Identification of Rainfall Intensity by Using Bahir Dar C-band Weather Radar products

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Abstract—Observation of rainfall accumulation, distribution and wind direction spatially and temporally is very essential for meteorologists and hydrologists in the Upper Blue Nile basin and different locations of Ethiopia. The Bahir Dar (BAH) C-band weather radar used to estimate the intensity, amount and distribution of precipitation with a high resolution temporally and spatially. It is dual polarization with horizontal and vertical reflectivity; six variables are used to determine the hydrometer and non-hydrometer types, shape and sizes of targets up to range of 250 km and 450 km at constant altitude plan position indicator (CAPPI) and plan position indicator (PPI) products. From our first observation, we used different types of products to observe rainfall intensity, distribution, wind direction and warnings across Upper Blue Nile. For RainN on 01 July 2016 the rainfall distribution over twenty four hours (24 Hr) UTC at Bahir Dar, parts of lake Tana, most northern parts, western parts of Gondar town, and south western parts of lake Tana a resolution of 809 m/Pixel with frequency of 600 Hz the maximum rainfall accumulation 91.6 mm was achieved. By using CAPPI product with vertical height of 1 km on 26 June 2016 the maximum reflectivity 53.5 dBZ is observed.

Index Terms—Weather radar, intensity, reflectivity.

I. Introduction

THE C-band dual-polarization weather radar system is one of the most important instruments for observing weather and early warning systems. The washera (BAH) C-band weather radar established in 2016 of Ethiopia more valuable for the Upper Blue Basin of Ethiopia. The dual-polarization radar started by [1], [2] and a valuable improvement was done by [3], [4], [5], [6], [7], [4], [8] improvements, analyze and verify variables available with linearly orthogonal polarimetric radars. The polarimetric radar is implemented for different applications like climate change, hydrological extremes, warnings, short-term forecasts, and quantitatively precipitation estimation [9].

The thermodynamic process of thunderstorm development is used to detect the coverage and intensity of precipitation and basis for severe thunderstorm and tornado warnings issues [10]. The polarimetric weather radar has been functional simultaneous transmission and reception of both horizontally and vertically polarized pulses [11].

The purpose this paper is to provide the first observation Bahir Dar (BAH) weather radar and observation of different output products with different range, azimuth and zenith angle to see targets of rain, wind and warning products in the future further work for operational meteorologists and hydrologists. Based on standard algorithms and assumptions, various products of practical utility for issuing forecasts and the warning to generate from base parameters; plan position indicator (PPI), range height indicator (RHI), maximum reflective display (MAX), vertical integrated liquid (VIL), base echo, top echo, tracks-250Km, tracks-450Km, RAIN1, RAINN, constant altitude PPI (CAPPI) products and in addition to these some values of non-meteorological targets are detected for the first time observation by using C-band weather Radar at Bahir Dar, Ethiopia.

II. Study Area

The Bahir Dar C-band weather radar covers most North western parts, partly south western and central parts of Ethiopia. Most of the Ethiopian landmass is part of the East African Rift Plateau with different elevation above sea level. The topography Horn of Africa increases with height above sea level [12] and reaches highest peak 4,620 meters Ras Dashen mountain north east of Gondar in Ethiopia. The northwestern highlands are considerably more extensive and rugged mountain are divided into northern and southern sections by the valley of the Blue Nile [13].

The rivers of Ethiopia originate in the highlands and flow outward in many directions through deep gorges [14]. The Blue Nile tributaries account for two-thirds of the Nile River flow below Khartoum in Sudan. Because of the general westward slope of the highlands, many large rivers are tributaries of the Nile system, which drains an extensive area of the central portion of the plateau [15]. The Blue Nile, the Tekeze, and the Baro are among them and account for about half of the country's water outflow [16].

In the Ethiopian Plateau, the weather is cool, mild or pleasantly warm, depending on the altitude, with a season characterized by scarce rains [17] from November to February, and a rainy season from June to September, preceded by a period, from March to May, when some showers and thunderstorms occur.

