International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol. 8, Issue.12, December 2020 E-ISSN: 2347-2693

Detection of Cloud Top Height, Cloud Base, Cloud Height and Cloud Temperature Using Ka-Band Radar Data

Nikita S. Tandale[1]*, S.V.Gaikwad[2]

[1,2]Department of Electronics and telecommunication, Pune Institute of Computer Technology, Savitribai Phule University, Pune, India

*Corresponding Author: tandalenikita2535@gmail.com, Mob no-8275524755

DOI: https://doi.org/10.26438/ijcse/v8i12.1014 | Available online at: www.ijcseonline.org

Received: 05/Dec/2020, Accepted: 11/Dec/2020, Published: 31/Dec/2020

Abstract— This paper presents a cloud detection based framework for addressing the problem of accurate cloud detection using Ka-band scanning polarimetric radar (Ka-SPR). This framework benefits from Python , which is capable of pixel level labeling of cloud regions and also for identification approach is proposed to identify Cloud Height(CTH), Cloud Base(CB), Cloud Top(CT) and Cloud Temperature (CTemp). Cloud properties detection is an important application of science and technology to detect clouds and measure the amount of water content over a region. The detection is based on various data collection means. Some most recent techniques for weather data collection are based on graphical data from satellite, sensor data collected from different areas, the radar data for cloud parameters, rain gauge which major liquid precipitation for a specific period and disdrometer data which gives drop size distribution. Correlation of CTH, CT, CB is used for calculating reasonable estimation of these parameters. Estimates may also improved somewhat by an observation of cloud types. By using CT data and Cloud pressure the estimation of CTemp is carried out. Different constants were derived from the microscopic properties correlation consistent with each respective cloud type.

Keywords— Cloud detection, Ka-band scanning polarimetric radar (Ka-SPR), Cloud Height, Cloud Base, Cloud Top and Cloud Temperature.

I. INTRODUCTION

Cloud is an important constituent of earth's water cycle. It is well known fact that clouds modify earth's energy budget and plays an important role in affecting Earth's climatic system. Therefore, study of Cloud variability in time and space is very important. A ka-band System has been built to study the low level clouds prevailing during monsoon period. This paper discusses about the Ka band radar scanning, Cloud types, its formation and cloud properties like Cloud Height(CH) etc. Computer aided system has been integrated and deployed a klystron based Ka-band Scanning Polarimetric Radar (Ka-SPR) at Mandhardev[9].

During monsoon there are heavy clouds in Mandhardev region. The targeted reflectivity (Z) of the cloud for the system design has been taken as -40 to 40 dBZ vertical height of 5 km. Scientific requirement demands long-term observations of non precipitating clouds, precipitating clouds and rainy clouds. In view of this, the developed system are coherent, Polarimetric, Doppler Radar. It would measure the following parameters at each range, typically from 0.5 km above ground level to height of 5 km,

- Horizontal Reflectivity
- Vertical Reflectivity
- Latitude
- Longitude
- Clutter description
- Filtered data
- Radar parameters such as Gain, antenna height, Beam width, Transmitted Power
- Sweep mode
- Start time, End time.
- Log differential reflectivity

Studying clouds may be a top priority among many atmospheric scientists because clouds are one among the best unknown factors in predicting changes within the Earth's climate. Clouds are generally classified consistent with their appearance, composition, and height.

High-level clouds: cirrocumulus, cirrus, and cirrostratus.
Mid-level-clouds:altocumulus, altostratus, and nimbostratus.
Low-level-clouds:status, cumulus, cumulonimbus and satrocumulus

The Indian Institute of Tropical Meteorology (IITM), Pune, has deployed a klystron base 2.2 kW Ka-band (35.29 GHz) dual polarimetric scanning Doppler cloud radar at a remote hilly location, Mandhardev (18.04°N, 73.86°E and ~ 1.3 km MSL) in Western Ghats region, India. The cloud radar and its geographical location on the map can be seen in Fig. 1. The technical specifications of the Ka-band radar are given in Table 1. The scan strategy of the Ka-band scanning polarimetric radar (Ka-SPR) comprises three displays, namely, plan position indicator (PPI), range height indicator (RHI) and vertically pointing height time indicator (HTI), all with a maximum range of ~ 26 km. The present study utilizes the Ka-SPR's vertically pointing measurements on BB incorporated with the PPI cloud surveillance measurements to account for the large-scale cloud features[9].

