Effect of Cirrus Cloud on Normalized Difference Vegetation Index (NDVI) and Aerosol Free Vegetation Index (AFRI): A Study Based on LANDSAT 8 Images

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***Abstract*—The present study is an attempt to identify the influence of cirrus cloud on NDVI and AFRI values and to check the scope of replacing NDVI with AFRI in cirrus affected satellite images. Multi-spectral channels of LANDSAT-8 satellite image collected for two different dates of acquisition are used in the current study. Reflectance values of cirrus band are used for correcting red and near infra-red spectral channels based on standard cirrus correction algorithm. The NDVI values obtained after cirrus correction is found to be significantly more than that of NDVI values without cirrus correction. In the case of AFRI(2.1m), the difference in values between before and after cirrus correction is found to be considerably lower than that of NDVI variation. These outcomes show the suitability of AFRI(2.1m) over NDVI for cirrus affected satellite images. The results of analysis also reveal that NDVI difference is directly proportionate with optical thickness and ice particle size distribution of cirrus clouds.**

***Keywords*—NDVI, AFRI, cirrus clouds, LANDSAT 8**

I. INTRODUCTION

Geo-spatial based analysis spans across various domains of research like climate change, water resource management, ecological sustainability etc. The major challenge of todays Geo-spatial community is to provide accurate and frequent satellite images to the research world without any discontinuity of data sets. In this context, LANDSAT series became a boom for the scientific community since 1972 which provides free global data accessibility from its archive with no discontinuity over space and time [1]. The major lacunae of the satellite images acquired by optical remote sensing system like LANDSAT is its sensitivity to cloud cover. The level of influence of cloud cover on quality of satellite images varies based on the thickness of the cloud. Thick cloud cover obstructs the solar radiation to reach the surface of the Earth and thus no information is recorded by the sensor from the surface underneath the cloud. The presence of thick cloud can be easily detected in a satellite image, whereas it is difficult in the case of thin clouds like cirrus. Because of its low optical thickness, cirrus clouds are difficult to detect in broadband multispectral satellite images [2].

The cirrus clouds normally occur in the upper troposphere and lower stratosphere. The altitude of cirrus clouds ranges from roughly 7 - 20 Km. Cirrus cloud consists of a large number of thin ice crystals of non-spherical shape. These ice crystals scatter and absorb the solar radiation and contaminate the reflectance values recorded from the surface of Earth [2], [3]. Hence it is necessary to eliminate the effect of cirrus cloud contamination for accurate retrieval of information from satellite images. The spectral band centered at 1.38 μm is found to be appropriate for cirrus cloud removal from satellite images. In this particular spectral region the ground reflected signal will get totally absorbed by the water vapour and only the cirrus scattered signal will be received by the satellite sensor [2], [3]. By virtue of this, the regions affected by cirrus cloud appear brighter whereas region with no cloud cover appear as completely dark in the image. The capability of 1.38 μm spectral channel for cirrus cloud detection led the research community to incorporate it in various satellite missions such as LANDSAT 8, Sentinel-2, MODIS etc.

Gao et al. [2] developed a standard cirrus removal method using 1.38 μm and 0.65 μm spectral channels. This method is applicable only for the spectral bands located between 0.4 - 1.0μm. It was based on the fact that the thin cirrus reflectance values in the 0.4 -1.0 μm spectral range is nearly constant and linearly related to the reflectance values of the red band. The standard cirrus removal method does not hold in the Short Wave Infrared (SWIR) regions (1.6 and 2.2 μm) where cirrus absorption is higher.

Accurate retrieval of satellite image based surface products requires the removal of atmospheric effects like cirrus contamination. NDVI, one of the most commonly used index for natural resources management can be significantly improved after removing cirrus contamination from the image pixels [2]. In most of the studies that were carried out in the recent past did not incorporate cirrus impacts on determination of NDVI. This may be due to the non availability of cirrus band in the older satellite missions such as IRS, Landsat 1-7 series, SPOT etc. In order to overcome the limitations of NDVI an alternative index called Aerosol Free Vegetation Index (AFRI) was developed [4]. It uses SWIR bands centered at 1.6 μm and

