MAUSAM, **65**, 1 (January 2014), 93-98

551.501.81 : 551.58

Sector wise echoes study and climatology around Jaisalmer

B. N. VISHNOI

India Meteorological Department, Weather Radar Station, Jaisalmer - 345001

(*Received 7 March 2012, Modified 29 April 2013*)

e mail : bn.vishnoi@imd.gov.in

सार – गर्ज वाले मेघ और वर्षा को देखने की क्षमता के अद्वितीय गुणों के कारण मौसम रेडार सुदूर वायुमंडल का सर्वेक्षण करने का अद्भुत साधन बन गया है। रेडार के प्रभावी संसूचन रेंज में वास्तविक समय में तूफानों के गुजरने के साथ विभिन्न अवधि और तीव्रता वाले वर्षा क्षेत्र का मानचित्रण करने के लिए पल्स्ड रेडार तकनीक का सफलतापूर्वक उपयोग किया गया है। रेडार की निगरानी के अंतर्गत आने वाले क्षेत्र में तूफानों के आने और भारी वर्षा की चेतावनी देने के लिए मौसम पूर्वानुमानकर्ता के लिए रेडार एक अच्छा उपकरण हैं जिससे तूफान से होने वाले नुकसान को कम किया जा सकता है जबकि जल संसाधन प्रबंधन जैसे उनसे उपयोग को जारी रखा जा सकता है। इस शोध पत्र में रेडार प्रतिध्वनियों की आवृत्तियों का जैसेलमेर के आसपास के 200 कि. मी. क्षेत्र में विस्तृत अध्ययन करने का कार्य किया गया है और इसे चार समान सेक्टरों जैसे सैक्टर–1 (उ.प., 270°–360°), सैक्टर–2 (उ.प., 0°–90°), सैक्टर–3 (द. प. 90°–180°) तथा सैक्टर–4 (उ.प.,180°–270°) में विभाजित किया गया है। इसमें 19 अप्रैल, 1993 से 31 दिसम्बर, 2010 तक की अवधि के कुल 28918 प्रतिध्वनियों का अध्ययन किया गया। सैक्टर–1 में 5441 (18.8%), सैक्टर–2 में 9554 (33.0%), सैक्टर–3 में 9479 (32.8%), सैक्टर –4 में 4444 (15.8%), प्रतिध्वनियों का विश्लेषण किया गया। रेडार प्रतिध्वनियों को माहवार भी वर्गीकृत किया गया और दिसम्बर माह में 0.4%, नवम्बर में 0.5%, अक्तूबर और मार्च में 1.6% तथा जनवरी और फरवरी में 2.0% न्यूनतम वार्षिक औसत प्रतिध्वनि प्रेक्षित की गई। प्रतिध्वनियों की उच्चतम वार्षिक औसत संख्या जुलाई में 30.1%, इसके बाद अगस्त में 24.6%, जून में 17.2%, मई में 8.3% अप्रैल में 6.3% और सितम्बर में 5.8% प्रेक्षित की गई। ऊँचाई के अनुसार भी रेडार की प्रतिध्वनियों का विश्लेषण इस शोध पत्र में किया गया है और सभी चारों सेक्टरों 3 कि. मी. की ऊँचाई पर प्रतिध्वनियों की उच्चतम संख्या 29% रही और 16 कि. मी. की ऊँचाई पर न्यूनतम संख्या 0.2% रही।

ABSTRACT. The capability of Weather Radar to see through the thunder clouds and rain has made it a unique observation tool for remotely surveying the atmosphere. Pulsed radar technique has been applied with remarkable success to map the rain field of various duration and intensities along with movement of storms in real time within the effective detection range of radar. It is a very good tool for forecaster to provide better warning for impending storms and heavy rainfall over the area under radar surveillance and thereby losses due to storm can be minimized while their benefits can be continued like water resource management. In the present work attention has been focused on conducting a comprehensive study of frequencies of occurrence of echoes around Jaisalmer up to 200 km from radar site and the surrounding of it has divided into four equal sectors, *i.e*., sector-1 (NW, 270°-360°) , sector-2 (NE, 0°-90°) , sector-3 (SE, 90°-180°) and sector-4 (SW, 180°-270°). Total number of echoes under the study was 28918 for the period from 19th April, 1993 to 31st December, 2010. Total number of echoes analyzed in Sector-1, were 5441(18.8%), in sector-2, number of echoes analyzed were 9554(33.0%), in sector-3, number of echoes analyzed were 9479 (32.8%) and in sector-4, number of echoes analyzed were 4444(15.4%). Radar echoes to be classified month-wise and the lowest number of average echoes observed in the month of December was 0.4%, in the month of November 0.5%, in October and March 1.6% and in the month of January and February 2.0% .The highest number of annual average echoes observed in the month of July was 30.1% followed by August 24.6%, June 17.2%, May 8.3%, April 6.3% and September 5.8%. Height wise echoes analyzed and the highest number of echoes found for 3 km in all the four sectors were 29.0% and the lowest were for 16 km as 0.2%.