Figure (1): A Mandhardev radar site.
Source: Adapted from [9]

Table 1: Technical specifications of Ka-band scanning polarimetric radar (Ka-SPR)

Parameters	Values
Frequency (GHz)	35.29
Wavelength (cm)	0.8
Transmitter	Klystron
Peak power (kW)	2.2
Pulse widths	50-13000 µs
Antenna gain (dB)	49
Minimum detectable signal	-45 dBZ at 5 km
Antenna diameter (m)	1.2
Cross-pol isolation (dB)	-27

Source: Adapted from [9]

II. PROPOSED METHOD

A. Cloud detection framework

In this project a computer aided system used to detect clouds and its properties using radar data .The dataset was collected from IMD; these were preprocessed data. From this data, reflectivity factor is defined and Displayed it on RHI or PPI plots by using Matplotlib. By using reflectivity factor detect the clouds in atmosphere. For this Numpy and math module library is used and formulate these cloud properties. After that using matplotlib, plot all this properties in readable form.The figure(2) represents the block diagram of the design for detection of LWC.

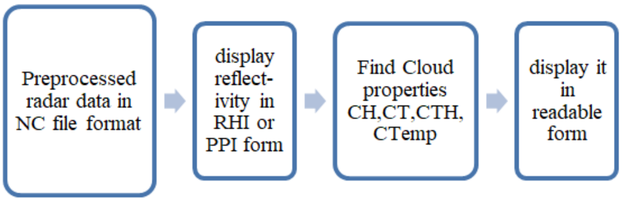

Figure (2):Block diagram for design to detect LWC

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B. Dataset

The dataset used for this project is recorded from IMD. It has NC file format. This Data has two types of files PPI and RHI. The Network Common Data Form, (netCDF), is an interface to a library of data access functions for storing and retrieving data in the form of arrays.It supports a view of data as a set of self-describing, portable objects which will be accessed through a simple interface. Generic utilities and application programs can access netCDF datasets and transform, combine, analyze, or display specified fields of the information data. We can read this data from the NC file using Panoply application. The radar data which we get is preprocessed and it contains Horizontal Reflectivity, Vertical Reflectivity, Latitude, Longitude, Clutter description, Filtered data Radar parameters such as Gain, antenna height, Beam width, Transmitted Power Sweep mode Start time, End time, Log differential reflectivity,The scan duration is approximately 12 minutes.

III. EXPERIMENTAL SETUP

C. Reflectivity factor (Z)

The Probert-Jones radar equation will help to quantify the physical aspects of pulsed E-M energy and the associated limitations of target detection. The Probert-Jones radar equation is shown below[7],

$$\overline{P}_r = \left[\frac{P_t G^2 \Theta^2 H \pi^3 K^2 L}{1024(ln2)\lambda^2}\right] \times \frac{Z}{R^2} \qquad \text{--- [7,eq]}$$

Where ,

P_r = power returned to the radar from a target in watts

P_t = peak transmitted power in watts

G = antenna gain

θ= angular beamwidth

H = pulse length

π= pi (3.141592654)

K = physical constant

L = signal loss factors associated with receiver and attenuation detection

Z = target reflectivity

λ = transmitted energy wavelength

R = target range

Solving for Z, the above equation becomes,

$$Z = \frac{\overline{P}_r \cdot R^2}{C_r L_a}$$

Hence it is very convenient to express it in logarithmic scale

$$dBZ = 10log_{10}(Z)$$

Z varies from - 30 dBZ for fog to + 75 dBZ for heavy rain.

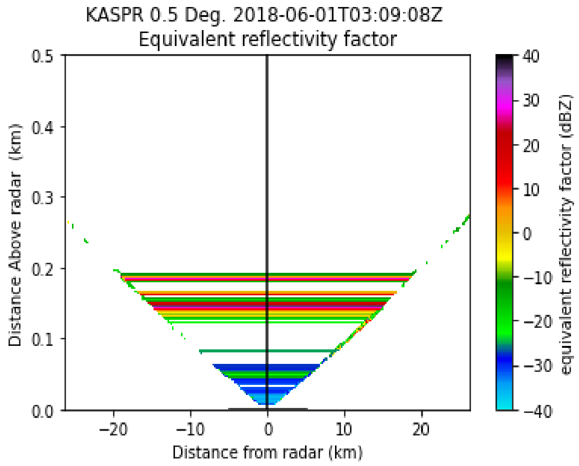


Figure (3): reflectivity at 1 June 2018.

