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Extraction of Time Series Convective Cloud Profile from Doppler Weather Radar MAX (Z) Product Using A Novel Image Processing Technique

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Abstract- *The information about a convective cloud profile is important in understanding the type of convective cloud present over a location. Based on time series cloud profile at a location, the approximate time for which rainfall has occurred and the intensity of rainfall can be estimated based on the reflectivity. In the present work continuous extraction of convective cloud optical information such as reflectivity (MAX (Z) in DBZ), cloud base height (CBH), cloud top height (CTH) and cloud optical depth (COD) from the Doppler Weather Radar (DWR) located at the Indian Meteorological Department, Chennai. Reflectivity measurements in different locations within the DWR range of 250 Km radius of the circular disc area can be retrieved using this technique. It gives both time series reflectivity of point location and also Range Time Intensity (RTI) maps of reflectivity of the corresponding location. The Graphical User Interface (GUI) developed for the cloud reflectivity is user friendly. This technique is also applicable for retrieving other DWR products such as Plan Position Indicator (Z, in dBZ), Plan Position Indicator (Z, in dBZ)-Close Range, Volume Velocity Processing (V, in knots), Plan Position Indicator (V, in m/s), Surface Rainfall Intensity (SRI, mm/hr), Precipitation Accumulation (PAC) 24 hrs at 0300UTC.*

Keywords: *Cloud base, Cloud optical depth, Cloud top height, Reflectivity, Time series profile.*

I. INTRODUCTION

Clouds represent a key component in our climate system by regulating both water and energy cycles[17]. Clouds play a crucial role in the earth's radiation budget and global climate change owing to interfacing with sun powered and earthly radiation[7]. Of all the ten different clouds classified by International Satellite Cloud Climatology Project (ISCCP), low level stratus and stratocumulus are the most vital in the earth's radiation budget since they are optically thick and have a large global coverage. The clouds reflect a large portion of the incoming solar radiation and permits long wave radiation to outer space, subsequently it has the cooling effect on climate[11, 13]. Much work has been done to classify clouds based on satellite images. The Radiative fluxes at the earth's surface causes the change of phase, vertical and horizontal development of clouds [4]. Cyclogenesis is caused due to latent heat released during transformation with the phase change in clouds.

Radars utilized as a part of meteorology are categorized by their frequency of operation. Conventional Radars are used for measuring Maximum Reflectivity (Z) alone, though current Doppler radars have the capability to measure Radial Velocity, Velocity Spectrum width and Reflectivity. Radial velocity is a measure of absolute outright velocity away from or towards the RADAR. Velocity Spectrum width is characterized as velocity within the radar sample volume. Doppler Weather Radar (DWR) based convective cloud classification is an observational technique, has gotten more consideration from the research fields. Until now, convective clouds are still classified by human observers who have received professional training in meteorological station. Regardless of their obvious convenience, this strategy takes high cost of human resource and diverse eyewitnesses may get discrepant order comes about. As a result, automatic DWR based convective cloud classification technique is urgently required in this area. The DWR-MAX (Z) product from the DWR station located at IMD Chennai will provide the reflectivity values in image format over 250 Km radius with Chennai as the center point. The reflectivity factor is proportional to the moments of drop size distribution (DSD). As the number of cloud liquid droplets and ice crystals in the cloud increases, reflectivity value increases, which has a direct relation to rain [12]. Typical RADAR cannot extract the reflectivity for non convective clouds. The proposed algorithm is this paper is used for extracting the Maximum Reflectivity of a convective cloud over a location and vertical cloud profile at a particular point over a period of time. This algorithm can be applied to the derived products from DWR such as Surface Rainfall Intensity (SRI), Precipitation Accumulation (PAC) etc.

II. DATASETS

The Doppler Weather RADAR reflectivity images (Doppler weather radar max (Z) product) from the Indian Meteorological Department (IMD) located at Chennai were downloaded continuously for every 10 minutes during the month of November and December 2015 and a database is maintained (images from IMD website) (http://www.imd.gov.in).

