

Small Cloud and Shadow Removal from Satellite Imagery

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Digital Image Processing

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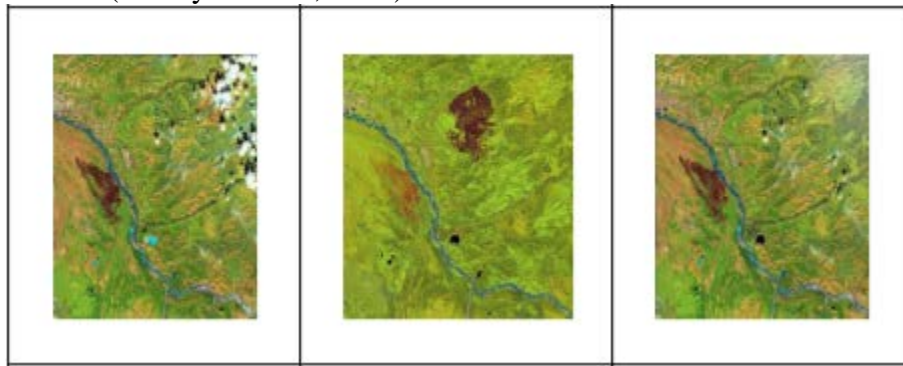
### Abstract

Analyzing satellite images can be difficult at times. An example of when it is difficult is when you obtain good imagery of an area of interest, but the clouds and the shadows they create are obscuring parts of the image. It is not always possible to obtain completely cloud-free imagery all the time, so at times there is a need to remove them, or to enhance them enough to be utilized in analysis. My project is to take an image with these clouds and their shadows and replace them or patch them with areas from another image that is cloud free. Both of the images obtained are within a week apart. This was done so that the land use and land cover is still up to date, so that in theory, analysis could be done on the final image because there is an assumption that land cover does not change that fast.

*Keywords:* Satellites, clouds, shadows

### Small Cloud and Shadow Removal from Satellite Imagery

In a journal article by Saranya M from the R.V.S College of Engineering and Technology, CLOUD REMOVAL FROM SATELLITE IMAGES USING INFORMATION CLONING, she introduces the idea of cloud removal from satellite images using information cloning. The satellite imagery she obtained for this journal article was through Landsat. The workflow in the proposed method is to have the input images that consist of a reference image that is cloud-free and another image that contains cloud cover. then to do the cloud detection a threshold approach was taken which reminded me of the lecture in Dr. Cho's class on cloud removal. Next do the shadow detection. After the cloud and shadow detection they utilized blob detection because it will return both the labeled area and its statistics that it finds while using blob detection. The information from the blob detection is used to remove the clouds by use known patches to utilize information cloning to fill in missing data points after removing the cloud and shadow contaminated pixels. The information cloning algorithm that was introduced in this technique is utilized to "reconstruct the information of cloud-contaminated regions using several high similarity and cloud-free patches acquired at different times...to find an accurate and optimized reconstruction result the problem is formulated as an optimization equation with the boundary condition" (Saranya M n.d., 2014).



A second journal article relating to the removal of cloud cover is from the U.S. Department of Agriculture, "CREATING CLOUD-FREE LANDSAT ETM+ DATA SETS IN TROPICAL LANDSCAPES: CLOUD AND CLOUD-SHADOW REMOVAL". Cloud-free data acquisition for a particular time is difficult or near impossible for the entirety of an island. This only gets more difficult in higher elevations. In Puerto Rico, where this study was first done, this area in the higher elevations is where most of the islands protected forest resources are situated. In order to keep an eye on their forest resources and thus its habitat, cloud-free or nearly cloud-free imagery needs to be obtained. In their study they have "developed a simple and semiautomated method to mask clouds and shadows in Landsat ETM+ imagery, and have developed a recent (for the time of the article in 2006) cloud-free composite of multitemporal images for Puerto Rico and its adjacent islands that can be used for a variety of landscape analyses" (Sebastián Martinuzzi, et al., 2007) The study's data set contains 18 images that were acquired between 1999 September and 2003 February. In order to accomplish atmospheric correction, they applied a model to convert radiance to reflectance corrected by Rayleigh scatter (Poalini et al. 2004) created by the Institute for Astronomy and Space Physics. Their next step in the process was to identify the clouds and to develop a mask using brightness values in the blue band and thermal band, and then to develop a final cloud and shadow mask by using the cloud mask, the brightness values in the near infrared band for the shadowed spots, the geometry

between the clouds and their shadows position on the ground. “For the image composition the most cloud-free scene from each path/row was selected as the reference image, i.e., the top scene for each path/row in the mosaic. Cloud and cloud-shadow areas in reference images were replaced with data from other dates” (Sebastián Martinuzzi, et al., 2007).