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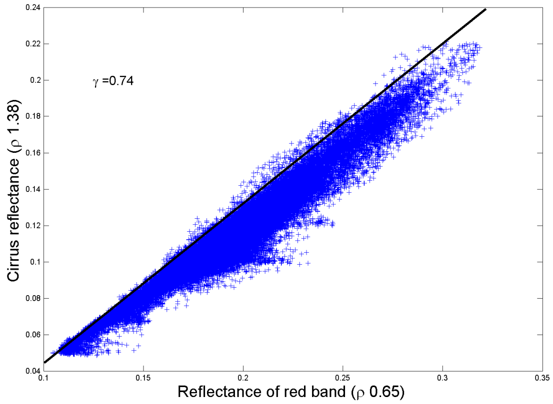

Fig. 1. Scatter plot between red band reflectance and cirrus band reflectance of image acquired on 25th December 2013

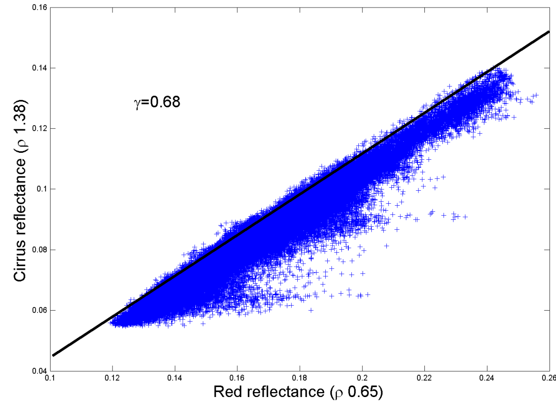

Fig. 2. Scatter plot between red band reflectance and cirrus band reflectance of image acquired on 11th July 2013

2.2 μm instead of the Near Infrared band(NIR) in NDVI. The SWIR has both the advantage of being sensitive to vegetation, while at the same time being less susceptible to the influence of aerosols except dust particles. AFRI produces a dynamic range of values between -1 and +1 which is similar to that of the NDVI. It was also found that the correlation of AFRI with the NDVI values may reach up to 0.98 for various land cover types [4].

The importance of cirrus cloud removal to improvise the accuracies of NDVI values forms the basis of deciding the objective of the present study. More specifically, the current research aims to determine the extent of cirrus cloud influences on NDVI values and to check the scope of replacing NDVI with AFRI in cirrus affected satellite images. Apart from these, the study also attempts to correlate the optical thickness and effective radius of ice particles of cirrus cloud with reflectance values. To achieve these, the relationship between red band reflectance values with optical thickness and that of SWIR (1.6 and 2.2 μm) bands with effective radius of cirrus ice particles are considered [5]. The recent satellite mission of LANDSAT-8 with cirrus band (Band-9 1.38 μm) combined with SWIR (1.6 μm and 2.1 μm) has been found to be appropriate to accomplish the objectives of present research.

II. Study Area And Satellite Data

The site selected for the present study is located in Kerala between 75.6° E and 77.68° E longitude and between 9.07° N and 11.17° N latitude. LANDSAT-8 images of the study area (Path- 144 and Row- 53) for two different acquisition periods (11th July 2013 and 25th December 2013) are used in the current study. The images are downloaded from the LANDSAT archive of U.S. Geological Survey website (http://earthexplorer.usgs.gov/). Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) are the two sensors of LANDSAT-8 with a swath width of 185 Km. The instrument OLI collects image data for nine spectral bands with 30 m spatial resolution for all bands except for 15 m panchromatic band. TIRS instrument is to collect the data for two thermal bands with a spatial resolution of 100 m [6]. To accomplish the objectives of the present study, five spectral bands of OLI