D. Cloud Top

The CTis that the highest altitude of the visible portion of the cloud. It is traditionally expressed either in metres above the planetary surface, or as the pressure level in hectopascal. The Cloud Top is where the snow, rain come from. CT can be estimated from the bottom by triangulation. However, this is often inconvenient as this is practically feasible just for isolated clouds in full view of (and some horizontal distance away from) the observers. Ground-based radars can be used to derive cloud property.

In convective clouds, the CTwhich get influenced by the strength of the convection activity, which often itself depend upon surface properties, in the way the supply of heat and water vapor below the cloud. CT is often far more variable than CB elevation[4].

$$CT(km) = -\frac{RT}{g} * log\left(\frac{Cloud\ top\ pressure}{Surface\ pressure}\right)\text{--------(12)}$$

Where,

High level cloud pressure 50-440 hPa
Mid level cloud pressure 440-680 hPa
Low level cloud pressure 680-1000 hPa

Where, R is the ideal gas constant,
T is the mean temperature,
g is the gravitational constant

The first factor comes to value of -8km if T≈273 K. This value is also known as scale height. Surface pressure is approx 1013 hPa.

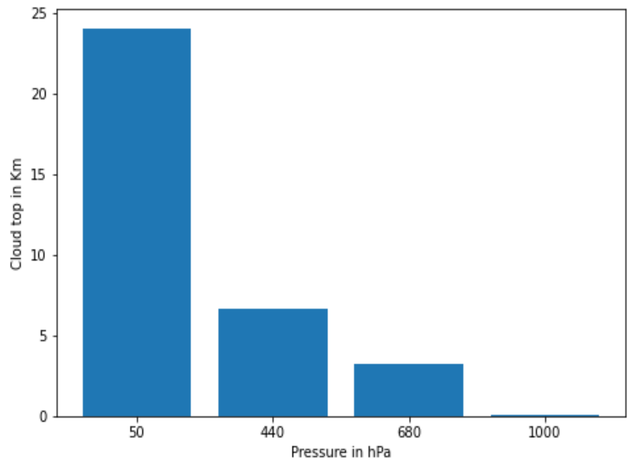


Figure (4)-Cloud top observed by Ka-SPR

Table 2: Types of clouds with different top height

Optical thickness Pressure (hPa)	0 - 3.6	3.6 - 23	23 - 379
50 - 440	**(Cirrus)**	**(Cirrostratus)**	**(Deep convection)**
440 - 680	**(Altocumulus)**	**(Altostratus)**	**(Nimbostratus)**
680 - 1000	**(Cumulus)**	**(Stratocumulus)**	**(Stratus)**

Source: Adapted from [4]

E. Cloud base

CB is that the lowest altitude of the visible portion of a cloud. It is measured either in meteres or feet above mean water level or above a planetary surface, or the pressure level corresponding to this altitude in hectorpascals.

The height of the CB are often measured in ceilometer. This device reflects a beam of light off the CB then calculates its distance using either triangulation or time period.

Alternatively, the CB are often estimated from surface measurements of air temperature and humidity by calculating the lifted condensation level. One method for doing thisas follows [5]:

1. Find the difference between the surface temperature and dew point. This value is known as the "spread".
2. Divide this spread by 2.5,if the temperatures are in °C or 4.4,if the temperatures are in °F and then multiply by 1000. This will give the CB altitude in feet above ground level.
3. Add the results from step (2) to the elevation to get the altitude of the CB,

$$CB\ (km) = ((Temperature - Dew\ point)/4.4 \times 1000) + elevation\text{----(13)}$$

$$Td = T - ((100 - RH)/5)$$

Where,Td is the dew point temperature (in degrees Celsius), T is the observed temperature (in degrees Celsius), and RH is the relative humidity (in percent).

Apparently this relationship is accurate when relative humidity values above 50%.