In the journal article “SEMI-AUTOMATED CLOUD/SHADOW REMOVAL AND LAND COVER CHANGE DETECTION USING SATELLITE IMAGERY” by Honji, et al., from the PASCO Corporation in Japan they devised a plan, and used a tool produced from their corporation, for cloud, shadow and haze removal and land cover change detection in a semi-automated approach. They chose an area to study in the Democratic Republic of Congo, Lake Mai-Ndombe because of its forest, crop and grassland covers. They also chose three different periods to work with, 1990, 2000 and 2010. The imagery data sets are as follows: Landsat 5 Thematic Mapper, path 180/row 062, dated 1995 February 19. The Landsat 7 Enhanced Thematic Mapper, path 180/row 062, dated 2002 May 5. And ALOS AVNIR-2, path 278/frame 3650, dated 2009 July 4. The clouded areas were extracted using Unsupervised Classification for 3 visible bands (bands 1, 2 and 3 for both Landsat and AVNIR-2) and then recoding their presenting classes. Then, for the shadow identification, they incorporated the shadows direction and estimated the average distance from the cloud this way. The shadow direction was known using the Sun Azimuth angle of the image, which is obtained through the metadata. The average distance of the shadows from the clouds were found through testing a few points. Finally, both the cloud and shadowed areas were extended for proper representation. Then, both were combined to one. For the haze identification component, they used the Tasseled Cap (TC) transformation. The clear and hazy areas were separated using the following equation:

$$T_c = (X_1 * DN_{BLUE}) + (X_2 * DN_{RED})$$

Where,  $DN_{BLUE}$  = DN value in Blue band

$DN_{RED}$  = DN value in Red band

$X_1$  : weighing coefficients for Blue band

$X_2$  : weighing coefficient for Red band

The pixels with values greater than the mean TC was selected as haze cover (Richter, 2011). Once the haze was removed, the clouds and their shadows were removed by replacing their pixels "with free pixels of same image with the help of PALSAR image by nearest neighborhood" (Sah et al. n.d., 2012). Their results showed that the cloud, shadow and haze removal for the ALOS AVNIR-2 was hopeful. The result for removing clouds in the Landsat Enhanced Thematic Mapper was also promising, though some pixels in the image were found to be mis-replaced. They assumed this to be because of the range between the acquisition dates between the two. the algorithm they used for the haze removal also worked and removed haze from all visible bands they used. They also used this study to do a land change detection but I chose to leave that out since it was not correlated with any ideas to my course project, though they said in the results that the land change detection was seemingly promising. I liked this journal article more than the rest because they did the cloud/shadow removal plus a land change detection because they did the study over three different eras.

Throughout the process of acquiring satellite images, it is found that clouds vary the color and brightness of different areas within an image. It is explained in the journal article, THIN CLOUD REMOVAL FROM SINGLE SATELLITE IMAGES, that “light transmission and scattering attenuation of clouds results in blurring and reduced contrast among ground objects”

(Jun Liu et al. n.d., 2014). The proposed method in this journal was to use a two-step method that is based on the cloudy images degradation model to remove thin clouds from satellite imagery. They estimated the cloud background by using a low-pass filter. They applied a type of Fourier transform (the FFT, fast Fourier transform) to each independent band of the input image, after that they then applied a Gaussian low-pass filter. The inverse of the FFT is applied to that result in this study to estimate all the reflection coming off the top of the thin clouds. They then “suppressed” the areas with high gray values and enhanced the dark ones. According to the journal, after removing the cloud background from the original image, they found that in every band, the effect of evenly distributed transmission resulted in high gray values in all pixels across the image. Therefore, some dark objects with gray values that were supposed to be close to 0 showed high values, and some bright objects had become dimmer. They explained these observations were radiation errors caused by the transmission of clouds. So, they did a max–min radiation correction approach to eliminate the effect of transmission and enhance the contrast. To do this, a histogram was obtained where the gray values of the darkest and brightest objects were adjusted to 0 and 255, respectively. Since this journal article was all for experimental purposes, their experimental results provided better cloud removal results than the other methods they compared their work to (pictured below).

Their method effectively removed clouds, restored the true color and enhanced contrast.

