Convective cloud characteristics for the Bethlehem area

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Abstract

During the summer months the Enterprise radar situated at Bethlehem is operated in volume scan mode. Calculated characteristics such as storm lifetimes, storm first echoes as function of time, areal distribution, direction of movement and radar echo properties as a function of merging are presented.

Introduction

This study was performed as part of the Bethlehem precipitation research project (BPRP). The BPRP area is defined as the region within a circle of 100 km radius around the town of Bethlehem in the Orange Free State of the Republic of South Africa. Bethlehem, situated at 28°S and 28°E, is located on the eastern portion of the interior plateau of southern Africa referred to as the Highveld region, at an elevation of 1 687 m above sea level.

The northern and western parts of the region consist of rolling country-side with a gradual rise in elevation from west to east. To the south of Bethlehem towards Lesotho the land rises more sharply as the mountain ranges of the Rooiberge and the Witteberge are approached. To the south-east there is a sharp rise in terrain, reaching a maximum elevation of over 3 000 m at some of the mountain peaks in the Drakensberg mountain range. This mountain range runs north-south along the eastern border of the area, beyond which there is a rapid fall in elevation towards the east, and also forms the escarpment between the interior plateau and the Indian Ocean. The topography of the area, which sometimes plays an important role in the initiation and maintenance of convective development, is displayed in Fig. 1.

Approximately 85% of the annual precipitation falls during the summer months, mainly due to convective activity, although occasional prolonged periods of rain also occur.

Storm climatological studies using radar echo data of thunderstorms in the Highveld region with the emphasis on the characteristics of thunderstorms that produce hail have previously been reported by Held (1974), Carte and Held (1978), Carte (1981) and Mader *et al.* (1985) for the Transvaal Highveld.

The purpose of this study is to provide background knowledge of the general and typical cloud development in the north-eastern Orange Free State, against which the hypothesised effects of rainfall stimulation studies can be assessed. This paper presents the information on radar storm characteristics of cloud development in the Bethlehem region for the period November 1988 to February 1989. Only days with convective cloud development were considered.

Data collection

The radar employed at Bethlehem is a 5,3 cm, C-band radar. The characteristics of the radar are summarised in Table 1. The antenna was operated in a step-scan mode with 0,7° steps from 1,1 to 20° elevation with a rotational speed of 6 rpm (revolutions per minute), completing one volume scan in approximately 5 min. This provided a vertical resolution of 1,2 km at a range of 100 km. The returned radar signal was digitised and recorded on magnetic tape for further processing. The horizontal resolution was 1 km along the radials. The azimuthal resolution was 1,0°, which is 1,7 km at the range of 100 km. The radar system is stable to within 1 dB from day to day. A calibration routine as described by Schroeder and Klazura (1978) was used and calibrations were recorded daily.

Radar storms were identified and tracked from composite B-scan reflectivity maps (Schroeder and Klazura, 1978; Brady *et al.*, 1980) which were created from the digitally recorded radar data, and storm properties were subsequently determined from the three-dimensional reflectivity array. Storm echo properties were calculated for all echoes that appeared between 20 and 120 km from the radar. Statistical outputs for each property were produced using a statistical software package developed by Nie *et al.* (1975). The following properties were determined for all the storm echoes:

- Average number of storms per day
- Storm lifetimes
- Storm speeds and direction of movement
- First echo heights
- Storm vertical depths
- Storm maximum growth rates
- Areas of development
- Storm merging

Radar data on 33 days between October 1988 and March 1989 were analysed for the purpose of this study.

Results

A general overview of the different storm properties is presented

TABLE 1
CHARACTERISTICS OF THE ENTERPRISE RADAR AT BETHLEHEM

Frequency	5,635 GHz
Wavelength	5,32 cm
Peak power	250 kW
Pulse duration	1,95 μs
Pulse repetition frequency	250 s^{-1}
Minimum detectable signal	-103 dBm(5dBz at 100 km)
Beam width	1,0 (all plains)
Antenna gain	44,05 dB