III. METHODOLOGY

The DWR reflectivity products of IMD Chennai depict the existence of strong convective activity within the range of DWR as shown in Figure 1. The maximum value of reflectivity (Max (Z)) product shows the value of reflectivity over each pixel of the cylindrical volume in its plane view. The height corresponding to the maximum value of the Reflectivity through west to east can be found along the right hand side display and the height of maximum reflectivity when viewed from south to north is projected over the top. Cloud heights exceeding 6 km and reflectivity exceeding 45dBZ have been considered as thunderstorm/ Cumulonimbus (Cb) cloud (Suresh and Bhatnagar, 2005). The flowchart for the extraction of convective cloud parameters is shown in the Figure 2. An image showing no convective activity has been chosen from the database and is considered as the reference image (I_{ref}). An image from a database or a present reflectivity image from IMD Chennai showing reliable convective information is taken as an image of interest (I_{int}) as shown in Figure 2. The different colours of the reflectivity image indicate the variation in the strength of reflectivity for different locations as noticed from the colour bar information provided on the right side of the image. Median Filter reduces image noise while preserving edges and also it is scale invariant nonlinear smoothers as defined in equation 1 [8]. Two dimension Median filter is applied on both I_{int} and Iref to remove the salt and pepper noise from the images. Image pre-processing is performed on the I_{int} image to make it suitable for further processing.

$$\mathrm{median}(x) = \begin{cases} x_k\,; & \text{for } n = \text{Odd number of terms} \\ \frac{1}{2}(x_k + x_{k+1}); & \text{for } n = \text{Even number of terms} \end{cases} \tag{1}$$

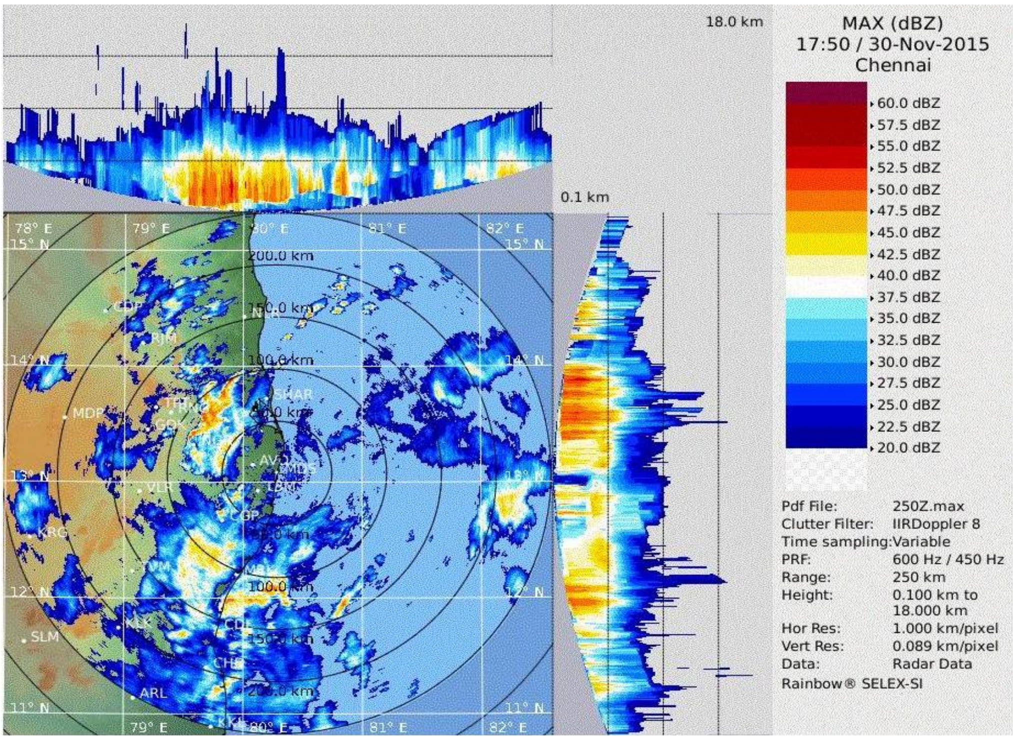

Figure 1. Image of interest

Now, the Iref image is subtracted I_{int} image to get the offset image which will show the cloudy information of the image. The offset image is then converted to a gray image. The gray level image is then converted to a binary image by using the hard thresholding algorithm [5]. The image will be degraded due to the above sequence of operations and unwanted information will be present at the edges. The cloudy portion of the image is expanded by dilation operation and thereby small gaps which occur due to hard thresholding will be filled by the nearest value. The structuring element chosen for dilation operation is 5 X 5 mask with diamond pattern [6]. The dilation is shift invariant and relates to the Minkowski addition, as defined in equation 2. The expanded portion will have some blur at the edges which will be removed by the erosion operation as defined in equation 3 [2]. The checkerboard effect occurs during the conversion of gray to binary. This effect will be minimized by image closing operation (dilation followed by erosion) as defined in equation 4.