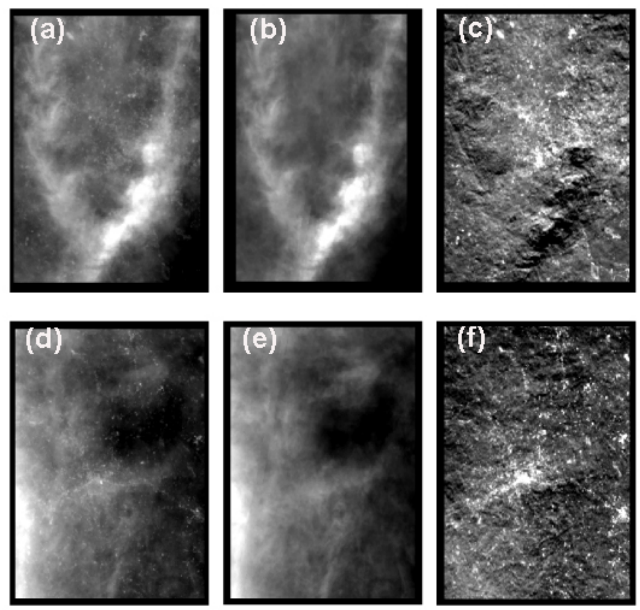

Fig. 3. Cirrus correction using red band and cirrus band reflectance (a) Red band for the image acquired on 25th December 2013 (b) Cirrus image for 25th December 2013 (c) Cirrus corrected red band for the image acquired on 25th December 2013 (d) Red band for the image aquired on 11th July 2013 (e) Cirrus image for 11th July 2013 (f) Cirrus corrected image for 11th July 2013

sensor are selected. They include band 4 (0.65 μm), band 5 (0.86 μm), band 6 (1.6 μm), band 7 (2.1 μm) and band 9 (1.38 μm) with spatial resolution of 30 m. Band 4 (Red) and band 5 (NIR) spectral bands are used for NDVI determination whereas AFRI values are calculated using band 6 (SWIR 1) and band 7 (SWIR 2). The band 9 also called cirrus band (1.38 μm) is used for detecting the presence of cirrus cloud in the image.

III. Data Processing

The Top of Atmosphere (TOA) reflectance values with correction for sun angle for selected bands are derived us-

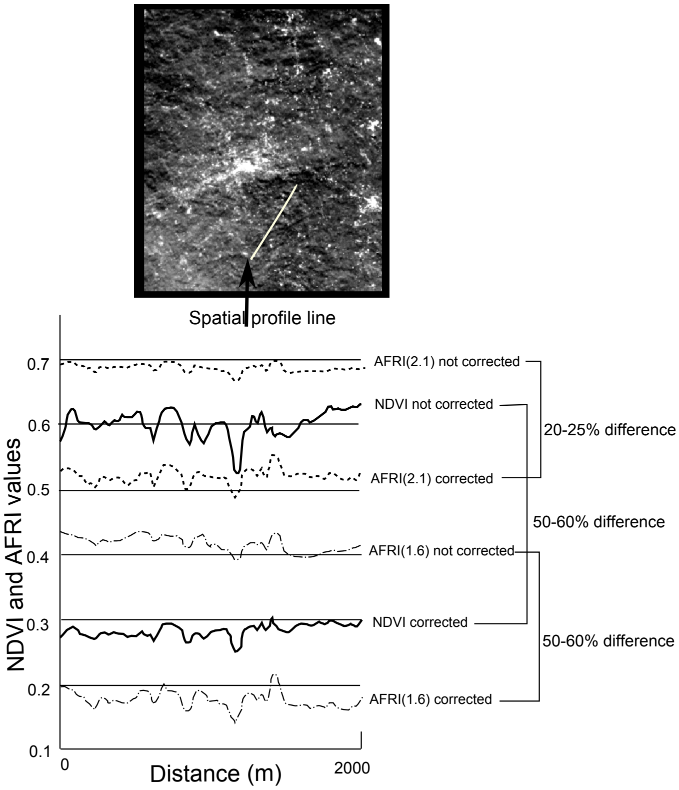

Fig. 4. Variations of cirrus corrected and non cirrus corrected indices

ing radiometric rescaling coefficients provided in the product metafile based on LANDSAT Data Continuity Mission (LDCM). Correction of thin cirrus path radiance in the 0.65 μm (Red) and 0.86 μm (NIR) spectral channels are carried out based on the algorithm developed by Gao et al. [2] for the land area extracted from the image. Scatter plot between apparent TOA reflectance of cirrus band ($\rho_{1.38}$) and red band ($\rho_{0.65}$) are computed and an empirical parameter γ is derived which is equal to the slope of the scatter plot. The straight line represented by this slope is usually oriented at the left-side boundary of data points. The cirrus-contaminated pixels are clustered around this line. The cirrus corrected $\rho_{cc(\lambda)}$ image for a particular band is obtained based on the equation 1.

$$\rho_{cc(\lambda)} = \rho_{(\lambda)} - \rho_{1.38}/\gamma \tag{1}$$

Where $\rho_{cc(\lambda)}$ is the "cirrus path radiance corrected" apparent reflectance image, $\rho_{(\lambda)}$ is the apparent reflectance of the band with wavelength λ. NDVI image is created with cirrus corrected red and NIR bands using equation 2.

$$NDVI = \frac{\rho_{(NIR)} - \rho_{(Red)}}{\rho_{(NIR)} + \rho_{(Red)}} \tag{2}$$

The NDVI images created using cirrus corrected and non-corrected bands are compared. The difference in NDVI values before and after cirrus correction helps to identify the influence of cirrus cloud contamination on NDVI values.

