# Correlation Between Hail Diameter and VILD in Bayannur

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**Abstract.** The vertical integrated water liquid content density(VILD) can be calculated using the ratio of the vertical integrated liquid water content(VIL) to cloud thickness. This paper processes the reflectivity factor data of hail-days observed by the new generation of weather radar (CINRAD-CD) in Linhe area of Inner Mongolia from 2012 to 2020, and combines hail size data collected by the hail-pad of each weather modification operation site, using the least squares method for regression fitting, and processing the VILD and the actual hail size. The results show that there is a good correlation between the VILD and the hail diameter on the ground. The power function model has the smallest cost value of 27.31, and using VILD as a recognition factor is more accurate than VIL. The power function model is fitted using hail-pad information, and the cost is 5.97, It can be concluded that the diameter of hail recorded by the hail-pad is more accurate, and the fitting result has certain reference significance for the estimation of hail particle diameter in Bayannur.

**Keywords:** Vertical integrated liquid water content; Vertical integrated liquid water content density; Hail diameter; Hail-pad

## 1 Introduction

In recent years, some scholars at home and abroad have conducted some studies on hail recognition, path tracking, regional distribution, generation mechanism and artificial hail prevention, and have drawn a large number of effective conclusions, but there are few studies on calculation of hail size.

In the 1970s, Greene[1] proposed a method to calculate the vertical integrated liquid water content by using the radar reflectivity factor. The research results of

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Robert [2] also show that the VIL center is closely related to the precipitation center. Winston [3] also found that VIL has a good indicator effect on hail.

In China, with the development of digital weather radar, the application research of VIL has also been developed. Wang Wei, Fu et al. [4] [5] used VIL to predict hail, and Pan Jiang [6] et al. used VIL to carry out the study of estimate precipitation. Liu[7] used the 3D-Barnes scheme to interpolate the new generation weather radar reflectivity factor contour plane data. The maximum diameter of hail is calculated by the ratio of VIL to the height of the cell, that is, the vertical integrated liquid water content density of the cell.

The hail-pad is a commonly used hail measuring instrument at present. It is low in cost and suitable for field observation. By measuring the diameter of the pit, the size of the local hail can be estimated, and the spectral distribution, hail density and end velocity of the hail can also be calculated. It can also objectively measure the intensity of hail and the degree of damage to crops [8].

## 2 Study Area and Data

Bayannur is located in the western part of Inner Mongolia, and the middle and high latitudes. As shown in Fig.2.1. Affected by this special geographical environment, the weather in Bayannur is complex and changeable, Disasters occurs frequently. Among them, frequent hail disasters have caused serious impacts on agricultural production and people's lives.

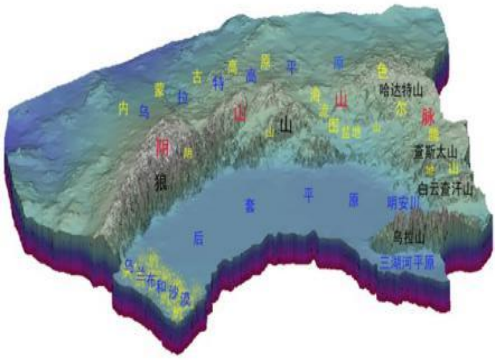


**Fig. 2.1** Topography of Bayannur

The research area in this paper includes the new-generation weather radar centered in Linhe, Inner Mongolia (107°21′36″E, 40°43′48″N), and the effective scanning radius is 150km. The actual hailfalls are from the hail disaster events reported by the county meteorological bureaus. The Table 2.1 shows part of the hail diameter data.

**Table 2.1** Cases of hail clouds and the maximum hail diameter on the ground

| Time | Site Location | Longitude | Latitude | Hail Diameter |
|---|---|---|---|---|
| 2012/6/23 | Hanghou | 107. 51 | 40. 99 | 5mm |
| 2014/6/29 | Denkou Dukou | 107. 12 | 40. 42 | 10mm |
| 2016/6/3 | Linhe Xinhua | 107. 49 | 41. 16 | 5mm |
| 2017/6/4 | Taohai Hongsai | 108. 07 | 40. 92 | 6.5mm |

In order to obtain more accurate and objective hail particle data, highlighting the accuracy of hail-pad, this paper uses the hail-pad data obtained during the hail prevention test in 2020.