$$A \oplus C = \{z \mid (\acute{C})_z \cap A \neq \Phi\} \tag{2}$$

$$A \ominus C = \{Z \mid (B)_z \cap A^c \neq \Phi\} \tag{3}$$

$$f \circ b = (f \oplus b) \ominus b \tag{4}$$

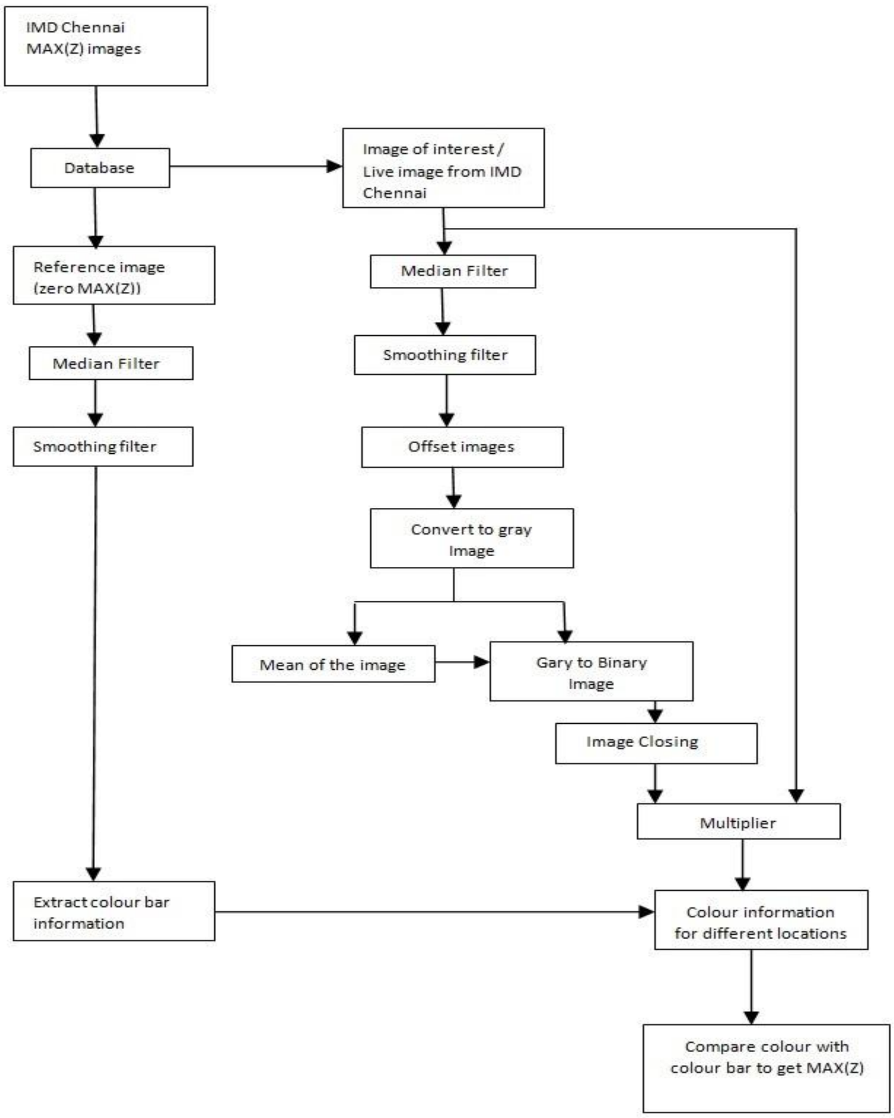

Figure 2. Flow chart for the extraction of convective parameter from the DWR image.

Based on the information of a binary image, the convective cloudy portion of the image is extracted. The noticeable changes in the I_{int} image are identified and the colour information will be extracted from the Iint for different locations within the DWR range of 250 km radius locating Chennai at the center of the disc. The reflectivity information at different locations is obtained using the colour information at that location and the corresponding colour bar scaling. Colour is an important feature for image representation. It is invariant with respect to translation, rotation and scaling. Colour moments, colour histogram and colour coherent vector are the important components of colour feature extraction [14]. The information provided on the right side and top of the image is used to extract the convective cloud parameters. The colour information at a particular location is compared with colour information available on the top and right side of the image. The overlapped portion will provide the convective cloud base height, convective cloud optical depth and convective cloud top height.

