/////

// Calculate NDVI using Sentinel 2

// Import and filter imagery by location and date.
var sfoPoint = ee.Geometry.Point(-122.3774, 37.6194);
var sfoImage = ee.ImageCollection('COPERNICUS/S2')
    .filterBounds(sfoPoint)
    .filterDate('2020-02-01', '2020-04-01')
    .first();

// Display the image as a false color composite.
Map.centerObject(sfoImage, 11);
Map.addLayer(sfoImage, {
    bands: ['B8', 'B4', 'B3'],
    min: 0,
    max: 2000
}, 'False color');
```

Fig. F2.0.3 False color Sentinel-2 imagery of San Francisco and surroundings

The simplest mathematical operations in Earth Engine are the `add`, `subtract`, `multiply`, and `divide` methods. Let's select the near-infrared and red bands and use these operations to calculate NDVI for our image.

```
// Extract the near infrared and red bands.
var nir = sfoImage.select('B8');
var red = sfoImage.select('B4');

// Calculate the numerator and the denominator using subtraction and
addition respectively.
var numerator = nir.subtract(red);
var denominator = nir.add(red);

// Now calculate NDVI.
var ndvi = numerator.divide(denominator);

// Add the layer to our map with a palette.
var vegPalette = ['red', 'white', 'green'];
Map.addLayer(ndvi, {
    min: -1,
    max: 1,
    palette: vegPalette
}, 'NDVI Manual');
```

Examine the resulting index, using the **Inspector** to pick out pixel values in areas of vegetation and non-vegetation if desired.

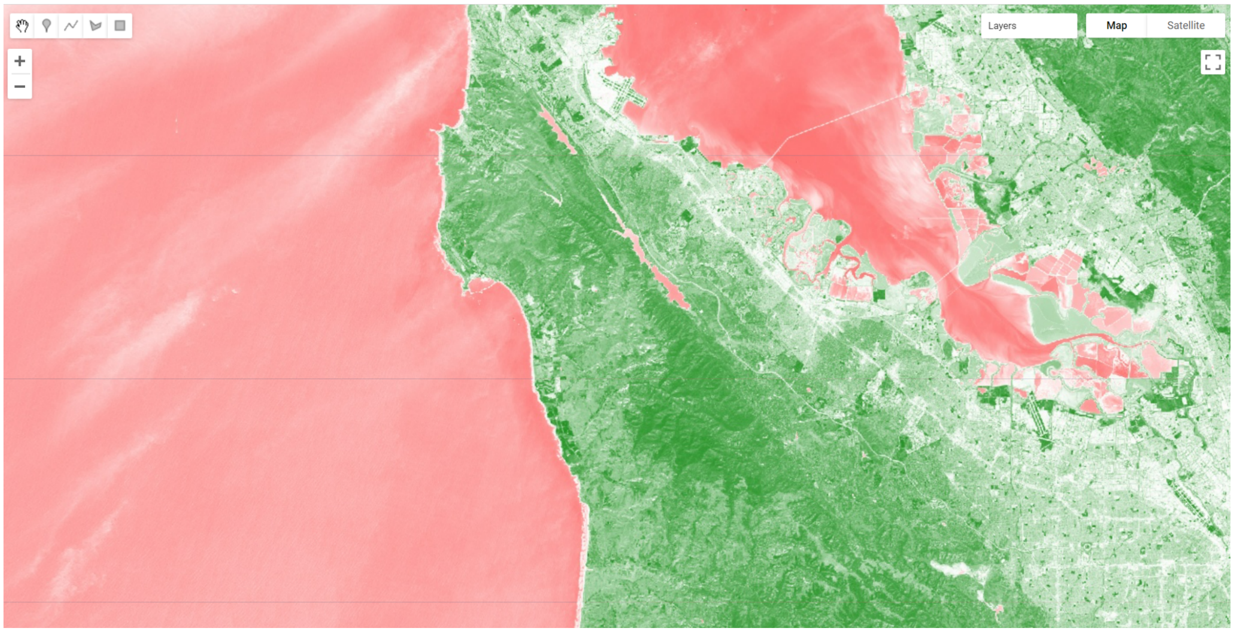

Fig. F2.0.4 NDVI calculated using Sentinel-2. Remember that outputs for NDVI vary between −1 and 1. High amounts of green vegetation have values around 0.8–0.9. Absence of green leaves gives values near 0, and water gives values near −1.

Using these simple arithmetic tools, you can build almost any index, or develop and visualize your own. Earth Engine allows you to quickly and easily calculate and display the index across a large area.

Single-Operation Computation of Normalized Difference for NDVI

Normalized differences like NDVI are so common in remote sensing that Earth Engine provides the ability to do that particular sequence of subtraction, addition, and division in a single step, using the `normalizedDifference` method. This method takes an input image, along with bands you specify, and creates a normalized difference of those two bands. The NDVI computation previously created with band arithmetic can be replaced with one line of code:

```
// Now use the built-in normalizedDifference function to achieve the
same outcome.
var ndviND = sfoImage.normalizedDifference(['B8', 'B4']);
Map.addLayer(ndviND, {
```

```
    min: -1,
    max: 1,
    palette: vegPalette
}, 'NDVI normalizedDiff');
```

Note that the order in which you provide the two bands to `normalizedDifference` is important. We use B8, the near-infrared band, as the first parameter, and the red band B4 as the second. If your two computations of NDVI do not look identical when drawn to the screen, check to make sure that the order you have for the NIR and red bands is correct.

Using Normalized Difference for NDWI

As mentioned, the normalized difference approach is used for many different indices. Let's apply the same `normalizedDifference` method to another index.

The Normalized Difference Water Index (NDWI) was developed by Gao (1996) as an index of vegetation water content. The index is sensitive to changes in the liquid content of vegetation canopies. This means that the index can be used, for example, to detect vegetation experiencing drought conditions or differentiate crop irrigation levels. In dry areas, crops that are irrigated can be differentiated from natural vegetation. It is also sometimes called the Normalized Difference Moisture Index (NDMI). NDWI is formulated as follows:

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \qquad \text{(F2.0.2)}$$

where NIR is near-infrared, centered near 860 nm (0.86 μm), and SWIR is short-wave infrared, centered near 1,240 nm (1.24 μm).

Compute and display NDWI in Earth Engine using the `normalizedDifference` method. Remember that for Sentinel-2, B8 is the NIR band and B11 is the SWIR band (refer to Chaps. F1.1 and F1.3 to find information about imagery bands).