III. Data and Methodology

The Bahir Dar (BAH) Weather radar operates in C-band of the electromagnetic spectrum with energy bands corresponds to wavelength 4 to 8 cm. Radar emits a pulse of electromagnetic energy scattered by the atmosphere [18] and some of energy returned to the radar antenna to display a variety of information about the atmosphere indicating the location of

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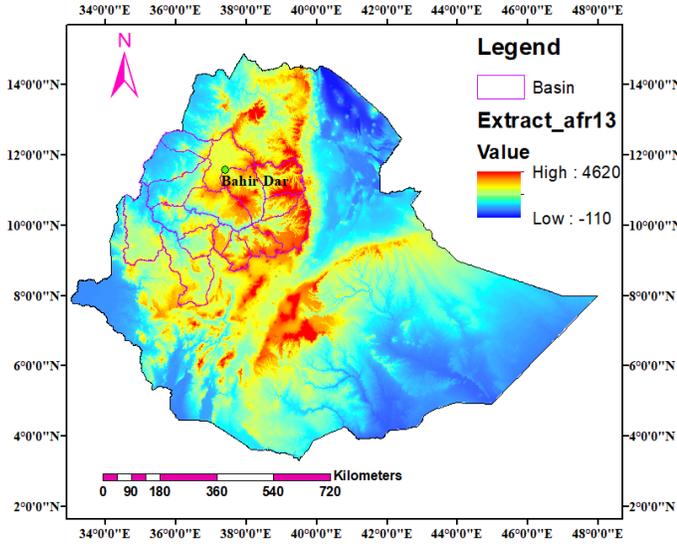
Fig. 1. The location of Bahir Dar Weather Radar and the topography of Ethiopia

precipitation, amount of reflectivity, rainfall accumulation and distribution of rainfall spatially [19].

The BAH C-band weather radar measures moment at both horizontal and vertical polarizations. Groundlevel precipitation estimates from typical radar systems are made for areas of typically 2 km^2, successively for 5-10 minute periods using low elevation plan position indicator scans with beam widths of 0.5 degree. In processing the returned energy, it is assumed that all the energy comes from the aimed direction of the beam [1].

The radar reflectivity (Z) and rainfall rate (R) are related, where Z is proportional to the backscatter power from a radar scan for measuring rainfall [20]. The radar reflectivity (Z) assuming spherical droplets can be expressed as:

$$\int_0^\infty N(D)D^6 dD mm^6 m^{-3} \tag{1}$$

where $N(D)dD$ is the number of concentration of droplets with diameter between D and dD; Z usually measured in dBZ can be expressed on a logarithmic scale as

$$Z(dBZ) = 10\log_{10}\left(\frac{Z(mm^6 m^{-3})}{1mm^6 m^{-3}}\right) \tag{2}$$

Empirical relationships exist relating Z to R using

$$Z = aR^b \tag{3}$$

Reflectivity (Z) is proportional to the concentration of drops with fixed diameter D given in (1). The relationships proposed rain coefficients a and b vary, dependent on drop diameter and concentration, giving rise to unique relationships characteristic of different rainfall types. Measurements of polarization parameters, with increasing information on drop size, shape and orientation used for better estimates of rainfall rate (R) than those available from reflectivity alone.

The differential reflectivity Z_{DR} and differential phase shift Φ_{DP} used for more accurate rainfall predictions [21]. It is proportional to the number of concentration of particles and tends to increase with increasing particle size and attractive variable to use for attenuation correction and quantitative precipitation estimation. Linear polarization techniques transmitting and receiving pulses with both vertical and horizontal returns Z_H and Z_V provide valuable measurements for estimate raindrop shape, size and orientation. We analyzed hourly, daily and weekly data based on observations are detected with a range of up to 250 or 450 km for constant altitude plan position indicator a horizontal cut through the atmosphere, plan position indicator volume scan at multiple elevation angles respectively.