IMD Chennai will update the reflectivity images for every 10 minutes. We will get 144 images per day. The reflectivity calculation for a particular point over a period of time gives us the time series reflectivity at that location.

IV. RESULTS AND DISCUSSIONS

The DWR reflectivity images downloaded from IMD Chennai was compared with the reference image. Static information from the current image is eliminated and a cloudy portion of the image is extracted as shown in the Figure 3. From this image, the reflectivity information is extracted by using the procedure mentioned in the previous section.

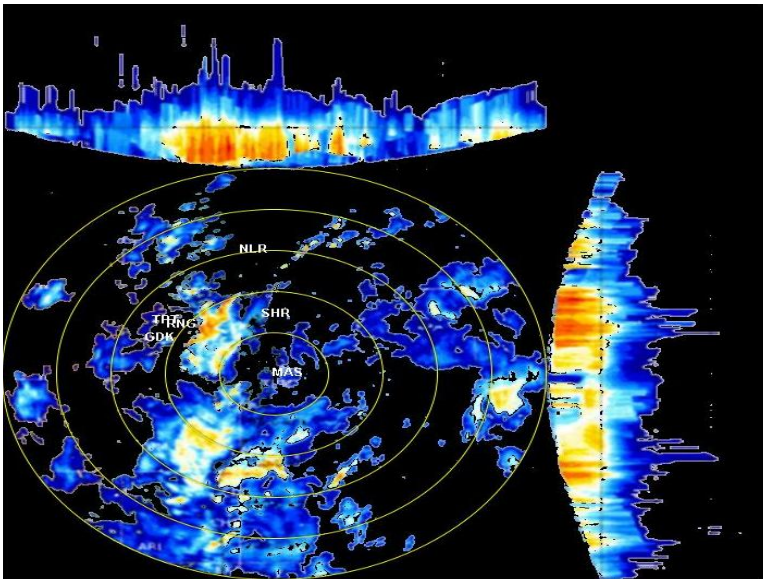

Figure 3. Processed image

The reflectivity information for a particular location is extracted using the above procedure and it is repeated for a series of images to obtain the time series reflectivity of a particular location over a period of time as shown in Figure 4. If a location has no convective cloud, the cloud base height and top will be zero and reflectivity will be 0 dBZ by default. The time series reflectivity information will give us how the clouds are moving with respect to time, i.e. how cloud base or cloud top changes with respect to time and how the reflectivity changes with time [3]. The time series reflectivity information over Chennai and Tirupati region is extracted on 30th November 2015 and is plotted as shown in Figure 4 and Figure 5. The database which doesn't contain the image files or the file which doesn't contain any convective cloud over a location will be treated as a not a number.

The information provided on the top of the I_{int} image conveys the vertical extension of the cloud in a North South direction. The information provided on the left side of the I_{int} image conveys the vertical extension of the cloud in the East West direction. The North-South reflectivity profile and East-West reflectivity profile over the Chennai region on 30th November 2015 is shown in Figure 6 and Figure 7.