**Fig. 2.2** Hail drop marks on the Hail-pad

# 3 Methodology

## 3.1 Three-Dimensional Barnes Interpolation

The doppler radar data is located in the spherical coordinates centered on the radar and is not continuous in height. For the convenience of analysis and application, it is often necessary to interpolate the radar data to Cartesian coordinate grid points.

Currently, the adaptive Barnes scheme is defined in terms of polar coordinates. The defined weight function and analysis equation are as follows:

$$w_0 = \exp[-\frac{(r_g-r_0)^2}{k_r} - \frac{(\varphi_g-\varphi_0)^2}{k_\varphi} - \frac{(\theta_g-\theta_0)^2}{k_\theta}] \quad (1)$$

$$f_0 = \sum_{k=1}^{N} w_k f_k / \sum_{k=1}^{N} w_k \quad (2)$$

Among them, $w_0$ is the weight of a sampled echo value point; $f_0$ is the interpolated echo value; $f_k$ is the i-th sampled echo value that affects the echo value; N is the total number of sampled echoes; $r_g$, $\varphi_g$, $\theta_g$ are the polar coordinates of the interpolation grid points; $r_0$, $\varphi_0$, $\theta_0$ are the linear distance, elevation angle and azimuth angle of the radar sampling echo value point from the radar; $k_r$, $k_\varphi$, $k_\theta$ are Barnes interpolation parameters.

## 3.2 Radar Derived Parameters

### 3.2.1 VIL

VIL is based on the assumption that the reflectivity factors obtained by the reflection of the solid and liquid water droplets inside the cloud meet the empirical derived relationship caused by the liquid water droplets.

This paper uses the 3D-Barnes scheme to interpolate the PPI data of the radar volume scan to the 40-layer reflectivity factor Z ($mm^6/m^3$) contour plane data (height interval is 0.5km, horizontal grid is 0.01°×0.01°). After the interpolation is completed, the calculation formula of VIL is:

$$VIL = 3.44 \times 10^{-6} \sum_{i=1}^{n-1} [(Z_i + Z_{i+1})/2]^{\frac{4}{7}} \Delta h \quad (3)$$

Among them, $Z_i$,$Z_{i+1}$,$\Delta h$ and n are the reflectivity factor, vertical height and number of data layers of the two adjacent layers in the Contour plane data of reflectivity factor. In this paper, the vertical height $\Delta h$ is 0.5km, and the data layer number n is 40 layers.

### 3.2.2 VILD

The meaning of VILD is the ratio of the VIL value to the height H of the hail cloud, the unit is $g/m^3$, and the formula is:

$$VILD = \frac{VIL}{H} \quad (4)$$

Among them, H is the height of the hail cloud echo, and the unit is m.

The final calculation formula of VILD can be obtained by bringing equation (3) into equation (4):

$$\mathrm{VILD} = \frac{3.44 \times 10^{-6} \sum_{i=1}^{n-1} [(Z_i + Z_{i+1})/2]^{\frac{4}{7}} \Delta h}{H} \quad (5)$$

The cloud height H in formula (5) can be obtained from the 40 layers reflectivity factor grid after interpolation.

## 4 Results and Discussion

This paper selects the reflectivity factor within 150km from the Linhe CD radar site for interpolation, and selects two hailfall cases in the study area to discuss the results.