The BAH weather radar since it is dual polarimetry collects horizontal and vertical reflectivity, Doppler velocity, and spectrum width data every 5 to 10 minutes (volume scan) for a three dimensional volume above the C-band weather radar at the Bahir Dar location. By using meteorological algorithms used to track storm motion or to help access the severity of a particular storm cell in a particular location, vertically integrated liquid water and wind profile. This weather radar has high resolution which shows temporal and spatial variation of rain fall. When a new volume scan becomes available, the creation process stops where it is on the list and starts at the top of the list with the new data set. For typical dual polarization weather radar, the displayed variables are reflectivity, rainfall rate, radial velocity and spectrum width. The plan position indicator is a polar format display of a variable, obtained from a single full antenna rotation at one selected elevation. The range height indicator is display of a variable obtained from a single elevation sweep, typically from 0° to 90°, at one azimuth. A horizontal cross-section display of a variable a specified altitude produced by interpolation from the volume data.

IV. RESULTS AND DISCUSSIONS

The Bahir Dar (BAH) weather radar which is dual polarimetry available to the meteorological research community in a number of forms from June, 2016 with both the vertical and horizontal pulses, this weather radar is better able to determine hydrometers type, shape, and size. It has important applications for operations to improve accuracy of precipitation estimation and the generation of hydrometer identification (HID) products. Meaningful information is obtained by comparing the amplitudes and phases of the signals returned at horizontal and vertical polarizations, providing a suite of new variables product values.

Reflectivity (Z) is a measure of the radiation returned by atmospheric scattering to the radar. It is expressed in decibels of reflectivity (dBZ). The radial velocity measures the motion of the scattering medium along the beam, not the total motion of the medium and spectrum width (W) is a measure of dispersion of velocities. The Bahir Dar (BAH) C-band weather radar has different types of product outputs which have different purposes for estimation of rainfall, wind direction and forecast, Early warnings like thunderstorms, hail and flood.

BAH weather radar covers most west north and parts of central Ethiopia; the scan is used for producing basic products

by using Scanning Strategies like the polar coordinate system common display of weather information. This weather radar is located at the center of the coordinate system and radar information from one antenna elevation scan is shown at the proper range and azimuth. With the conversion of these data to digital images, the ability to overlay a wide variety of information exists like political boundaries, cities and countries can be supplemented with highways or street locations, rivers and lakes.

The plan position indicator product can be configured to truncate the data at a range which is shorter than the actual task configuration range. It can improve a composite display by forcing the plan position indicator into a circle rather than a square. It can restrict the area of coverage for warn and track product. The RAIN1 product (Hourly Rain) uses CAPPI or SRI data over 60 minutes, to obtain an estimate of the rainfall that fell within an hour. The period of time desired for rainfall accumulation 60 minutes used to produce a one hour rainfall product however, the minimum accumulation time period allowed is 15 minutes. The RAINN is the sum any number of hours of individual RAIN1 products. The BAH weather radar product output shows the last N hours of accumulation. When the product runs, it integrates data for the last N hours. If a RAIN1 product is missing for one of the hours in the interval, it assumes that no rain fell during that hour. On July 01/2016 RainN for twenty four (24hr) UTC with range coverage 250 km volume-A scan as shown in Fig. 1; with resolution 809 m/pixel and its frequency is 600 Hz with maximum rain fall accumulation is 91.6 mm.

The rainfall distribution over 24 hours is observed at Bahir Dar, parts of lake Tana, most northern parts and western parts of Gondar town; southern and western parts of lake Tana. RainN for twelve hour (12 hr) UTC the maximum rain fall distribution is 42.0 mm with an azimuth angle 16 degree; a range of 223 and an azimuth angle 258 with a range of 99 km. For RainN 12hr UTC (Fig. 2) distribution rainfall have been made some correction in order to overcome topography of the surface southwest of the BAH weather radar and some parts of east from the position BAH weather radar. After correction with an azimuth angle of 268 degree and a range 96km the rain fall accumulation is 43.3 mm.