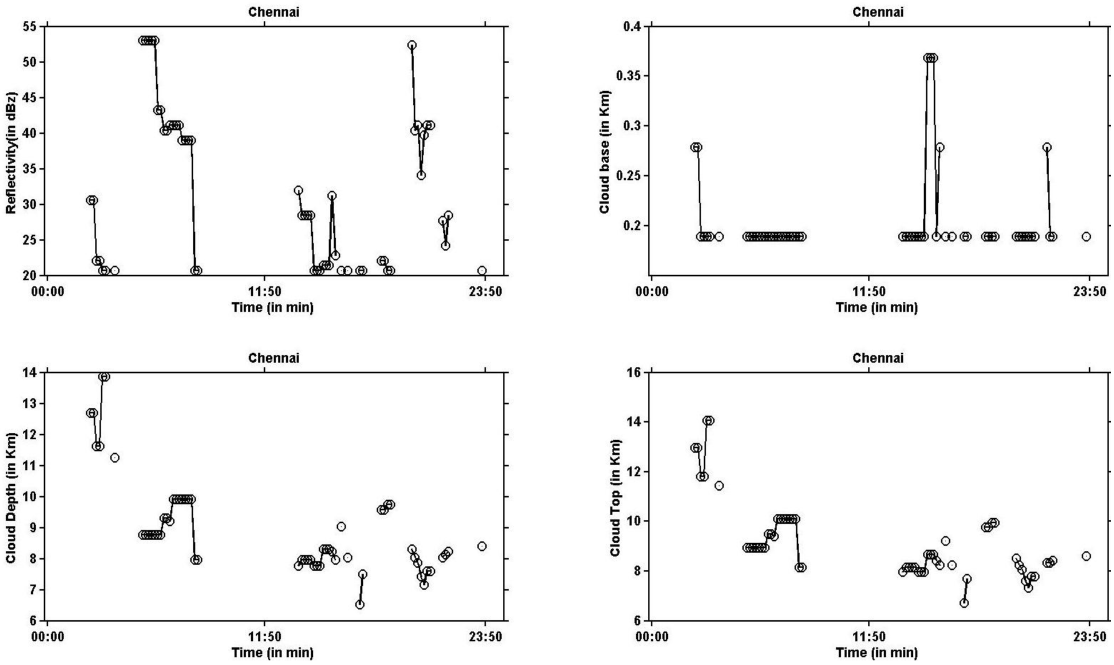

Figure 4. Convective cloud parameters over Chennai region on 30th November 2015

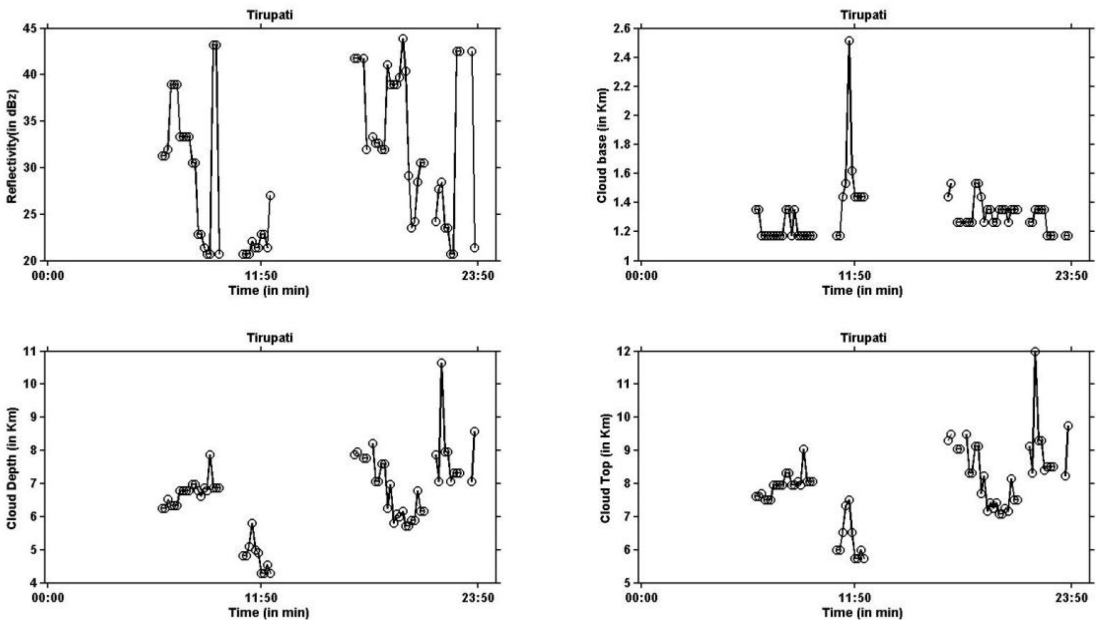

Figure 5. Convective cloud parameters over Tirupati region on 30th November 2015

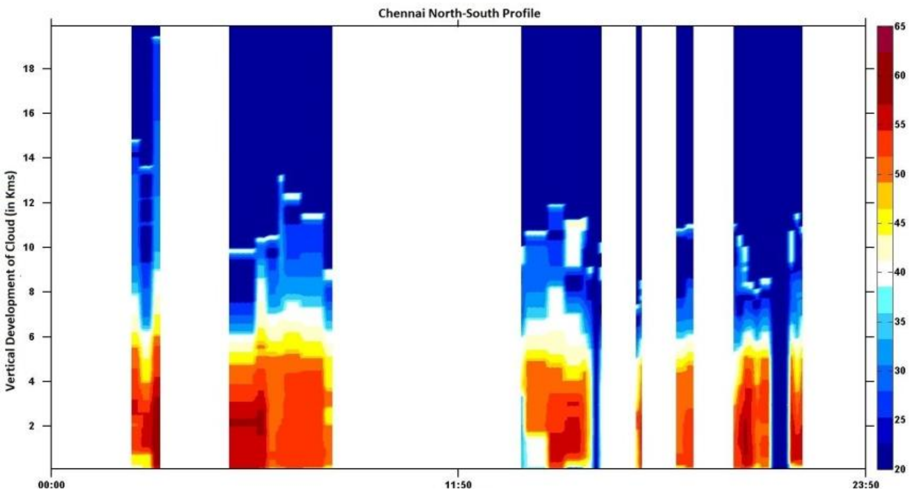