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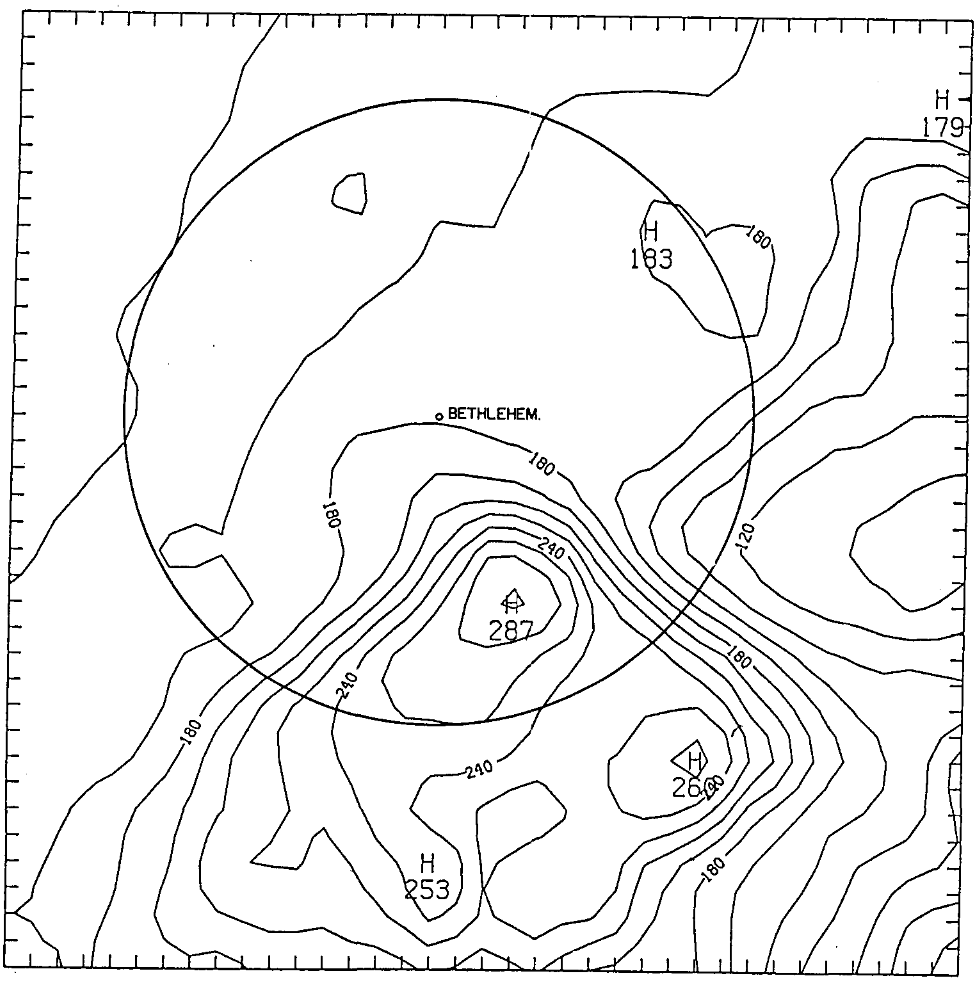

Figure 1
Topographical map of the Bethlehem area. Contours in decameters.

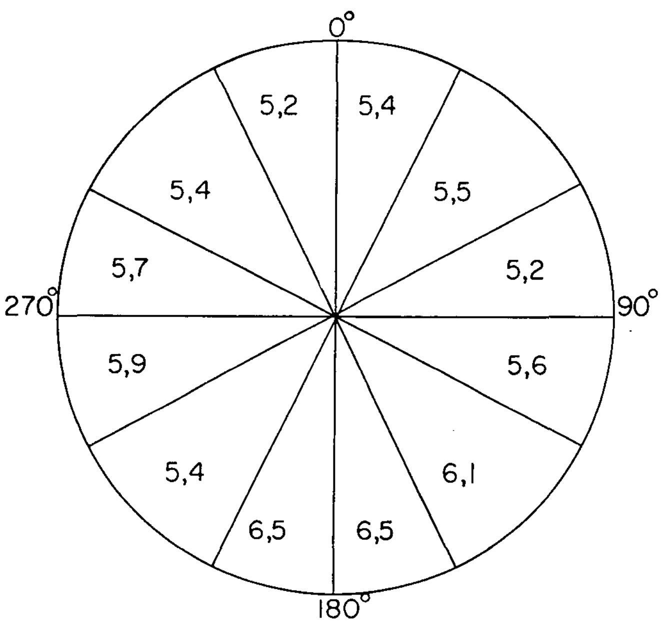

Figure 2
Mean first echo heights (km) for different sectors.

in Table 2. The data sample consisted of a total number of 3 345 echoes.