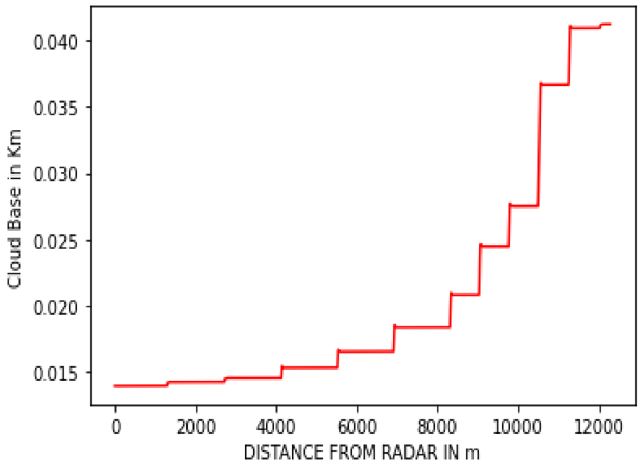


Figure (5)- Cloud base obsereved by Ka-SPR

Table 3: Types of clouds with different base

Assigned label	Cloud characteristics
All clouds	CB≥0 km
Thick clouds	CB≤ 1 km, CTH≥10
High-thick clouds	CB≥ 4 km, CTH≥ 4 km
High clouds	CB≥ 10km

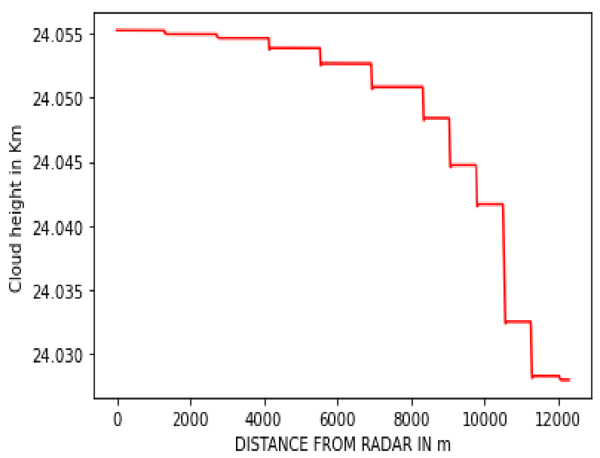
F. Cloud Height

The CTH referred as a Cloud Thickness or depth, isthat the distance between the cloud base and the cloud top. It's expressed either in metres or as a pressure difference in hectopascal.

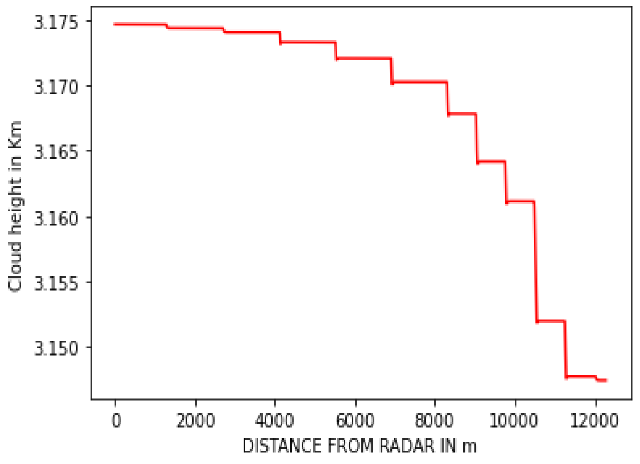
CH is not measured directly but is derived from separate measurements of CB and CT altitudes.

CTH equation is shown below,

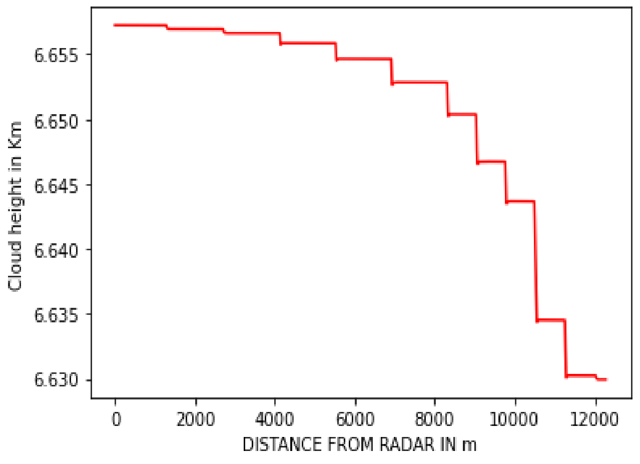
$$CTH(Km) = CT\text{-}CB \text{------(14)}$$