Figure 6. North South Reflectivity profile over Chennai on 30th November 2015

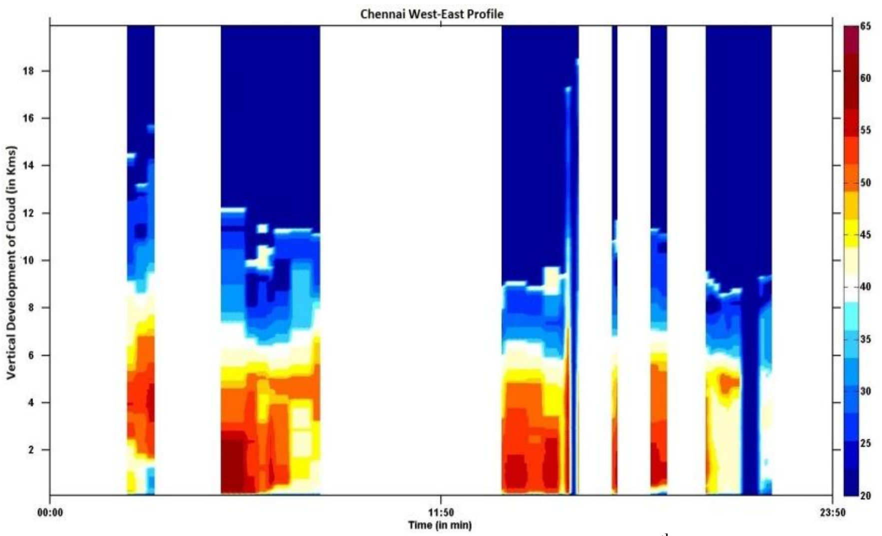

Figure 7. East West Reflectivity profile over Chennai on 30th November 2015

The North-South reflectivity profile and East-West reflectivity profile over Tirupati region on 30th November 2015 is shown in Figure 8 and Figure 9.