The BAH vertically integrated liquid product is very important to understand the depth of atmosphere and precipitation aloft and not reach to the ground surface if in case missed by altitude or plan position indicators. It is very powerful to estimate storm activities within altitude interval as well as the extreme of storm is found when the layer height above the freezing level. If the layer height extends from the surface up to 3 km, then the vertically integrated liquid values serve as a forecasting guide as to how much precipitation is likely to fall during the next few minutes.

The vertically integrated liquid covers 250 km the maximum height is 20.0 km with a resolution of 809 m/pixel and frequency of 600 Hz. The maximum rainfall achieved 45.8 mm and much amount of rainfall is observed North west Gonder, Ashere, South west of Adet, and eastern parts of Bahir Dar. Maximum reflective display product shows the maximum echoes on each pixels between user selected heights. The
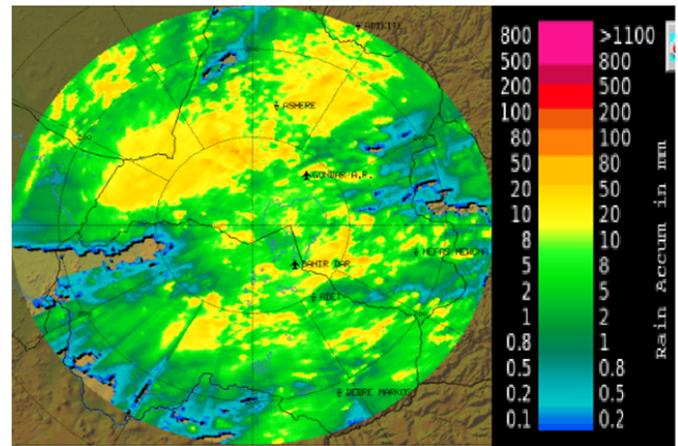

Fig. 2. RainN 24Hr UTC maximum rain fall accumulation of 91.6mm 1 July 2016
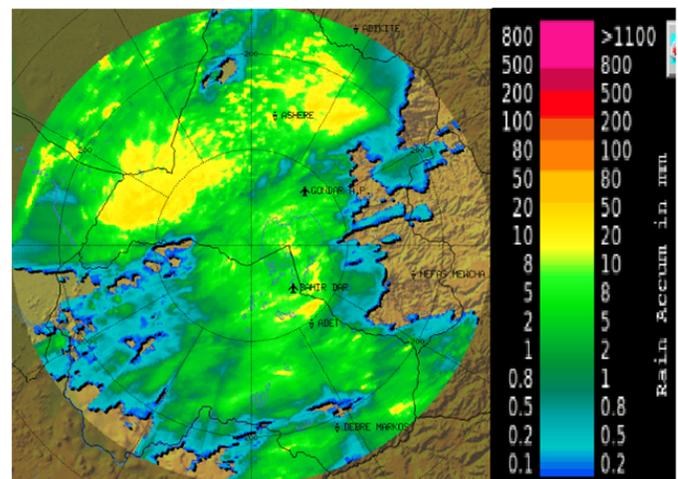

Fig. 3. RainN 12Hr UTC maximum rain fall accumulation of 43.3mm 1 July 2016

maximum height 15 km weather radar of first observation 250 km range with a resolution 882 m/pixel and frequency of 600 Hz. The maximum reflectivity is 59.5 dBz and the minimum reflectivity -27.0 dBz and an azimuth angle 358 degree with range of 37 km as shown in Fig. 4. Constant altitude plan position indicator product is a horizontal cut through the atmosphere, therefore, it requires a PPI volume scan at multiple elevation angles. The number of angles and their spacing depends on the range and height of the constant altitude plan position indicator. Using the constant altitude plan position indicator product with the vertical height of 1 km and range of 125 km using volume A scanning method from time 17:00:45 UTC to 17:55:45 UTC of 26 June 2016 are listed in the following table.