Key words – Thunderstorm, Mesoscale, Frequency, Echoes, Sectors, Convective.

1. Introduction

The capability of microwaves to penetrate clouds and rain has placed the weather radar in an unchallenged position for remotely surveying the atmosphere. The radar is the best remote sensing instrument that can detect heavy rainfall region veiled by clouds. Pulsed radar technique has been applied with remarkable success to map rain field of various duration and intensities along with movement of storms. Such observations should normally enable weather forecaster to provide severe weather warning and researchers to understand the life cycle and dynamics of storm. The tropical land region of the earth is well understood as a central player in the convective overturn of the atmosphere (Riehl & Malkus, 1958). Thunderstorm being one of the main agencies of energy exchange in the atmosphere and also being the potential source of precipitation on the surface of the earth. The juxtaposition of the land and sea to the south of India and the expanse of the hot and humid land surface to the north, are well suited for the large scale development of thunderstorms over India (Manohar and Kesarkar, 2003). These circumstances produce a valuable data base to scientific community to carry out studies of frequencies of thunderstorms at regular intervals over India. Thunderstorm is a meso scale weather phenomenon which develops due to convective activity on the surface of earth and lower level of atmosphere. The hot and humid weather is conducive for development of thunderstorm in any region. Also strong wind and vertical wind shear in the middle and upper troposphere are considered essential for growth of thunderstorms (Choudhary & Mazumdar, 1983; Sharma & Srivastava, 2009).

Thunderstorm is a severe weather that leads to severe floods, strong winds, hail, lightning strikes, destruction of property and even loss of life. Thunderstorms are one of the most spectacular weather phenomena offered by nature. Thunderstorms pose serious hazard to aviation as well as some of other activities such as transportation, agriculture, construction, communication, power transmission etc. Though this meso-scale phenomenon may occur at any time and over any part of the country at any time of the year, they are most severe over northwest India during pre-monsoon season. Early detection and forecasting of thunderstorm is important in safeguarding and prevention of damages, resulting from these violent thunderstorms. During summer season common man looks at the majestic and towering thundery cumulonimbus clouds with a hope, to provide relief from scorching heat, while farmers welcome thunderstorms for rain and consequent benefits. The aviator dreads at and tries to keep away from it, as thunderstorm is a well known hazard to aviation and a large percentage of weather related aircraft accidents have been due to thunderstorms. Knowledge of thunderstorm with respect to its frequency of occurrence, intensity, diurnal variation and duration is essential particularly in the interest of safe air navigation and other human activities that are affected by these weather phenomena.

2. Echo duration

Echoes study by Chatterjee and Prakash (1990) out of the total 55 echo cases studied in Delhi region in the two seasons, their life period were limited to less than one hour in about 90% cases, with a mean duration of 38 minutes. Mean duration of convective echoes found around Delhi comparatively higher than that found by Battan (1953) for echoes studied in USA (*i.e.*, 23 minutes). However a study of the duration of convective echoes by Blackmer (1955) yielded a mean duration of 42 minutes which compare well with the mean duration reported by Chatterjee and Prakash (1990). During pre-monsoon, duration of the convective echoes were found to vary between 14 and 83 minutes (Manohar and Kesarkar, 2004). As it has assumed that average life period of echo is less than 60 minutes, for this radar once echo reported, next observation used to take after one hour, in this way we can assume that after successive hours, the development of a new echo is taking place.