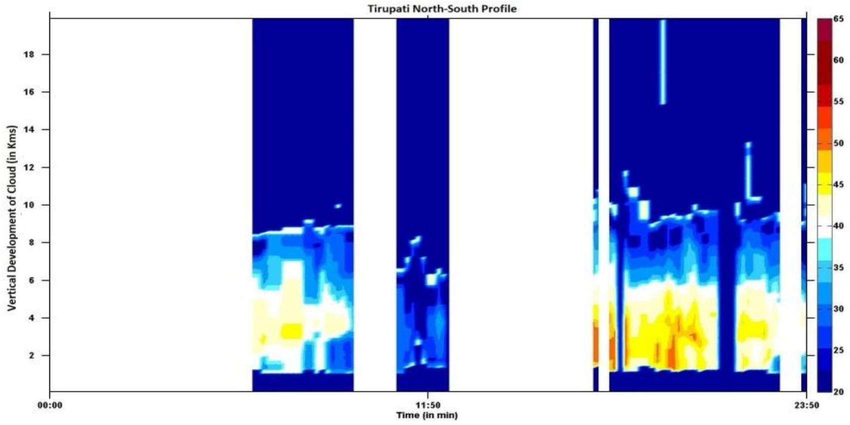

Figure 8. North South Reflectivity profile over Tirupati on 30th November 2015

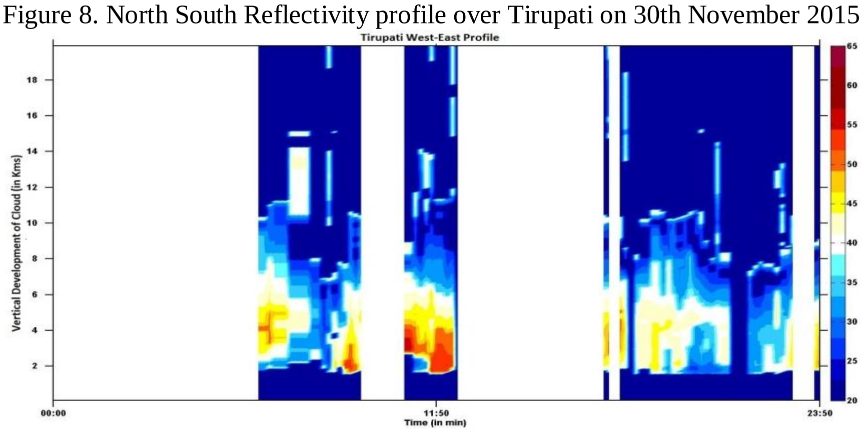

Figure 9. East West Reflectivity profile over Tirupati on 30th November 2015

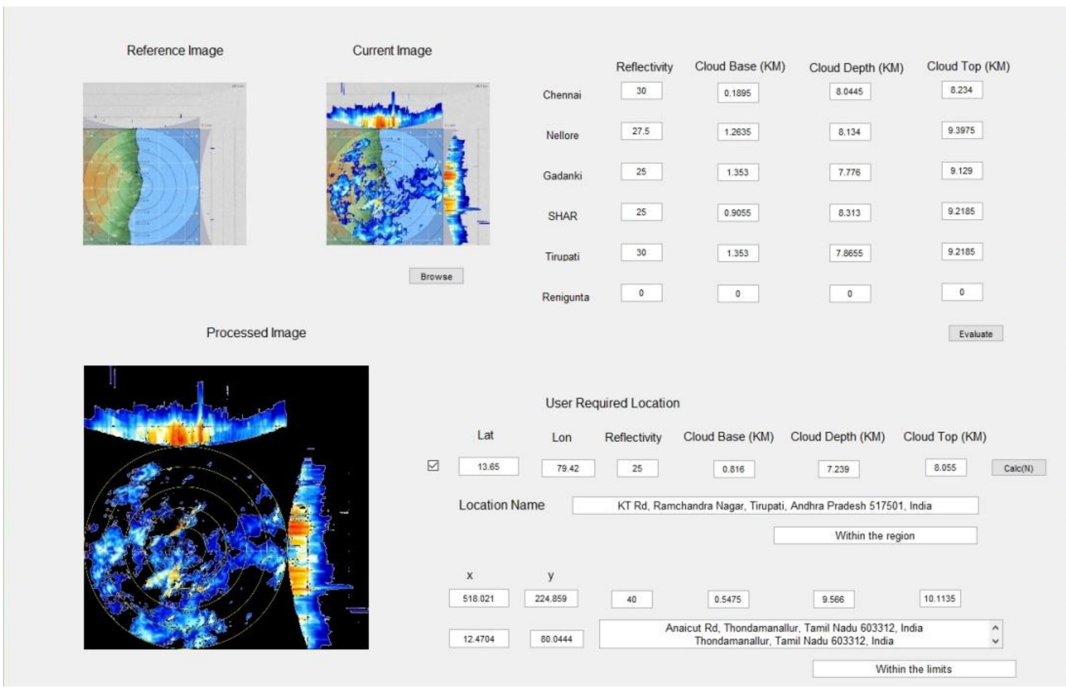

Figure 10. Sample GUI developed for this application

A Graphical User Interface is developed for this algorithm using MATLAB [18], wherein the user may select the image at runtime to get the convective cloud parameters for the image of interest. The GUI will display the reference image, image of interest and processed output image. The end user will get the information of an unknown location on the image, by extracting the latitude, longitude from the image and the name of the location will be displayed. The user can also get the information, if the user has the latitude and longitude information. The sample for the GUI is shown in Figure 10. The user has the provision of estimating the reflectivity for a single image of time line profile over a location.

V. CONCLUSION

In this paper, convective cloud parameters such as reflectivity, cloud base height, cloud optical depth and cloud top height are extracted from the DWR data located at IMD Chennai in different locations. Time series reflectivity at different locations is plotted. GUI developed for this algorithm is user friendly. This work can be extended to other DWR centers located at different stations. The present technique of extracting reflectivity information from DWR is robust to noise.

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