Table 1 shows resolution (m)/pixel of 347 and pulse repetition frequency (PRF) of 600 Hz. From the above Table 1 the range of minimum reflectivity through a given time in between -18.0 - 12.5 dBz and the range of maximum reflectivity is 50 53.5 dBz. The minimum reflectivity is observed at azimuth angle of 124 degree and a range of 33 km and the maximum reflectivity observed at azimuth angle 208 degree and a range
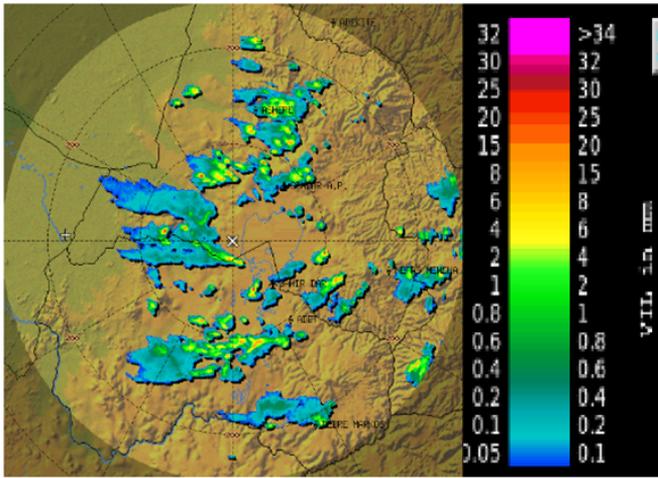
Fig. 4. Vertical integrated liquid (VIL) with maximum height 20 km maximum rain fall accumulation of 1 July 2016
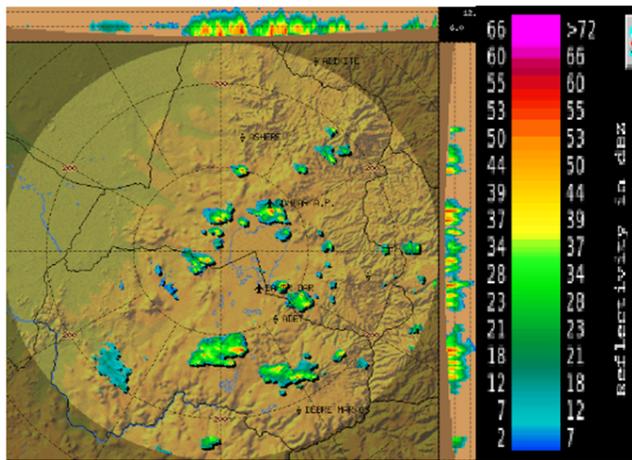

Fig. 5. Maximum reflective display with maximum height 15 km maximum rain fall accumulation of 59.5 mm 29 June 2016

TABLE I
THE CAPPI PRODUCT WITH THE VERTICAL HEIGHT OF 1 KM WITH AZIMUTH RANGE OF MINIMUM AND MAXIMUM REFLECTIVITY USING VOLUME A SCANNING METHOD

Max dBZ	Azimuth degree	range km	Min dBZ	Azimuth degree	range km	Time UTC
53.5	208	79	-18	124	33	17:00:45
52.5	156	77	-16	105	90	17:05:45
53	229	105	-16	247	63	17:10:45
52	140	96	-14.5	101	90	17:15:45
50	212	101	-16	260	85	17:20:45
51	132	121	-14.5	254	56	17:25:45
51	134	120	-14.5	134	20	17:30:45
52	136	119	-15	253	52	17:35:45
52	195	92	-15.5	100	91	17:40:45
52	196	93	-14.5	254	56	17:45:45
51.5	134	88	-14.5	102	55	17:50:45
52	190	61	-12.5	281	7	17:55:45
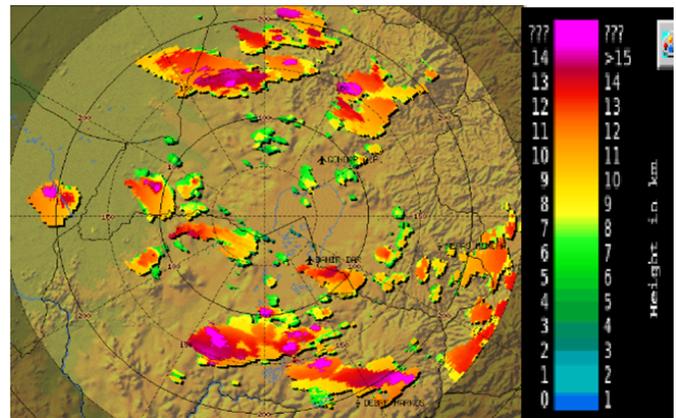
Fig. 6. TOPS with maximum height 18.9km maximum and minimum 3.2 km 28 June 2016