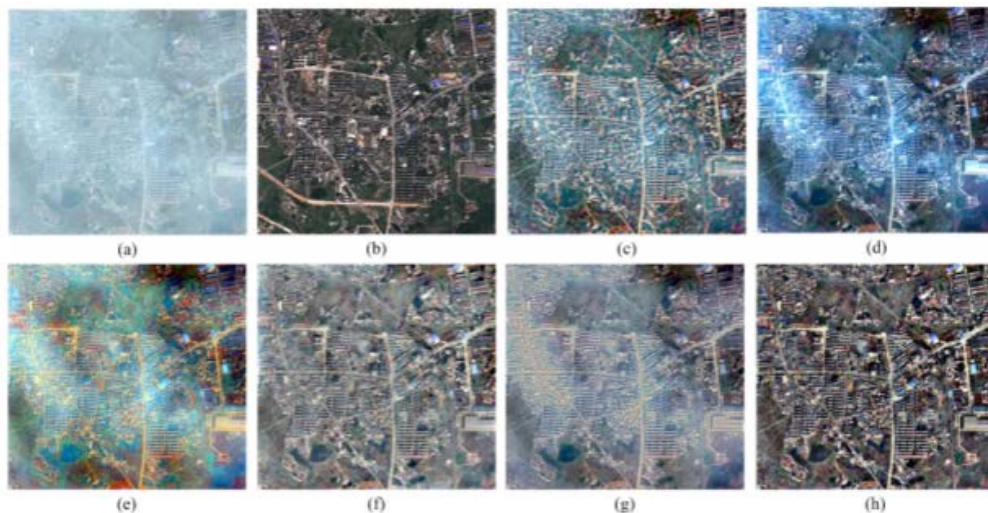


Fig. 8. Thick cloud removal results: (a) Original cloudy image, (b) Ground truth image, (c) Tarel's result, (d) He's result, (e) MSRCR, (f) HF, (g) Wavelet-based result and (h) Our result.

In this journal, SHADOW DETECTION AND REMOVAL OF PANCHROMATIC SATELLITE IMAGES, by Amrutha Vishnupriya and Vicky Nair, they focus on panchromatic high-resolution images and the idea that they exhibit more detailed information to increase analysis that are object-oriented, but most of the high-resolution satellite images contain shadows which causes partial losses of information. In order to restore shadowed objects, shadow detection and shadow removal must first happen for these panchromatic high-resolution satellite images.

To start the process the shadows are detected. The shadowed image is classified to shadowed and non-shadowed areas in a resulting binary image. They then used an image matting method to calculate the shadow coefficient for each pixel based on the mask image. This results in soft shadow detection results. Finding the soft results, you can then remove the shadows. They firstly

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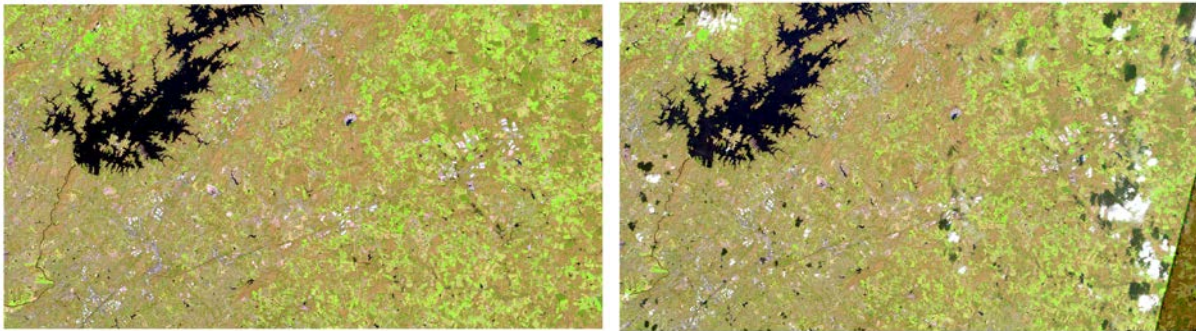
applied "the linear correlation method to enhance the shadows. The obscured areas then are the recovered by the unit of patches based on the patch intensity difference" (Vishnupriya and Nair 2017). In their conclusion they stated that the soft shadow detection was done automatically and accurately, and the method they proposed for the shadow removal part could restore the shadowed objects.

After reading a few journal articles on cloud cover and the shadows they make and how to remove them efficiently, I realized quickly that cloud cover and their shadows are more of a problem than I had originally thought them to be. This problem of cloud cover only intensifies as you go further up in elevation or as you get closer to coastal, more tropical areas that are just more naturally cloudy due to the abundance of moisture in the atmosphere. It is not always possible to obtain completely cloud-free imagery all the time, so at times there is a need to remove them, or enhance them enough to be utilized.

