

Evaluation of Two Radar-Based Hail Detection Algorithms

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Abstract

Radar data were analyzed for severe thunderstorms that produced severe hail across the south west, west and northern plains of the Iran during the 2008-2010. In order to gain insight in the probability of observing hail at a certain location and the seasonal variation thereof, 3 years of upper-air sounding data and synoptic observations of hail have been analyzed. A dataset containing 32 reports of hail include parameters such as freezing level, echo-top, 45 dBZ Reflectivity Max Heights and Vertical Integrated Liquid water (VIL). The height of the freezing level has been calculated from the upper-air sounding data of 12 UTC for each day. In this research, two methods of hail detection have been selected. The first method is based on criterion of the Waldvogel hail algorithm that uses the maximum altitude at which a reflectivity of 45 dBZ is found in relation to the height of the freezing level. The results show that for height difference greater than 5 km, the probability of hail detection (PHD) is 100%. This value depending on warm and cold climate can be varied up to 1 km. The second Method uses Vertical Integrated Liquid (VIL) product of radar. Thresholds for VIL-based hail warnings have been calculated 10 mm.

Keywords: Radar data; Hail detection algorithm; 45-dBZ reflectivity max height; Freezing level; Vertical integrated liquid water

Introduction

Various techniques such as those by Lemon [1], Paxton [2] and Amburn [3] have been developed in the quest to detect thunderstorms capable of producing severe-sized hail. Severe-sized hail is defined by the National Weather Service as hail that is 19 mm (3/4 in.) in diameter or greater. Previous research regarding severe hail detection has focused on derived radar products such as Vertically Integrated Liquid (VIL). Paxton [2] developed an equation for "VIL of the day" and Amburn [3] worked to correlate VIL density (VIL divided by echo top) with the size of large hail. Edwards [4], however, found that VIL-based parameters offered little to no skill in predicting hail size and severity. Some methods use radar data only, while some others use additional information on the vertical temperature profile or uses additional information on the cloud-top temperature determined by a geostationary satellite, e.g. Meteosat.

The operational implementation of a hail detection product based on the method of Waldvogel is rather straightforward and in this research we try to optimize this method according to local weather conditions. On the other hand, we focused on derived radar products such as VIL to find a threshold for issuing hail warnings. The performances of these two different hail detection methods have been verified using data of 32 selected days with thunderstorms in Iran during 2008-2010.

Hence, this study follows under mention final goals:

1. Verification of hail detection Waldvogel criterion in our region.
2. Try to find a threshold of VIL for issuing hail warnings.

Material and Methods

In order to gain insight in the probability of observing hail at a certain location, 3 years of upper-air sounding data, synoptic observations of hail and radar products have been analyzed. Iran National Doppler Weather Radar Network consists of five radars (four radars- C band and one- S band). The sensitivity of the radars is such that a reflectivity of 7 dBZ can still be observed at a range of about 250 km from the radar site. The radars network operates in C- and S-band Doppler radar which is performing low-elevation volume scans every 15 minutes. From these scans, a plan-position indicator of the radar reflectivity and a display of the echo top heights are produced operationally. The all-tilts display allows the warning to quickly assess thunderstorm structure at each elevation slice in a Volume Coverage Pattern (VCP) in real time. Figure 1 shows volume coverage pattern of the radars with high vertical resolution.

The first method (NEXRAD) is based on criterion of the Waldvogel [5] will focus upon difference between the Maximum height of 45-dBZ reflectivity and the height of freezing level and examine its usefulness as an indicator for severe hail potential. In this algorithm, the Probability of Detection (POD) is based on the following criterion:

$$H_{Z45} - H_{T0} > +1.4$$

Where H_{45} is the Echo-Top height (ETOP) of the 45 dBZ data, and

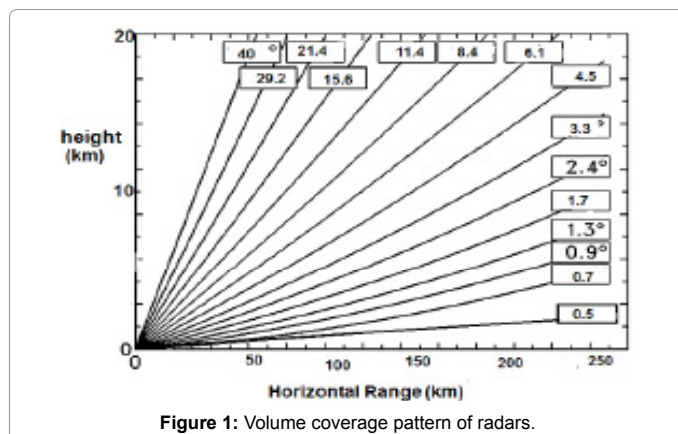


Figure 1: Volume coverage pattern of radars.