Only echoes which were identified for at least two volume scans were incorporated into the sample. This was done to exclude any spurious or radar noise returns which only appeared on one volume scan. An echo was accepted into the data sample when the radar reflectivity factor was greater than 10 dBz. The radar was operated daily from 08:00 to 20:00 SAST (South African Standard Time).

The average number of storms observed during one day was 101 while the average number of storms with a lifetime of more than one hour was 10 per day. The storms generally tended to move with the mid-level winds. The averages for the first echo height, maximum cloud depth, and the maximum growth rate were 5,8 km MSL, and 4,2 km, and 3,9 m/s respectively.

Fig. 2 displays the average first echo heights for 12 different sectors around Bethlehem. The lowest first echo heights were encountered in the northern sectors while an increase in first echo height was evident in the southern and south-western sectors, which might be due to the higher terrain elevations towards the south and south-west of Bethlehem providing additional forcing. A different forcing mechanism might be operating in these sectors compared to the rest of the area.

The diurnal distribution of first echo development for each hour is shown in Fig. 3. The distribution indicates that 80% of the echoes developed after 13:00 SAST, while approximately 50% of

TABLE 2 AVERAGE RADAR ECHO CHARACTERISTICS	
Number of days for data sample	33
Total number of echoes	3 345
Average number of echoes per day	101
Average number of echoes living > 1 hour per day	10
Mean echo lifetime (min)	38,4
Mean average echo speed (km/h)	30,6
Average height of first echoes (km) MSL	5,8
Average maximum vertical cloud depth (km)	4,2
Average maximum echo top growth rate (m/s)	3,9

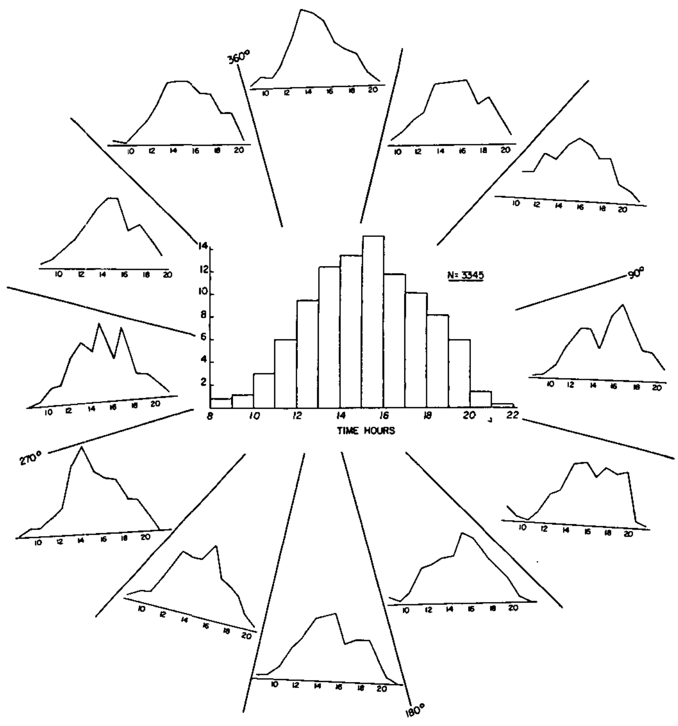

Figure 3
Diurnal distribution of first echo development (inner diagram) and diurnal distribution of first echoes for different sectors.

the echoes developed between 13:00 and 17:00 with a peak between 14:00 and 16:00. This again emphasises the major influence of surface heating in the onset of convection in the BPRP area. In a study by Harangozo (1986) on the diurnal distribution of rainfall for the same area a peak in rainfall at the surface was found between 17:00 and 18:00. This agrees well with the present study if one allows for the fact that time is needed for storms to develop to higher intensity levels before rainfall at the surface is produced and for storms to develop into larger complexes which ultimately produce the bulk of the rainfall.

The diurnal distribution of first echo development for the different sectors in the BPRP area is also displayed in Fig. 3. It is evident from this figure that the diurnal distribution in areas where the terrain is fairly flat shows a pronounced peak in first echo development while for the higher terrain to the south of Bethlehem two or more peaks are found. In this area the topography combined with the surface heating acts as a trigger mechanism for the onset of cumulus development.

To determine whether any preferred areas of storm development were present the percentages of storms that developed in each sector were calculated. The results are shown in Fig. 4. The highest percentage of storms occurred again in the mountainous areas.