of 79 km.

The amount of precipitation concentration is directly related to radar reflectivity. When amount of reflectivity is high the amount of hydrometer is high. From the reflectivity rain fall and warning issues are estimated. In 26 June 2016 for the last of 55 minutes we observed 53.5 dBz maximum reflectivity south west region from the site of Bahir Dar weather radar. The BAH Echo Tops product is a display image of the height of the highest occurrence of a selectable threshold dBZ contour. A 50 dBZ top 1 km above the freezing level produce a vigorous convective storm. Echo Tops over a range of 250 Km with Vol-A scanning method and its resolution is 694 m/pixel with a pulse repetition frequency of 600 Hz. The maximum height 18.9 km and 2.3 km is the minimum height.

The Base resolution is 809 m/pixel and with pulse repetition frequency of 600 Hz depicted in Fig. 6. The maximum height that achieved by the base reflectivity is 14.4 km and minimum height is 2.3 km at 12:36:03 UTC in 29 June 2016.

The BAH weather radar has a capability for observing further vertical structure of a storm. Area of interest can be scheduled by RHI TASK. During RHI scanning, the antenna azimuth is fixed and the elevation is swept, typically from near 0° to 90° to create a vertical cross-section effect.

A display is generated with the range on the x-axis and the height of the cloud targets on the y-axis. A Cartesian grid is displayed as on overlay to facilitate reading height of clouds as depicted on Fig. 7.

After a series input products at different temporal and spatial resolution the track products can be projected to visualize the movement of storm characteristics as shown in Fig. 8. The track shows movement of one centroid over a specified time span, plus a forecast point indicating where the centroid will be given its current direction and speed. As new data comes in, the track product evaluates whether a new track point is an extension of a previous track, the start of a new track, or the end of a track. Track parameters, such as the maximum velocity and tolerance for new points, influence this determination. Horizontal wind vectors are displayed as wind speed and direction with either wind barbs or wind strings.

Suppose the freezing level is at 4 km, and we run an echo TOPS product for the 45 dBZ contour. The TOPS product shows 45 dBZ tops at heights greater than 5.5 km, there is a high probability of hail. However this is not the only issue to determine occurrence of hail checking the region of hail
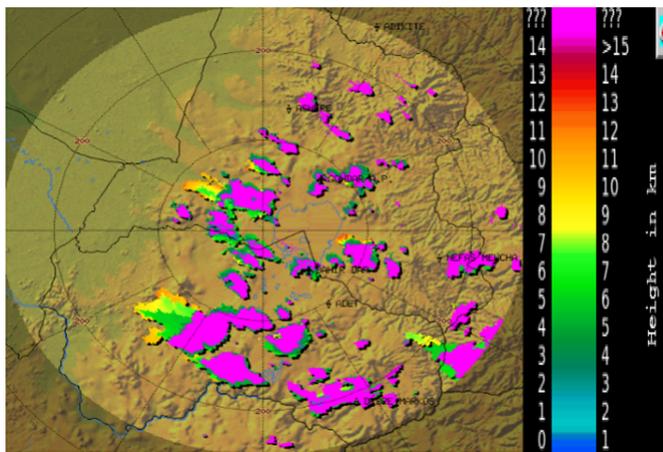
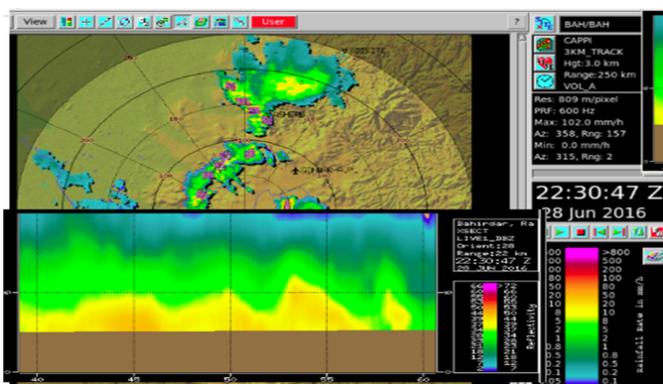Fig. 7. base with maximum height 14.4 km maximum and minimum 2.3 km 29 June 2016