Similarly AFRI images are created using the equation 3 and equation 4 [4], without applying correction for cirrus contamination.

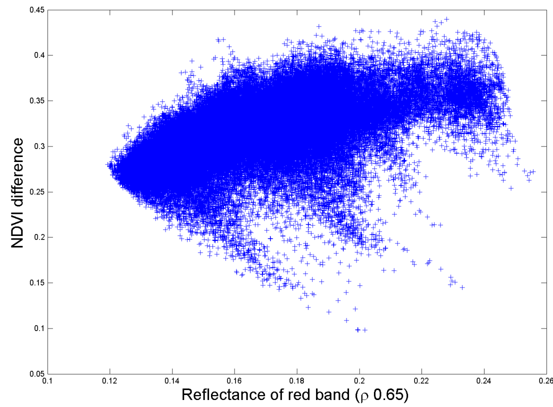

Fig. 5. Scatterplot between Red band reflectance and NDVI difference for image acquired on 25th December 2013

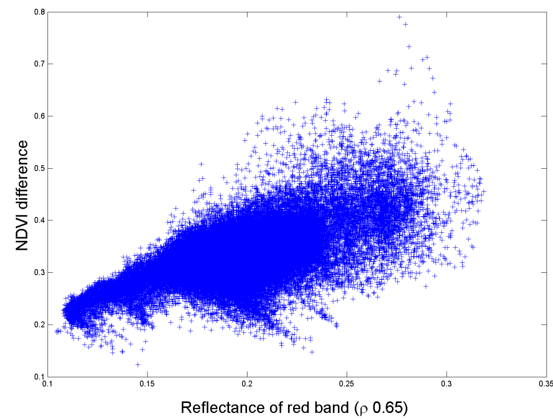

Fig. 6. Scatterplot between Red band reflectance and NDVI difference for image acquired on 11th July 2013

$$AFRI_{(1.6\mu m)} = \frac{\rho_{(NIR)} - 0.66\rho_{1.6}}{\rho_{(NIR)} + 0.66\rho_{1.6}} \tag{3}$$

$$AFRI_{(2.1\mu m)} = \frac{\rho_{(NIR)} - 0.66\rho_{2.1}}{\rho_{(NIR)} + 0.66\rho_{2.1}} \tag{4}$$

Cirrus correction is applied only for NIR bands since the standard cirrus correction algorithm by Gao et al. [2] is not valid for spectral channels above 1m. Therefore, cirrus corrected NIR band and non-corrected SWIR bands are used in equations 3 and 4. The same procedure is repeated for a different image of the same area for a different date of acquisition.

IV. Results and Discussions

The scatter plot between red band reflectance values and cirrus band reflectance values of the selected area is shown in Figure 1 and 2. The empirical cirrus cloud correction parameter γ is calculated for the image based on the slope of the scatter plot. The value of γ obtained for two images are different because of difference in the optical thickness of cirrus cloud in these images. Using equation 1, correction has been applied for both red and NIR bands. Figure 3 shows the image of red and NIR bands before and after cirrus correction. The NDVI images created based on equation 2 for two different acquisition dates show that there is a significant change in NDVI values before and after cirrus correction. The percentage increase in NDVI values after cirrus correction is more than 50 % for both the images.

The subtle variations in the NDVI values are more visible in the spatial profile of the cirrus corrected NDVI Image shown in Figure 4. The increase in NDVI values in the cirrus corrected NDVI image show a better scope of distinguishing spectral features compared to that of an NDVI image without cirrus correction. The $\mathrm{AFRI}_{(1.6\mu\mathrm{m})}$ images created using equation 3 for two different dates show that there is a significant change in values before and after cirrus correction (only NIR corrected). It has also observed that the values after correction are less compared to values obtained before correction. The percentage decrease in these values is more than 50% for both the images (Figure 4).