A histogram of the frequency of storm lifetimes is displayed in Fig. 5. It is evident that the majority of storms only lived for a short period while ~ 55% of storms lived longer than 20 min. These results are somewhat different to those found by Lopez *et al.* (1984) for Florida clouds. In the Florida case 90% of the storms lasted less than 20 min; however, they also incorporated clouds within the first volume scan.

The direction of movement of the storms was another property that was determined. The results are shown in Fig. 6. The majority of storms moved from the west to the east with storms rarely moving from east to west. Similar results were found by Kelbe (1984) for the Nelspruit area, while results for the Transvaal Highveld by Mader *et al.* (1985) show a greater tendency for movement from the south-west. However, the results of Mader *et al* (1985) were primarily for more intense storms.

Finally, several properties as a function of merging were calculated. Merging occurs when two or more storms, initially not linked at the 10 dBz level, merge together to form one storm echo. The results are presented in Table 3. It is clearly evident that when more storms merged, storm lifetime, maximum vertical depth, maximum height, average growth rate, and the maximum growth rate all increased resulting in a larger, more intense storm.

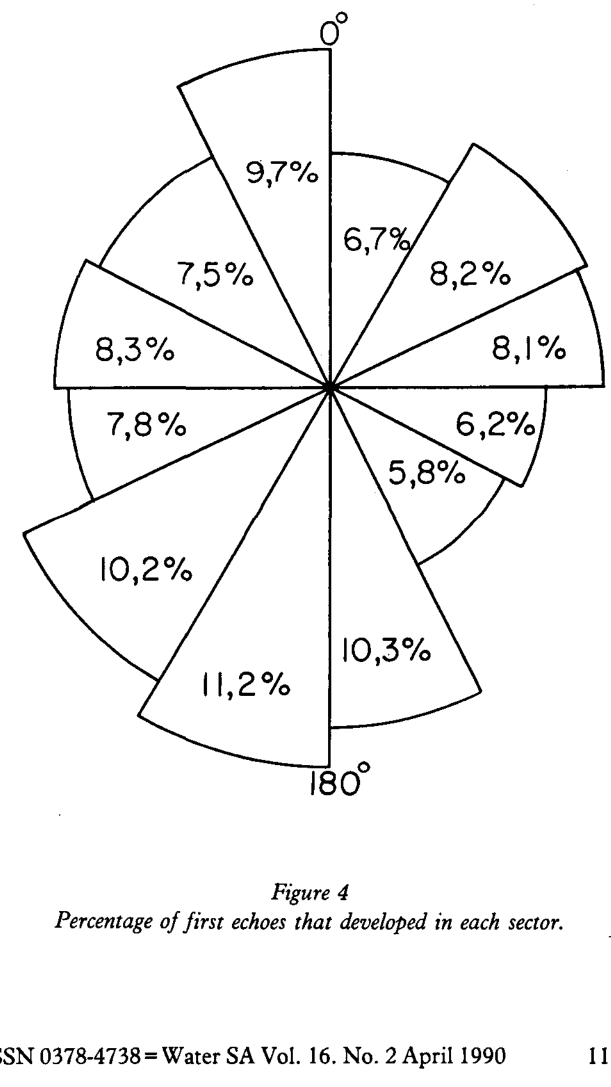

Figure 4
Percentage of first echoes that developed in each sector.

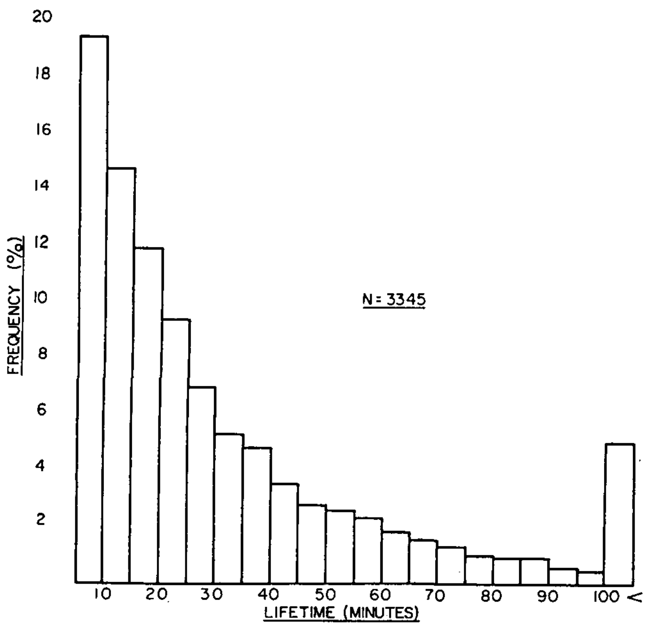

Figure 5
Frequency distribution of storm lifetimes.