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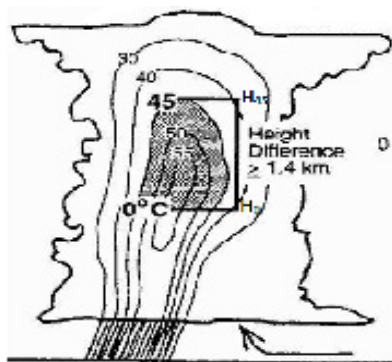


Figure 2: Schematic of a hail storm and the design of each Hail Detection Algorithm (figure taken from Kessinger [6]).

layer (freezing level). The height of the freezing level has to be entered manually, or it may be read automatically from a data file.

The second algorithm is based on VIL. VIL is a function of reflectivity, and converts reflectivity data into an equivalent liquid water content value based on drop-size distribution and a reflectivity factor. This factor is proportional to the total number of targets within a measured volume and to the target diameters taken to the sixth power. Thus, target diameter has a much greater effect on reflectivity than does the number of targets. Reflectivity increases exponentially as target diameter increases. Thus, VIL increases exponentially with reflectivity, so high VIL values require high reflectivity values, usually implying the presence of large targets (hail) aloft. As a result, VIL is used to identify thunderstorms that likely contain large hail and/or a deep layer of large drop sizes (http://www.crh.noaa.gov/lmk/?n=vil_density).

Episode Description

In order to evaluate the hail algorithms for our region, 32 hail events have been analyzed, here, we focus on 19 Sep 2009 hail event. In radar image is possible to appreciate the initiation of convective activity from 10:00 at the center part of the study area, those convective cells developed with a slightly east displacement later on (not showed). Figure 3 shows ZHail product (probability of the occurrence of hail) in Tehran radar coverage on 10:30 UTC 19 Sep 2009. (A), (B) and (C) convective systems are apparent in ZHail product field. The convective systems have maximum reflectivity up to 70 dBz and accompanied with hail event. (A) Locate in North-West of Tehran station (Mehrabad) in 5.45 km distance from radar with latitude 35.80°N and longitude 50.68°E and probability of hail event for (A) system was calculated 100% by hail algorithm at onset time. (B) system locate in west of Tehran station in 18.4 km distance from radar with latitude 35.64°N and longitude 50.96°E. The probability of the occurrence of hail for (B) system was 59.84%.

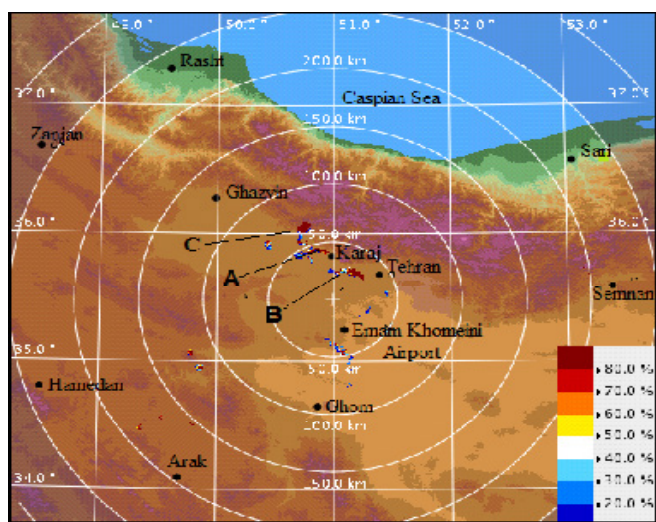


Figure 3: ZHail product for 10:30 UTC, 19-Sep-2009 at Tehran radar coverage, A, B and C are convective systems with high probability of the hail occurrence.

(A) and (B) systems move to East during 30 minute later (Figure 3). At 10:30 UTC, the probability of hail occurrence hasn't changed for (A) cell but for (B) system increases about 100%. Increases in probability of hail indicate that (B) system develop during 30 minute. (A) moved to northeastern and (B) system moved to East and located in Tehran station in 10:45 UTC (not showed). Exactly in this time, radar hail algorithm calculated 100% probability of the occurrence of hail for (B) system and also Tehran station reported hail occurrence.