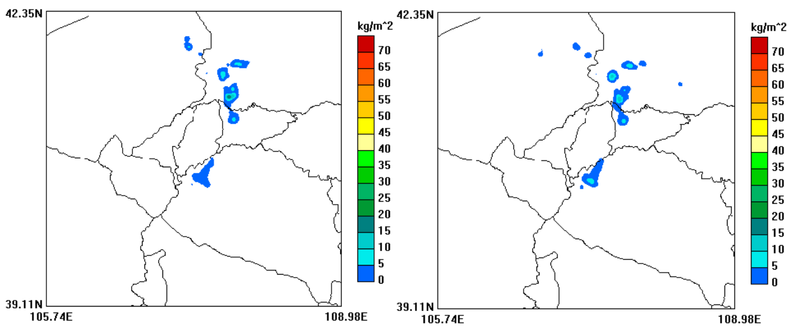


**Fig. 4.1** shows the VIL values at 16:03 on August 9, 2019 and 15:59 on August 9, 2019

As the VIL value above 20kg/m$^2$ may cause hail, it can be seen from the radar observation results in Fig. 4.1 that hail events may occur at these two moments.

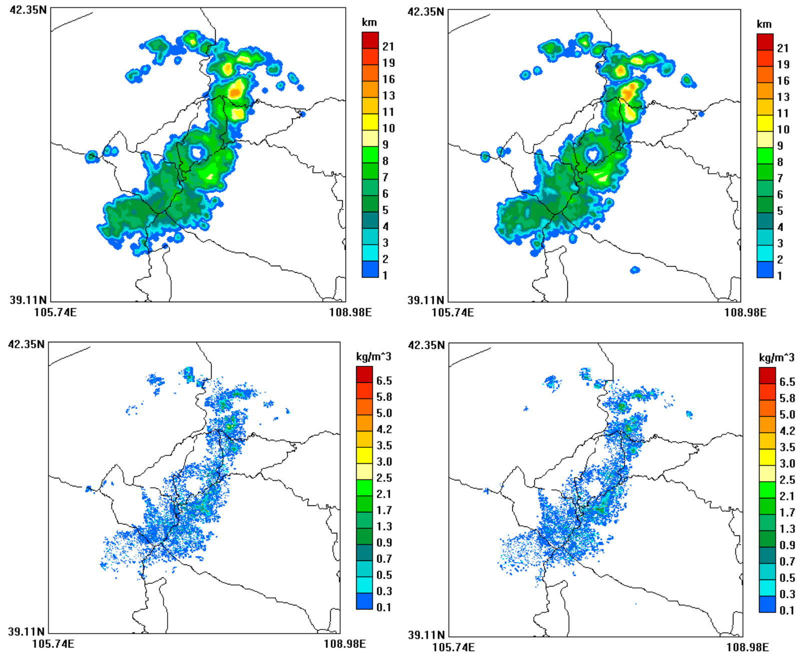


**Fig. 4.2** the corresponding cloud height H and VILD at 16:03 on August 9, 2019 and 15:59 on August 9, 2019

By judging the threshold value of the reflectivity factor in the vertical direction, obtaining the cloud top height H of the hail cloud, and the calculated VIL is divided by the cloud top height H of the corresponding position to obtain the VILD of the point. As shown in Fig. 4.2.

## 4.1 Human Evaluated Distribution

According to the approximate relationship of VILD-R, we use the least square method to fit the data with linear, logarithmic, exponential and power functions.

The fitting results are shown in Fig. 4.3. It can be obtained that there is a positive correlation between the VILD value of radar echo and the hail diameter.

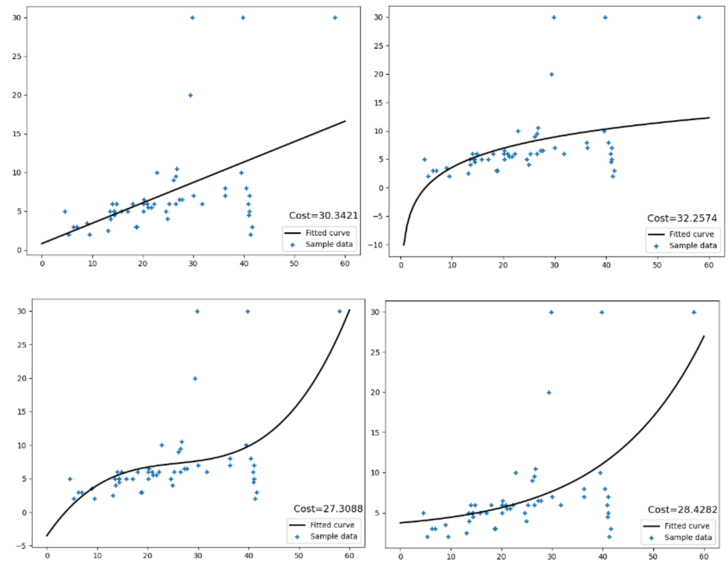


**Fig. 4.3** Hail diameter and vertical integral liquid water density fitting results

The function parameters after fitting are shown in Table 4.1.