For my project I wanted to do something similar, though not so much in depth due to my limited abilities on the subject. I wanted to propose a very simple and easy way to remove smaller sized clouds and their projected shadows.

### Materials and Methods:

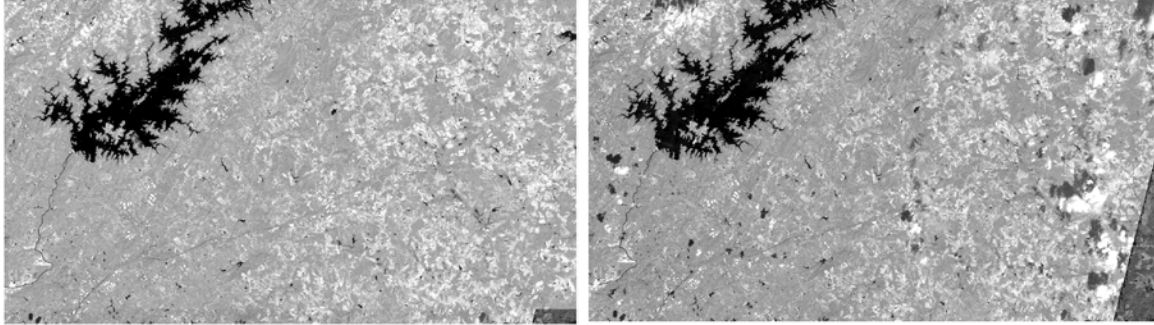
To start the process, I took two images that were taken over the same area, with the same spatial resolution, relatively close in dates. In this case, the two images were less than a week apart. The USGS (United States Geological Survey) LandsatLook Viewer was utilized to obtain the imagery for this course project.



*The cloudy image was acquired on 21 March, 2019 and the reference image containing no cloud cover was acquired on 27 March, 2019.*

I then added the images in separate bands to ArcGIS Pro and labeled the bands accordingly. Band 1 I labeled "R" for the red band, band 2 was labeled "G" for the green band, and band 3 for the blue band was labeled "B". I did this so that I could choose the best band to look at the reflectance values of the clouds. The band that I could see both the clouds and their shadows the most evidently was the band 2, or the green band. Therefore, I only observed this band for both images.

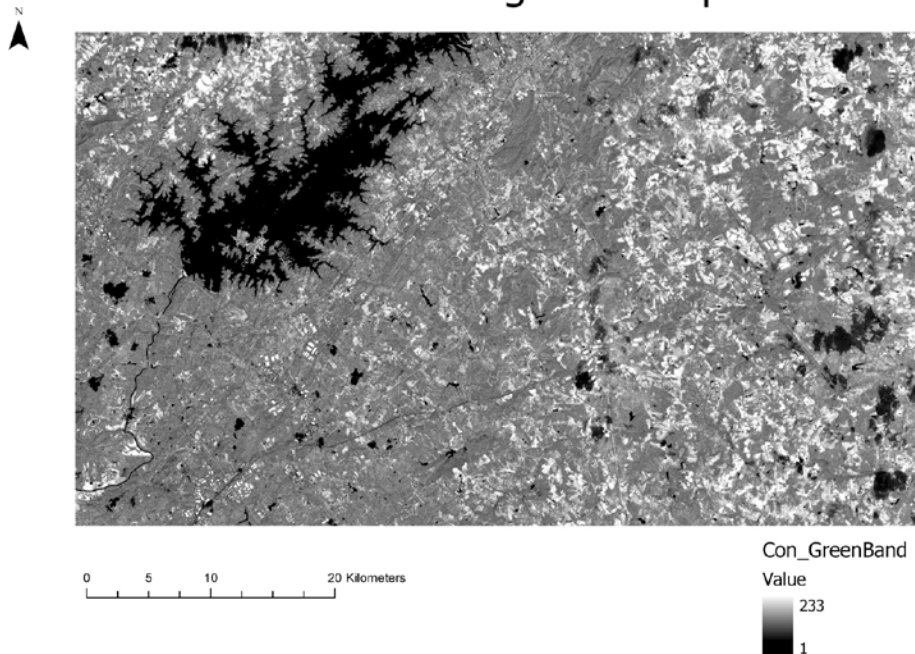
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Once the images were inserted in to ArcGIS Pro, I used the identify tool offered to get a threshold of values for the clouds that litter the imagery. After sampling quite a few clouds, I got a range that I felt pretty comfortable with utilizing. This range consisted of pixel values greater than or equal to 132. I then went under the Analysis toolbar and clicked on the toolbox. Under the Spatial Analyst toolbox, Conditional tools were chosen, then the “Con” tool. I found this tool to begin with in a video that explained a way to remove clouds or really ‘patch’ them over with pixels from a reference image, and then again in Dr. Huidae Cho’s Digital Image Processing course. I really liked the idea so much that I wanted to attempt to do my entire project around this “Con” tool. The input parameters for the query that will be used to patch over the cloud data for this tool were as follows:

- Input conditional raster = cloudy image
- Clouds masked using Query tool (within the con tool panel)  
“value” >= (value found) .....value was >=132
- Input true raster or constant value = non-cloudy image
- Input false raster or constant value = cloudy image
- Output raster = will name it ‘Con\_cloudRemoval’

### Cloud Free Image - Con operator



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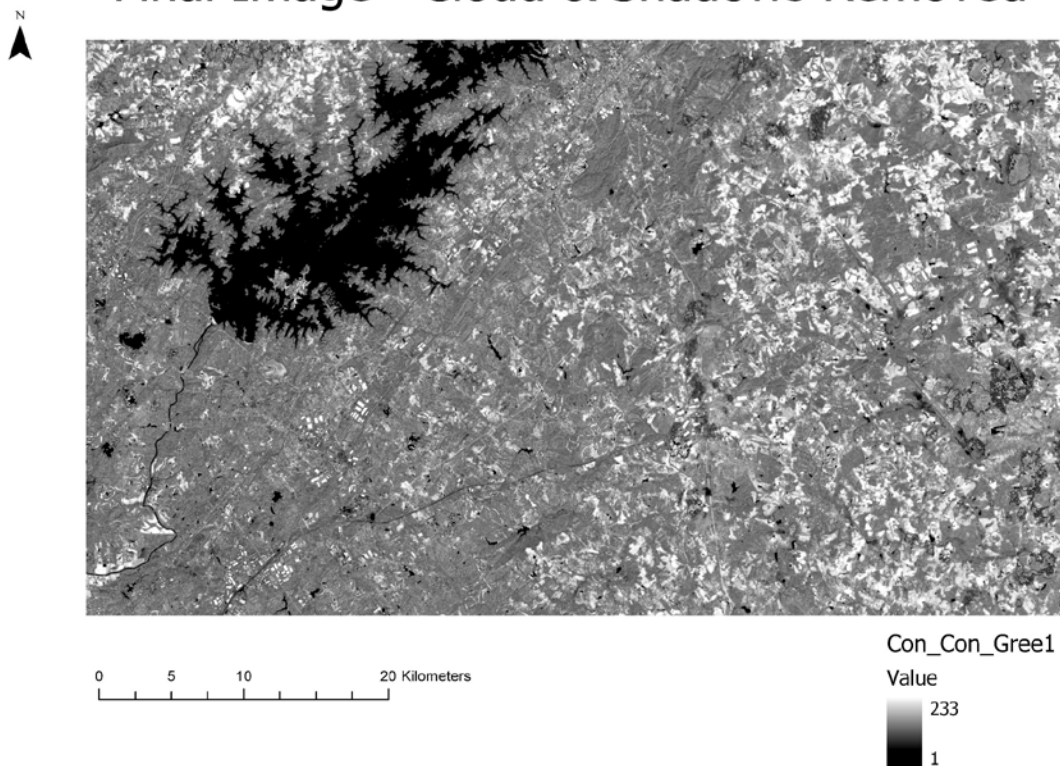
*The resulting image from the “Con” operator using Band 2*

Once I had gained the image without the clouds present, I wanted to attempt to do the same thing to patch out the shadowed areas. To do this I again used the “Con” operator with the following input parameters and with the needed query:

- Input conditional raster = used the Con\_cloudRemoval image
- Shadows masked using Query tool (within the con tool panel) got a good range for the shadows:  
“value” >= 60 AND “value” <= 79.
- Input true raster or constant value = Green band
- Input false raster or constant value = Con\_cloudRemoval
- Output raster = will name it ‘Con\_Cloud\_Shadow\_free’

Results:

### Final Image - Cloud & Shadows Removed



*The final image that was derived from using the “Con” operator tool of a total of 2 times*

The “Con” tool, a Spatial Analyst tool, does a really great job patching in the desired areas with the given parameters. If I were to have re done this project with more knowledge base, I would have liked to have made my first attempt at the removal of clouds to work. My initial goal was to make a binary image of clouded areas and use it to mask out the areas but I had a really hard time getting the ranges correct. All in all, I really enjoyed doing this project because I did not know ArcGIS products had the ability to do this.



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