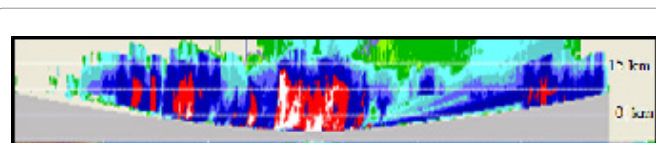


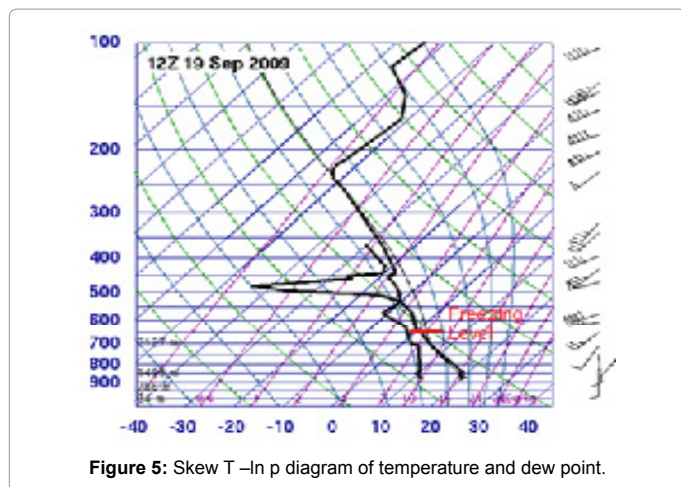
Figure 4: RHI product of Maximum Reflectivity (dBZ) for 10:30 UTC 19-Sep-2009 at Tehran radar coverage. The vertical growth of convective systems extended near to tropopause about 11 km.

The ECHOTOP values of 15 dBz surpassed the 11 km height near tropopause level. With such a vertical extension, heavy showers, wind gust and electrical activity are observed. The largest vertical extension for this Multi-cell thunderstorm occurs around 10:30 UTC. In the RHI product (Figure 4), can be appreciated the vertical homogeneity of reflectivity values in vertical, with values around 45 dBz from surface to more than 3 km, as usual in storm environment with hail presence. In the Zhail products set, we can see Multi-cell thunderstorm with more than 80% probability of hail presence over the area. During 30 minute the convective cells over study area presents an extended area of hail probability, hail probability increases as storms go through the east.

H_0 is the height of freezing level. It is evident from Figure 2 [6], when the 45 dBZ reflectivity Max height extends to 1.4 km or more above the freezing level, the presence of hail is likely, and the probability of the presence of hail increases with increasing height of this reflectivity core above the freezing level.

In the current NEXRAD hail detection algorithm, the maximum height of 45 dBZ reflectivity above the freezing level is converted to a probability. The ZHAIL product gives a probability of the occurrence of hail. The ZHAIL product is based on reflectivity data of a Three-Dimensional scan. It analyses the vertical reflectivity structure above

Freezing level was calculated 3.5 km from Skew-T diagram on 12z 19 Sep 2009 at Tehran station (Figure 5). According to diagram Humidity deficit is near to zero for 525 mb and 450 mb levels and



show humid weather condition. Difference between the height of 45 dBZ reflectivity (7.8 km) and freezing level was calculated about 4.3 km for this case. Based on Waldvogel algorithm the presence of hail is likely when 45 dBZ reflectivity extends to 1.4 km above the freezing level reflectivity. This result agrees with Waldvogel criterion.

Figure 6 shows relation of probability of hail (ZHail) with height difference between freezing and 45 dBZ reflectivity Max height. The probability of the presence of hail increases with increasing height of 45 dBZ reflectivity above the freezing level.

Figure 7 shows the VIL product for 10:30 UTC 19-Sep-2009 at Tehran radar coverage. According to this Figure, three convective cells (A, B and C) have VIL more than 9.6 mm. VIL product in radar is equal to precipitation water of cloud (PW) parameter. The increase in age and thickness of cloud lead to increase in PW. The threshold of PW for cloud is 9 mm for our area and less than this value; the probability of rainfall in the cloud is very low [7].