**Table 4.1** Fitting function parameters

| Fitting type | $\theta 1$ | $\theta 2$ | $\theta 3$ | 代价值 |
|---|---|---|---|---|
| Line type | 0.26 | 0.83 | —— | 30.34 |
| Logarithmic | 4.87 | -7.64 | —— | 32.36 |
| Cubic curve model | $5.06*10^{-4}$ | -0.04 | 1.09 | 27.31 |
| Exponential model | 1.05 | 2.74 | —— | 28.43 |

By directly fitting the result of VIL value and radius, as shown in Fig. 4.4:

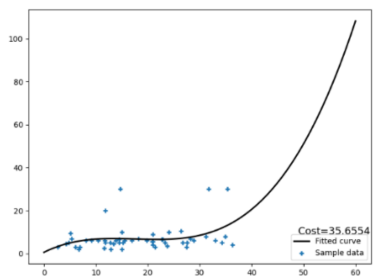


**Fig. 4.4** Hail diameter and vertical integral liquid water content fitting results

It can be seen from Fig. 4.3 and 4.4 that the regression equations established by the cubic curve model for VIL and VILD can be used to estimate the radius. And using VILD as the recognition factor is better than the recognition effect of VIL.

Selecting 50 hailfall cases in Bayannur area, correspond the actual hail diameter to the diameter calculated by the cubic curve model with the smallest value of VILD, and divide the hail particle diameter into three intervals: $R \leqslant 10$mm, 10mm< R<20mm, R≥20mm, find the mean square error (MSE) of each diameter interval, as shown in Table 4.2:

**Table 4.2** MSE of each hail diameter interval

| | R<=10mm | 10mm<R<20mm | R>=20mm |
|---|---|---|---|
| MSE | 4.85 | 94.22 | 347.03 |

## 4.2 Hail-pad Evaluated Spectrum

The least square method is also used to fit the hail diameter and the VILD cubic curve model, as shown in Fig.4.5 the fitting function is $y = 1.17 \times 10^{-3}x^3 + 0.06x^2 - 0.04x + 3.45$ , The mean square error of the fitting result is 5.98, and the accuracy is significantly improved compared with the result of human recording the diameter of hail.

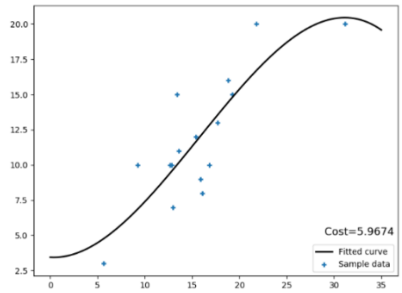


**Fig. 4.5** Fitting results of hail-pad data

# 5 Summary

There is a good correlation between the diameter of the hail on the ground and the density of the vertically integrated liquid water. It can be concluded that the result obtained by fitting the cubic curve model has the smallest cost function.

It can be seen that the smaller the hail diameter, the more accurate the hail diameter calculated by VILD, which has certain reference significance for the estimation of the hail diameter in Bayannur area.

Both VIL and VILD can use the regression equation established by the cubic curve model to estimate the hail radius, and using VILD as the identification factor is more accurate than VIL as the identification factor.

In this paper, the relationship between hail diameter and VILD is fitted with the hail-pad data of each site in Bayannur area, Inner Mongolia. The fitted cubic curve function model cost value is 5.97, which is significantly more accurate than the manual recording of hail diameter.

In the future, it is necessary to collect the hail diameter information of hail-pad at more stations in order to obtain the real-time hail diameter size more accurately.

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