3. Data and methodology

In the present work attention has been focused on conducting a comprehensive study of frequency of occurrence of echoes upto 200 km around Jaiaslmer. S-Band weather radar (Storm Radar) was commissioned and has been in operation since 19th April, 1993. This high power Bharat Electronics Limited (BEL) Ghaziabad, GRS-441 radar has been used for this study. The broad parameters of the radar set are as follows:

Wave length (λ) = 10 cm

Pulse length = 4 m sec

Frequency (f) = 2800 MHz

Pulse width = 2 μ sec

Peak power transmitted = 600 kW

Minimum detectable signal = -109 dBm

Average power = 300 W

Pulse repetition frequency = 250 Hz

Horizontal and vertical beam width = 1°

To start with author look into the data available to identify the sectors over a radius of 200 km around Jaisalmer in accordance with the trends of echoes concentration during winter (December, January and February), pre monsoon (March to May), monsoon (June to September) and post monsoon seasons. During winter season western disturbances approach with westerly wind at 700 hpa in monsoon season (June-Sept) the rainfall occurs mainly due to the system in easterlies, *i.e.*, monsoon trough, depression and low pressure area and upper air cyclonic circulation formation etc. In the present study the sector wise concentrations of radar echoes has been taken up. The movement of radar echoes around Jaisalmer for the period of 19th April, 1993 to 31st

December, 2010 has been taken up. The data used in present study about radar echoes are based on the radar reports. The data (Radar report in coded form is known as RAREP) within the radius of 200 km around Jaisalmer. From 19th April, 1993 to 31st December, 2010, continuous records of radar observations available with current weather radar reports register of weather radar station, Jaisalmer. Thus 18 years of records on radar for all seasons have been taken up, except the major break down period, *i.e.*, almost two years period, net observation period remains 16 years. Major break down period means radar could not be operated for more than two days (> 24 hrs). The radar display map has been divided into four major sectors, *i.e.*, sector-1 (NW, 270º-360º), sector -2 (NE, 0º-90º), sector-3 (SE, 90º-180º) and sector -4 (SW, 180º-270º). The echoes have been analyzed sector-wise as well as height after sorting. Total numbers of echoes under study have been summed up 28918. During the active weather season (1st April to 31st August) radar has been operated round the clock on every synoptic hours and once any echo/echoes observed during any synoptic radar observation, then hourly radar observation taken, beyond active weather (fair weather) also, radar operated at 0830 hrs during fair weather period and if any demand from any agency (Aviation use) then station operated the radar, in case echo/echoes reported, then hourly observations used to be taken until it dissipated completely, Radar echoes have been analyzed season wise and echoes observed for winter season (*i.e.*, December to February) were 1264 (4.6%), for pre-monsoon season (March-May) total echoes observed were 4694 (15.8%), for monsoon season (June-September) total echoed observed were 22492 (77.8%) and for post monsoon season (October-November) total echoes observed were 468 (1.6%) only. Radar reports collected from the station echoes register, analyzed and arranged the echoes according to the height and month-wise in a particular sectors, *i.e.*, sector-1 (NW, 270º-360º), in the similar way echoes analyzed and arranged for the rest of sectors, *i.e.*, sector-2 (NE, 0º-90º), sector-3 (SE, 90º-180º) and sector-4 (SW, 180º-270º).

4. Results and discussion

Sector-wise analyses : In sector-1 (NW) all the echoes have been arranged, according to height (3-16 km) and months (January-December). The lowest height of the echoes which this radar has detected is up to 3 km and maximum height detected by this radar during the above mentioned period has been 16 km. In sector-1, total number of echoes have been arranged and analyzed were 5441(18.8%). In sector-2 (NE), total number of echoes have been arranged and analyzed, were 9554 (33.0%). In sector-3 (SE), total number of echoes have been arranged and analyzed, were 9479 (32.8%) and in sector-4 (SW), total number of echoes have been arranged and analyzed, were 4444(15.4%). Sector-1, in the months of October, November, December, January, February, March and April the echoes percentage were very poor. Although in the months of December, January, February and March the echoes percentage were due to western disturbances and echoes height found maximum up to 7-8 km. Sector-2 & 3, in the month of April, May, June, July, August and September good amount of echoes observed up to 16 km height and in sector-4, very less percentage of echoes observed in the month of June, July and August up to 16 km. Echoes have been arranged and analyzed in all the four sectors month wise and in the month of January total number of echoes observed 569 (2.0%). February total number of echoes observed 583 (2.1%), March total number of echoes observed 453 (1.6%), April total number of echoes observed 1833 (6.3%), May total number of echoes observed 2408 (8.3%), June total number of echoes observed 4983 (17.2%), July total number of echoes observed 8703 (30.1%), August total number of echoes observed 7106 (24.6%), September total number of echoes observed 1700 (5.8%), October total number of echoes observed 332 (1.1%), November total number of echoes observed 136 (0.5%) and December total number of echoes observed 109 (0.4%). Month and sector-wise echoes study are as follows.