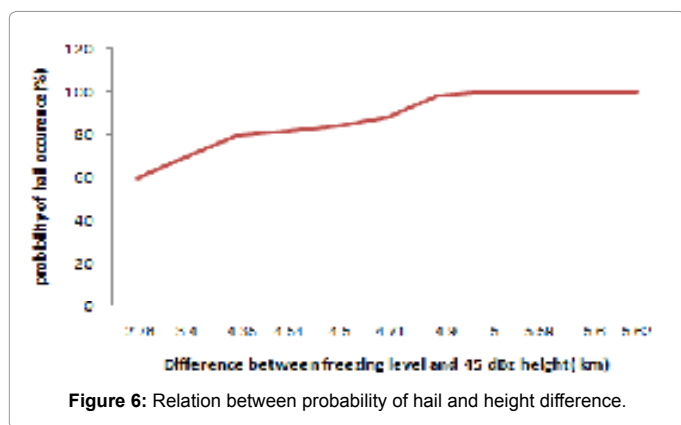
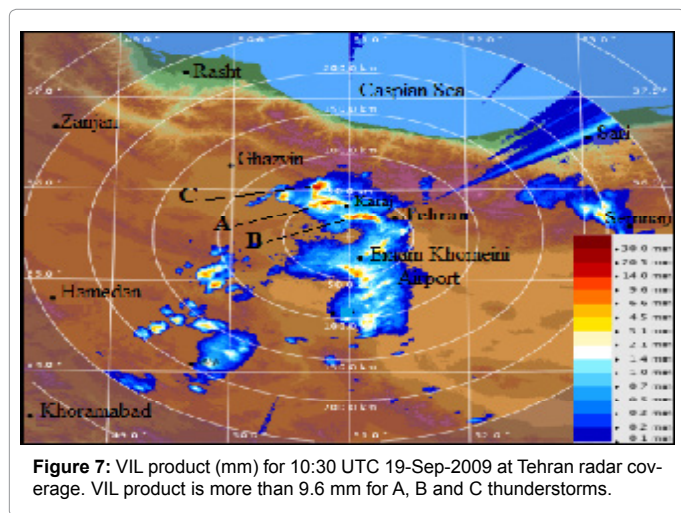


Table 1 lists location, Time, distance and also radar products (Etop 45dBz, ZHail and VIL) for Tehran hail events (A and B). Calculated VIL values for above mention case (A and B systems) has shown in last column in table 1. Increased the value of VIL, the probability of hail (ZHail) is also increasing. Analysis of 32 hail events shows that probability of hail will be %100 when VIL Value is more than 10 mm.

Conclusions

Two different methods for the detection of hail by using radar data have been verified. In the first method, PHD is determine based on difference between the detection of 45 dBZ Reflectivity Max height and Freezing level. According to results, PHD increases with ascending of 45-dBz Maxheight over the freezing level. The results show that for height difference greater than 5 km, PHD is 100% for our region. This value is bigger than waldwogle criterion because it shows 100% probability of hail occurrence. This value depending on warm and cold climate can be varied up to 1 km and in the cold regions is more than the warm region. The result consistent well with the result of the others works. A height difference of 6.0 km corresponds to 100% probability of hail [8].



In the second method, we used vertically integrated liquid water to find a threshold for issuing hail warnings. A high value of VIL correlates well with the occurrence of severe thunderstorm and hail. Base on the results, we consider thresholds for VIL about 10 mm. Holleman [9] calculated warning threshold for VIL about 15 mm. The warning threshold is different because we use various regions with different climates for calculation of VIL due to lack of information. In the coming years with increasing radar network data can be obtained more accurate value for a particular area.

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System	Time	Latitude	Longitude	Distance from radar (km)	Azimuth angle	Freezing Level (km)	Etop 45 dBz (km)	Zhail (%)	Vil (mm)
A	10:15	35.8	50.68	45.5	320.4	3.5	9.09	100	10.55
	10:30	35.7	51.16	28.8	33.7	3.5	7.85	100	8.27
	10:45	35.77	51.37	42	50.6	3.5	8.21	100	27.26
B	10:15	35.64	50.96	18.4	347.5	3.5	6.26	59.84	6.68
	10:30	35.06	50.79	64.7	338.1	3.5	9.09	100	20.49
	10:45	35.73	51.44	49.1	56.6	3.5	2.01	13.24	1.55

Table 1: Time and location of hail events and radar product for Tehran station.

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