Fig. 8. RHI with maximum height 3 km maximum and rainfall accumulation 102.0 mm 28 June 2016
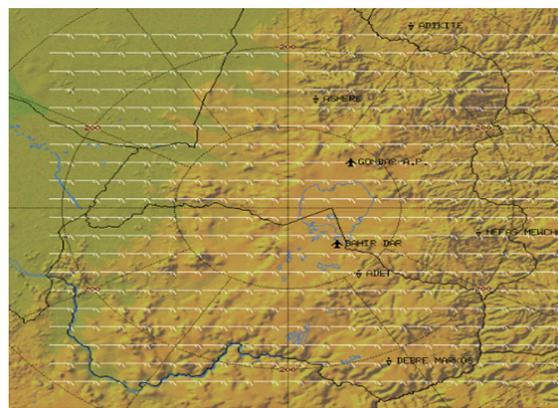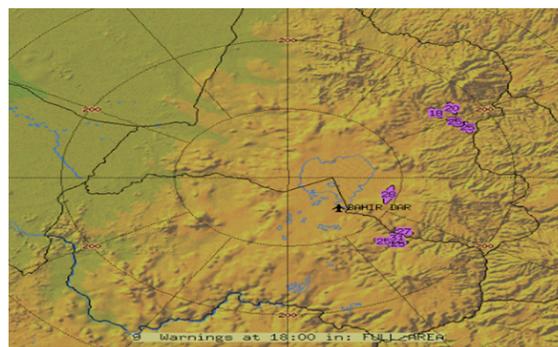

Fig. 9. 1km-TRACK volume scan method

Fig. 10. Warning Constant Altitude Plan Position Indicator product of thunderstorm North East and South east from the weather radar station27 June 2016

signature is another mechanism to observe warning issues. The warnings are located mostly north east around 170 km from the weather radar at 18:00:44Z 27 June 2016 shown in Fig. 9.

V. Conclusions

The Bahir Dar (BAH) weather radar operates in C-band of the electromagnetic spectrum with energy bands correspond to wavelength 4 to 8 cm. It is a dual polarimetric radar available to the meteorological research community in a number of forms from June, 2016 onwards with both the vertical and horizontal pulses has potential to capture hydrometers' types, shapes, and sizes. Spatially and temporally covers North western parts and central parts of Ethiopia to observe and analyze different products. The Bahir dar weather radar for the first time observation has been detected with a range of up to 250 km or 450 km for constant altitude plan position indicator and plan position indicator respectively. The Bahir Dar C-band weather radar has different types of product output which have different purposes for estimation of rainfall, wind direction and forecast, warnings like thunderstorms, hail and flood. The vertical integrated layer product can compute several different values over an altitude interval or layer in the atmosphere. It can compute integrated liquid, or averaged reflectivity. The

range of minimum reflectivity through a time of 17:00:45 UTC to 17:55:45 UTC of 26 June 2016 in between -18.0 - 12.5 dBz and the range of maximum reflectivity is 50 - 53.5 dBz. The minimum reflectivity observed at azimuth angle 124 degree and a range of 33km and the maximum reflectivity observed at azimuth angle 208 degree and a range of 79 km.

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