In contrary to the above results, the $\mathrm{AFRI}_{(2.1\mu\mathrm{m})}$ images created using equation 4 for two different dates show that there is comparatively less change in values before and after cirrus correction (only NIR corrected). The percentage decrease in this case is less than 25% for both the images.

The results obtained in the present study show that NDVI and $\mathrm{AFRI}_{(1.6\mu\mathrm{m})}$ values are more affected by cirrus cloud contamination and approximately 50-60 % changes are observed in the values. In the case of $\mathrm{AFRI}_{(2.1\mu\mathrm{m})}$, the effect of cirrus cloud contamination appears to be comparatively less than that of $\mathrm{AFRI}_{(1.6\mu\mathrm{m})}$ and NDVI. The percentage decrease in values is approximately less than 25% for $\mathrm{AFRI}_{(2.1\mu\mathrm{m})}$. Hence it shows the utility of $\mathrm{AFRI}_{(2.1\mu\mathrm{m})}$ as a better index for vegetation studies for satellite images in which cirrus bands are absent. The percentage of variation of NDVI and AFRI values are scene specific but the general trend of variation has a common behavior.

The variations of NDVI can be correlated to optical thickness and ice particle size distribution of the cirrus clouds. The reflectance values of the red band, which is sensitive to optical thickness, is plotted against NDVI variations obtained before and after correction. In Figure 5 and 6, it is observed that the differences in NDVI values are proportional to optical thickness of the cirrus cloud. The reflectance value in the $2.1\mu m$ channel, which is correlated to ice particle size distribution, is plotted against NDVI variations. The results show that the differences in NDVI values are proportional to wider range of ice particle distribution (Figure 7 and 8).

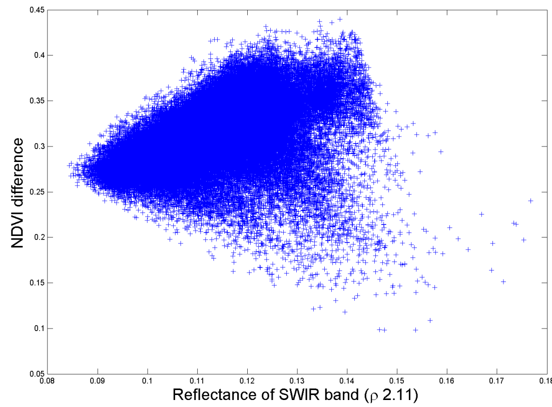

Fig. 7. Scatterplot between SWIR (2.11) band reflectance and NDVI difference for image acquired on on 25th December 2013

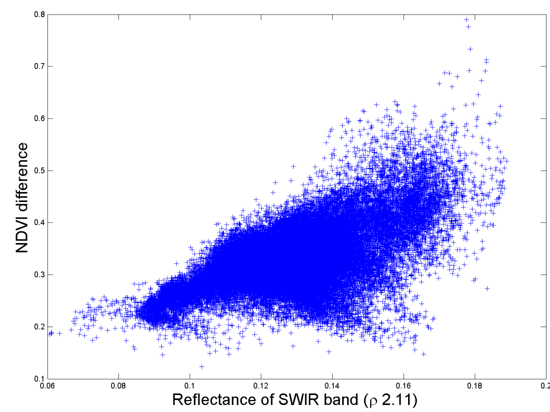

Fig. 8. Scatterplot between SWIR (2.11) band reflectance and NDVI difference for image acquired on 11th July 2013

V. Conclusions

The present study examines the influences of cirrus cloud on spectral indices of vegetation like NDVI and AFRI. The cirrus band of LANDSAT 8 is used for identifying cirrus cloud contamination present in the satellite images. The red and NIR spectral channels are corrected for cirrus cloud and used for identifying the impacts of cirrus contamination on NDVI values. The difference between NDVI values obtained before and after cirrus correction is found to be significantly higher compared to that of $\mathrm{AFRI}_{(2.1\mu\mathrm{m})}$ values. The percentage variation of values in the case of NDVI is more than 50 % whereas the corresponding variations of AFRI values are below 25%.

Hence it is clear that, it is wise to use $\mathrm{AFRI}_{(2.1\mu\mathrm{m})}$ values instead of NDVI values for satellite images without cirrus band. The correlation between differences in NDVI values with optical thickness and ice particle size distribution of cirrus clouds are also observed in the study. Further scope of the study is to use the cirrus corrected SWIR band for the determination of AFRI values. This may further improve the accuracy of AFRI values.

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