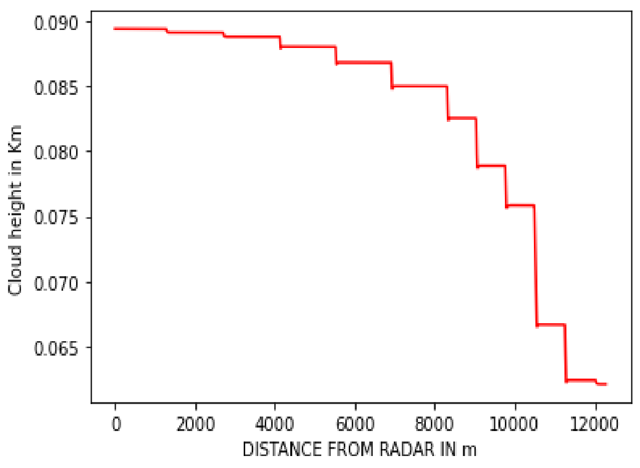
(A)



(B)



(C)



(D)

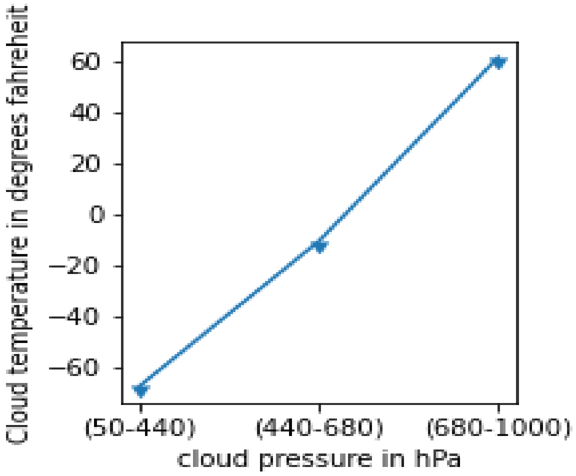
Figure(6)- Cloud Height observed by Ka-SPR

G. Cloud temperature

The Baseline Cloud Top Temperature estimates the temperature of the CT in degrees Celsius.Temperature of the top of the cloud is[5],

$$CTemp = temperature - 5.4 * (CB - elevation) \text{---(15)}$$

Temperature decreases by 5.4°F per 1000 feet of altitude. That means that per every 1000 feet of difference between the CB altitude and therefore the altitude of your measuring point, the air temperature will decrease by 5.4°F



Figure(7)- CTemp (Cloud temperature) observed by Ka-SPR

Table 6: Air temperature with surface pressure height from ground

Height in km	Temperature in °F/℃	Pressure in hPa
0 km	59°F /15℃	1013.25
11 km	-69.7°F /-56.5℃	226
20 km	-69.7°F /-56.5℃	54.70
32 km	-48.1°F /-44.5℃	8.68

IV. CONCLUSION

The verification and improvement of cloud and the understanding of cloud's microscopic properties are essential. In this study, microphysical parameters like Cloud Height, Cloud Base, Cloud Top and Cloud Temperature was calculated. For this calculation, Ka-band radar (Ka-SPR) reflectivity and data used, these were collected during a 2018 intensive observation period and tested. It uses a high frequency (short wavelength) of 35.29 GHz (8mm) to generate high resolution spatiotemporal observational data on clouds. The CTH data derived from radar measurements are in reasonable agreement if a single cloud type is observed. In case of multi-level cloud system, the information about the CT and CB is available for the lowest and the highest clouds and which might be used in cloud classification studies. By using CT and cloud pressure, CTemp is retrieved.

By comparing calculated results and standard results it gives best accuracy for CT is 66.50%. Result values for CTH, CTemp has accuracy between 66-95%.

The results are compared with the results obtained by various researchers where the different python algorithms are used. It is observed that comparatively less error has obtained in this experiment. This proposed computer aided system shows better accuracy with respect to the conducted research results by other researchers.

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