```
// Use normalizedDifference to calculate NDWI
var ndwi = sfoImage.normalizedDifference(['B8', 'B11']);
var waterPalette = ['white', 'blue'];
Map.addLayer(ndwi, {
    min: -0.5,
    max: 1,
    palette: waterPalette
```

```
}, 'NDWI');
```

Examine the areas of the map that NDVI identified as having a lot of vegetation. Notice which are more blue. This is vegetation that has higher water content.

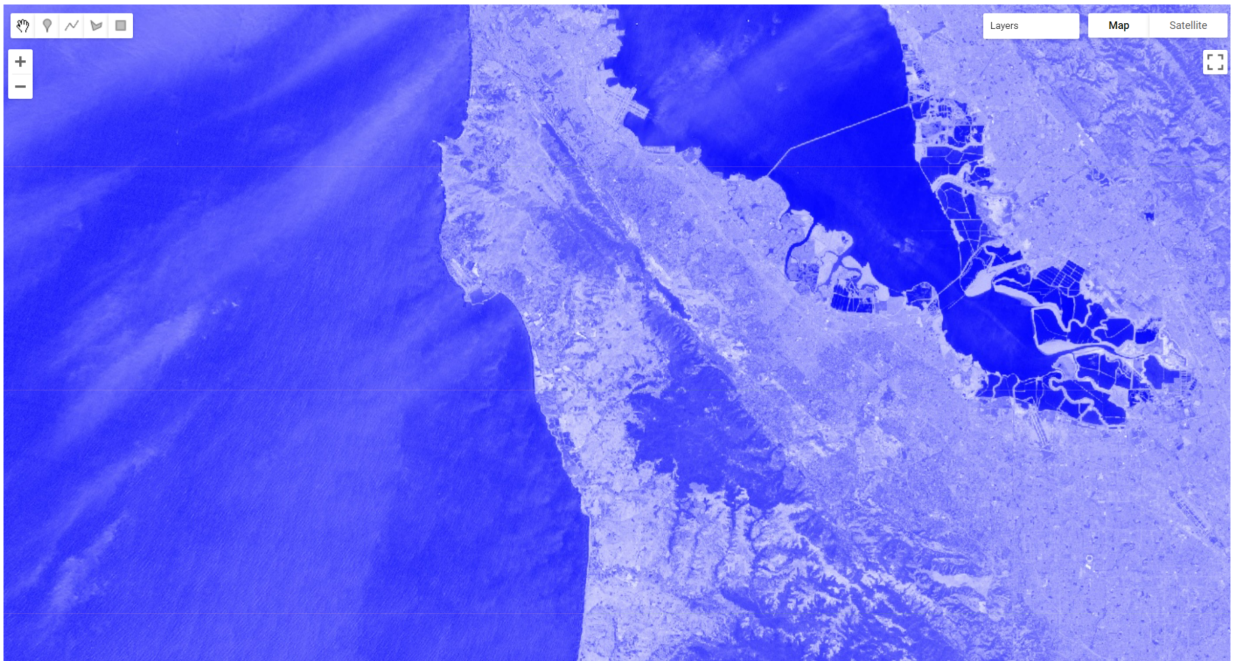

Fig. F2.0.5 NDWI displayed for Sentinel-2 over San Francisco

Code Checkpoint F20a. The book's repository contains a script that shows what your code should look like at this point.

Section 2. Thresholding, Masking, and Remapping Images

The previous section in this chapter discussed how to use band arithmetic to manipulate images. Those methods created new continuous values by combining bands within an image. This section uses logical operators to categorize band or index values to create a categorized image.

Implementing a Threshold

Implementing a threshold uses a number (the threshold value) and logical operators to help us partition the variability of images into categories. For example, recall our map of NDVI. High amounts of vegetation have NDVI values near 1 and non-vegetated areas are near 0. If we want to see what areas of the map have vegetation, we can use a threshold to generalize the NDVI value in each pixel as being either "no vegetation" or "vegetation". That is a substantial simplification, to be sure, but can help us to better comprehend the rich variation on the Earth's surface. This type of categorization may be useful if, for example, we want to look at the proportion of a city that is vegetated. Let's create a Sentinel-2 map of NDVI near Seattle, Washington, USA. Enter the code below in a new script.

```
// Create an NDVI image using Sentinel 2.
var seaPoint = ee.Geometry.Point(-122.2040, 47.6221);
var seaImage = ee.ImageCollection('COPERNICUS/S2')
    .filterBounds(seaPoint)
    .filterDate('2020-08-15', '2020-10-01')
    .first();

var seaNDVI = seaImage.normalizedDifference(['B8', 'B4']);

// And map it.
Map.centerObject(seaPoint, 10);
var vegPalette = ['red', 'white', 'green'];
Map.addLayer(seaNDVI,
    {
        min: -1,
        max: 1,
        palette: vegPalette
    },
    'NDVI Seattle');
```