TABLE 1

Echoes analyzed for months and sectors in %

Months	Sec-1	Sec-2	Sec-3	Sec-4
Jan	0.87	0.62	0.28	0.19
Feb	0.89	0.63	0.27	0.21
Mar	0.65	0.40	0.33	0.17
Apr	1.28	2.24	1.86	0.95
May	1.49	2.80	2.62	1.41
Jun	2.67	6.55	5.93	2.08
Jul	5.35	9.84	9.94	4.93
Aug	4.26	7.56	8.61	4.14
Sep	1.00	1.82	2.19	0.86
Oct	0.13	0.30	0.48	0.23
Nov	0.07	0.12	0.16	0.11
Dec	0.12	0.13	0.08	0.04

4.1. *January to March*

Table 1, sector-1, is having highest concentration with echoes of 0.87%, and mostly due to the system approaching from West, *i.e.*, western disturbances. Sector-2 is having second highest concentration with echoes of 0.62% and again mostly due to western disturbances.

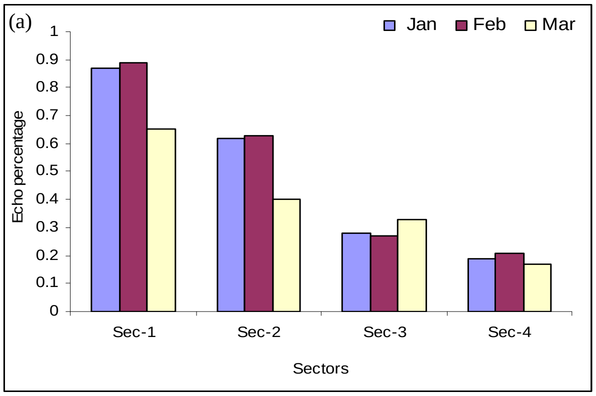

Fig. 1(a). Echo Percentage and sectors for Jan, Feb & Mar

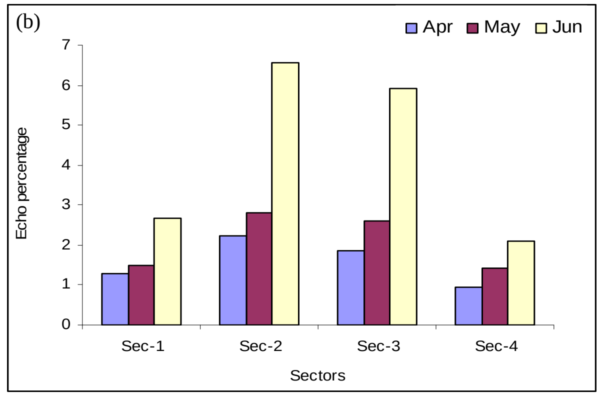

Fig. 1(b). Echo Percentage and sectors for Apr, May & Jun

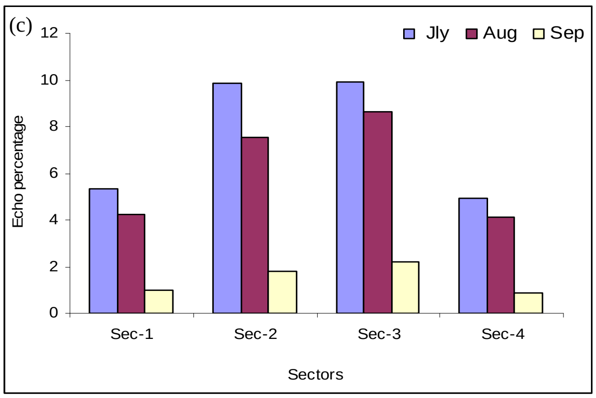

Fig. 1(c). Echo Percentage and sectors for Jul, Aug & Sep

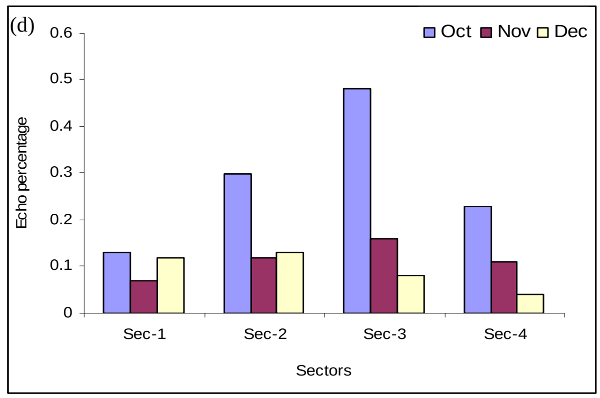

Fig. 1(d). Echo Percentage and sectors for Oct, Nov & Dec

Sector-3 is having echoes of 0.28% and sector-4 is showing the minimum echoes concentration as 0.19%, all the sector wise echoes for the month of January is shown in Fig. 1(a). Echoes for the month of February are shown in Fig. 1(a). In the month of February sector-1 is having the highest concentration of echoes with 0.89%, followed by the sector-2 with 0.63% echoes, sector-3 with 0.27% and sector-4 is showing 0.21%. Echoes for the month of March are shown in Fig. 1(a). In the month of March, sector-1 is having the highest concentration of echoes with 0.65%, sector-2 is showing slightly lesser concentration of echoes with 0.40%, sector-3 is showing further less concentration of echoes with 0.33% and sector-4 is showing the minimum concentration of echoes as 0.17%.

4.2. *April to June*

Fig. 1(b) is showing sector-wise study of echoes for the months of April to June. In the month of April, sector-1 is having the less concentration of echoes with 1.28%, sector-2 is showing the highest concentration of echoes with 2.24%, sector-3 is showing slightly less concentration of echoes with 1.86% and sector-4 is showing the minimum concentration of echoes as 0.95%. Echoes for the month of May are shown in Fig. 1(b). In the month of May which is the month of pre-monsoon, sector-1 is having the less concentration of echoes with 1.49%, but sector-2 is showing the highest concentration of echoes with 2.80%, sector-3 is showing slightly less concentration of echoes with 2.62% and sector-4 is showing the minimum concentration of echoes with 1.41%. Echoes for the month of June are shown in Fig. 1(b). In the month of June which is treated as beginning of monsoon season, sector-1 is having less concentration of echoes with 2.67%, sector-2 is showing the highest concentration of echoes with 6.55%, sector-3 is showing with slightly less concentration of echoes with 5.93% and sector-4 is showing the minimum concentration of echoes with 2.08%.

