Cloud Detection and Removal Techniques for Landsat 8 Imagery
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Introduction

The creation of a cloudless orthoimagery basemap is a common application of remote sensing data. A complete global base map with no artifacts or clouds does not yet exist, therefore we have explored techniques for cloud detection and removal using Landsat 8 imagery.

We have studied two locations that are particularly lacking in cloudless imagery: Mt. Nyiragongo, in the Democratic Republic of the Congo, and Kawah Ijen, on the Indonesian island of Java. These active volcanoes are within the heavily clouded Intertropical Convergence Zone (ITCZ) and also provide their own occlusion with semi-permanent emission plumes.

Background and Previous Work

Base maps of the Earth consisting of satellite imagery of the visible spectrum have been readily available for several decades. Common sources include Google Earth, USGS NAIP, Bing, MapQuest, and now MapBox. When exploring these sources, you will notice instances of clouds blocking the Earth's surface as well as seams along the edges of the source imagery. Though MapBox has made great strides towards removing these problems, as of yet, no one has achieved a base map of the entire world devoid of clouds at every zoom level.

Cloud detection and removal is a common task in remote sensing. Cloud cover is not only visually obstructive of the ground, but also introduces error in products such as NDVI and EVI. Quality Assessment Bands (BQA) are commonly provided with standard Level-1 products to aid the analyst with flagging error prone data. This band is produced using the Automated Cloud-Cover Assessment Algorithm (ACCA). This algorithm utilizes the bands available in Landsat 7, however, it has not yet been adapted to use the new Coastal Aerosol and Cirrus bands introduced in Landsat 8. In addition, it fails to detect the shadows of clouds.

ACCA cloud classification is done through a series of filters that progressively declassify a pixel from being considered clouded to not clouded. The first filter begins with setting a brightness threshold and classifies pixels as non-clouds for values below the threshold. There is also a temperature threshold that uses the thermal infra-red bands. This filter is based on the principle that clouds are usually cooler than land. Further filtering uses several difference indices between bands to better delineate snow and vegetation from clouds.

MapBox has managed to take a simpler, yet more effective philosophy that does not use masks produced by ACCA. Instead, they sort the RGB values from a large set of imagery and choose an average of the subset of darker RGB values. Because clouds have a higher reflectance than the ground in the visible spectrum, this method alone is effective in removing clouds and other atmospheric effects. The resulting composite of dark pixels is then brightened, thus producing a cloudless image of the area.

We have created a method that is similar in nature, but instead of choosing the darkest RGB value for each pixel, we use the RGB value corresponding to the darkest value in the Coastal Aerosol band. This band is more sensitive to clouds than the RGB bands. Unfortunately, our sample size is too small to achieve good results with an average, so instead we use the single darkest value.

Methods

1. RGB Values Corresponding to the Darkest Pixel of the Coastal Aerosol Band

We have developed our own technique using the new
Coastal Aerosol band (0.43-0.45 µm). This band is within the indigo portion of the visible spectrum and is extremely sensitive to clouds and atmospheric effects. Clouded and occluded areas are significantly brighter than ground features, and this has proven to be more effective of a cloud mask than the error prone BQA band. By selecting the darkest pixel for a given day in this band, we are in effect choosing the day least likely to have clouds for the given pixel. We then use the corresponding values in the RGB bands for our composite.

It is important to notice that the Coastal Aerosol band as well as the BQA band do not identify cloud shadows. If clouds are removed but shadows are ignored, we are left with distracting artifacts resulting from these shadows. Because taking the darkest Coastal Aerosol pixel guarantees that we are also keeping all of the pixels within a shadow, we instead create an adjusted index that no longer classifies shadowed area to be the darkest pixel.

Since cloud shadows tend to be the darkest pixels in the green band, we created an index using the Coastal Aerosol (A) and Green (G) bands:

\[
\frac{1}{4} (A - G)
\]

Adding this to the Coastal Aerosol band brightens the cloud shadows just enough so that they are no longer darker than sunlit terrain. Once our corrected Coastal Aerosol band is prepared, we iterate through each pixel covered by our data set and create a composite using the RGB value from the day with the lowest value in our derived index.

2. Mean RGB Value of Pixels Classified as Cloudless from BQA

We are using the provided BQA (Quality Assessment Band) as a cloud mask from which we composite the cloudless pixels taken from our set of imagery. Each pixel in the BQA contains an integer value corresponding to a given classification based on cloud, cirrus, snow/ice, vegetation, cloud shadow, water, and other classifications. We then create a binary mask that takes all of these values that might suggest cloud cover and classify a pixel as either clouded (0) or cloudless (1). Then, for each RGB pixel from our set we create a mean of all of the values that are classified as cloudless.

Differences

The essential difference between these two methods is that Method 1 chooses only the darkest pixel from the set, and Method 2 creates a mean value from the set of valid pixels. Because the darkest pixel is also the pixel least likely to be clouded, we are less susceptible to error. A major disadvantage of using the darkest pixel is that if there is a cloud shadow in our source data, the shadowed pixel is guaranteed to be retained in the final composite. Creating a mean of the values, on the other hand, will introduce brighter pixels into the mix, therefore introducing more error-prone values. This approach retains more artifacts caused by undetected clouds and cloud edges, but taking a mean value has the benefit of reducing the effect of cloud shadows.

Sources of Error

Since Landsat 8 has only been in service since May 30, 2013, we have a very limited number of imagery samples to use. Some pixels, especially near the calderas of the volcanoes, do not have a single pixel within our set of samples that has been classified as cloudless. This leaves no other option than to choose the least cloudy pixel for the given area.

In addition, the Quality Assessment Band (BQA) is quite error prone. This band uses the Automatic Cloud Cover Assessment Algorithm (ACCA), and this does not fully utilize the new Aerosol (Band 1) and Cirrus (Band 9) bands from Landsat 8. In many instances, the edges of the clouds are not detected, and certain patches of pixels within the interior of cloud bodies are completely missed. In addition, BQA has many false positives, thus reducing the set of quality pixels to choose from.

Although a given BQA pixel has many classification values that can be construed as clouded, the implementation of the specification is incomplete. For example, the cloud shadow classification is not currently being used, though 2 bits in the BQA integer are reserved specifically for a confidence classification of cloud shadow.

Results

Overall, Method 1 produced a better result than Method 2. Because the quality of the BQA is poor, many clouded values were included in the mean composite of Method 2. Since the clouded values are much brighter than everything else, these errors produced marbled, white artifacts throughout the image. The composite produced by Method 1 avoids this problem, but some pixels are still clouded, because for some areas, not a single source
A pixel is cloudless. Also, our index is effective in removing cloud shadows, but the use of the green band overly emphasizes the algal blooms in the ocean surrounding Kawah Ijen.

**Discussion and Conclusions**

In future work, our image processing should adhere more closely to the MapBox philosophy of creating a composite based on an average of a subset consisting of the darkest pixels from the set. Right now, Method 1 takes the single darkest pixel, and we are likely to produce an image with less artifacts if we instead create values based on several of the darkest pixels.

When we have a larger data set in time from Landsat 8, the usefulness of the BQA will also increase. Though it is somewhat error prone, we can experiment with uniting our two methods and use the BQA as our first pass filter for clouded pixels. We can then take our images with the clouds “punched out” as the source to which we can apply Method 1. Then, rather than choosing only the darkest pixel, we can choose a mean, median, or another weighted combination of the darker pixels.

**References**


**Data**

**Source:** USGS Earth Explorer  
http://earthexplorer.usgs.gov/  

**Satellite:** Landsat 8  

**Samples:** 11 samples for each site with 16 day intervals