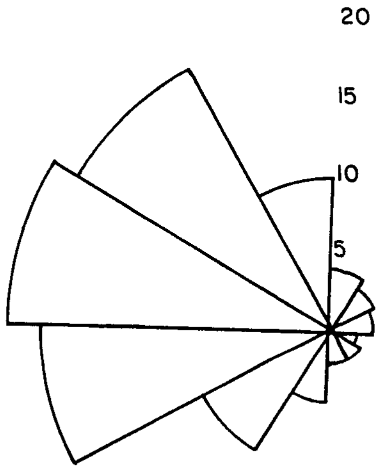

Figure 6
Direction of movement of storms.

It is important to note that the storms that merged could also be new growth on the side of the already existing larger thunderstorm.

Conclusions

Using radar data storm characteristics of convective cloud development indicated that a relatively large storm population exists on most days. However, the majority of these storms have short lifetimes which makes them inefficient rain-producing systems.

Surface heating and topography seem to be the primary triggering mechanisms for Highveld thunderstorms. First echo heights tended to vary with terrain height which is possibly related to the additional forcing in mountainous areas.

In general storms tended to move from west to east predominantly with the mid-level (500 hPa) winds. The development of more intense longer lived storms was related to the amount of storms merging in an already existing storm. This demonstrates the importance of mesoscale organisation.

This study provides a background for future studies of the general and typical cloud development in the Highveld region. Future studies will concentrate on understanding the mechanisms of merging thunderstorms.

TABLE 3
MEAN ECHO PROPERTIES AS A FUNCTION OF THE NUMBER OF ECHOES MERGING WITH A PARTICULAR ECHO

Number of mergers	Echo life-time (min)	First echo height (km)	Max. depth (km)	Avg. speed (m/s)	Max. height (km)	Max. growth rate (m/s)
0	25,3	5,8	3,3	7,9	8,0	3,2
1-10	38,4	5,8	4,2	8,5	8,8	3,9
>10	221,9	5,6	11,7	9,7	15,3	8,4
>20	263,4	5,3	13,0	9,9	16,5	9,9
>30	317,0	5,4	14,4	9,9	17,8	10,4

References

BRADY, PJ, SCROEDER, MJ and BRUENI, LJ (1980) Final Report Contract Number 14-06-D-7581, Office of Atmospheric Resources Management Bureau of Reclamation, Denver, Colorado.

CARTE, AE, and HELD, G (1978) Variability of hailstorms on the South African Plateau. *J. Appl. Met.* **17** 365.

CARTE, AE (1981) Morphology of persistent storms in the Transvaal on 16/17 October 1978. *Beiträge Atmos. Phys.* **54** 86.

HARANGOZO, SA (1986) The diurnal variation in summer rainfall in South Africa. *Proc. Second Int. Conf. on Southern Hemisphere Meteorology,* New Zealand.

HELD, G (1974) Hail frequency in the Pretoria-Witwatersrand area during 1962 to 1972. *Pure Appl. Geophys.* **112** 765.

KELBE, BE (1984) Cumulus cloud characteristics of the eastern Transvaal Lowveld. *Water SA* **10** 81.

LOPEZ, RE, BLANCHARD, DO, ROSENFELD, D and CASEY, MJ (1984) Population characteristics, development processes and structure of radar echoes in South Florida. *Mon. Weath. Rew.* **112** 1.

MADER, GN, NEISHLOS, H, SAUNDERS, MW and CARTE, AE (1985) Some characteristics of storms on the Transvaal Highveld. *J. of Clim.* **6** 173-182.

NIE, NH, HULL, EH, JENKINS, JG, STEINBRENNER, K and BENT, DH (1975) *Statistical Package for the Social Sciences,* 2nd edn. McGraw-Hill. 675 pp.

SCHROEDER, MJ and KLAZURA, GE (1978) Computer processing of digital radar data gathered during HIPLEX *J. Appl. Met.* **17** 498-508.