4.3. *July to September*

Fig. 1(c) is showing sector-wise study of echoes for the months of July to September. In the month of July which is peak monsoon and highest rain giving month, sector-1 is having less concentration of echoes with 5.35%, sector-2 is showing the highest concentration of echoes with 9.84%, sector-3 is showing slightly higher concentration of echoes with 9.94% and sector-4 is

TABLE 2

Echoes analyzed for height and sectors in %

Height	Sec-1	Sec-2	Sec-3	Sec-4
3 km	5.81	9.58	9.58	4.08
4 km	5.43	5.93	5.46	4.28
5 km	3.50	5.84	5.98	3.63
6 km	1.44	4.46	4.49	1.53
7 km	0.73	2.67	2.48	0.72
8 km	0.63	1.79	1.78	0.58
9 km	0.22	0.59	0.64	0.14
10 km	0.22	0.76	0.75	0.17
11 km	0.23	0.32	0.32	0.07
12 km	0.15	0.39	0.40	0.02
13 km	0.16	0.30	0.34	0.02
14 km	0.12	0.13	0.29	0.02
15 km	0.06	0.14	0.13	0.03
16 km	0.04	0.08	0.08	0.02

showing the minimum concentration of echoes with 4.94%. Echoes for the month of August are shown in Fig. 1(c). In the month of August which is the second peak monsoon and highest rain giving month, sector-1 is having less concentration of echoes with 4.26%, sector-2 is showing slightly higher concentration of echoes with 7.56%, sector-3 is showing the highest concentration of echoes with 8.61% and sector-4 is showing the minimum concentration of echoes with 4.14%. Echoes for the month of September are shown in Fig. 1(c). In the month of September which is the month of least and withdrawal of monsoon, sector-1 is showing the concentration of echoes with 1.0%, sector-2 is showing slightly higher concentration of echoes with 1.82%, sector-3 is showing the highest concentration of echoes with 2.19% and sector-4 is showing minimum concentration of echoes with 0.86%.

4.4. *October to December*

Fig. 1(d) is showing sector-wise study of echoes for the months of October to December. In the month of October which is the transition period between withdrawal of monsoon and beginning of winter had experienced some of the cyclonic activities, sector-1 is showing the minimum concentration of echoes with 0.13%, sector-2 is showing slightly higher concentration of echoes with 0.30%, sector-3 is showing the highest concentration of echoes with 0.48% and sector-4 is showing concentration of echoes with 0.23%.

Echoes for the month of November are shown in Fig. 1(d). In the month of November which is the beginning month of winter, sector-1 is having minimum concentration of echoes with 0.07%, sector-2 is showing slightly higher concentration of echoes with 0.12%, sector-3 is showing the highest concentration of echoes as 0.16% and sector-4 is showing concentration of echoes as 0.11%.

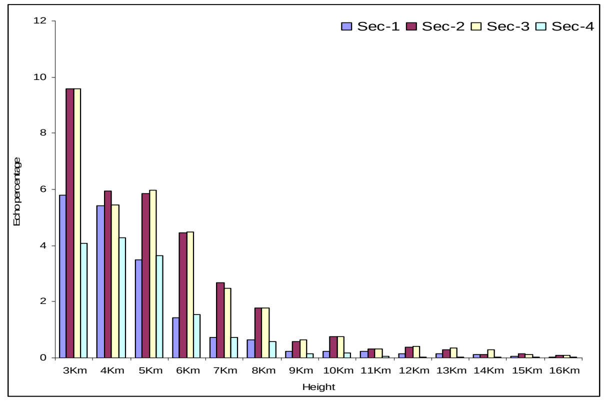

Fig.2. Echo Percentage and height for sector-1, sector-2, sector-3 & sector -4

Echoes for the month of December are shown in Fig. 1(d). In the month of December which is the beginning month of winter, sector-1 is showing the concentration of echoes with 0.12%, sector-2 is showing less concentration of echoes with 0.13%, sector-3 is showing slightly less concentration of echoes with 0.08% and sector-4 is showing the minimum concentration of echoes as 0.04%.

4.5. *Sector-1 (NW, 270º-360º)*

Further echoes having different height in a particular sector has been shown in Table 2, curves drawn between heights and sector-wise percentage of echoes. Fig. 2 is showing concentration of 18.8% of total echoes in sector-1 having different heights of 3 km to 16 km. The maximum concentration of echoes were 5.81% of 3 km, 5.43% of 4 km, 3.50% of 5 km, 1.44% of 6 km, 0.73% of 7 km, 0.63% of 8 km, 0.22% of 9 km, 0.24% of 10 km, 0.23% of 11 km, 0.15% of 12 km, 0.16% of 13 km, 0.12% of 14 km, 0.06% of 15 km and 0.04% of 16 km.

4.6. *Sector-2 (NE, 0º-90º)*

Fig. 2 is showing echoes in sector-2, having concentration of 33.0% of total echoes of different heights of 3 km to 16 km. The maximum concentration of echoes were 9.58% of 3 km, 5.93% of 4 km, 5.84% of 5 km, 4.46% of 6 km, 2.67% of 7 km, 1.79% of 8 km, 0.59% of 9 km, 0.76% of 10 km, 0.32% of 11 km, 0.39% of 12 km, 0.30% of 13 km, 0.13% of 14 km, 0.14% of 15 km and 0.08% of 16 km.

4.7. *Sector-3 (SE, 90º-180º)*

Fig. 2 is showing echoes in sector-3, having concentration of 32.8% of total echoes of different heights of 3 km to 16 km. The maximum concentration of echoes were 9.58% of 3 km, 5.46% of 4 km, 5.98% of 5 km, 4.49% of 6 km, 2.48% of 7 km, 1.78% of 8 km, 0.64% of 9 km, 0.75% of 10 km, 0.32% of 11 km, 0.40% of 12 km, 0.34% of 13 km, 0.29% of 14 km, 0.13% of 15 km and 0.08% of 16 km.

4.8. *Sector-4 (SW, 180º-270º)*

Fig. 2 is showing echoes in sector-4, having concentration of 15.4% of total echoes of different heights of 3 km to 16 km. The maximum concentration of echoes were 4.08% of 3 km, 4.28% of 4 km, 3.63% of 5 km, 1.53% of 6 km, 0.72% of 7 km, 0.58% of 8 km, 0.14% of 9 km, 0.17% of 10 km, 0.07% of 11 km, 0.02% of 12 km, 13 km and 14 km, 0.03% of 15 km and 0.02% of 16 km.

5. Conclusions

Early period of the monsoon season, *i.e.*, in the month of June and first half of July the formation of monsoon trough on an average every year is from Sriganganagar (Rajasthan) to Asansol (W.B.), but with progress of monsoon in the second half of July and August the formation of the monsoon trough is from Bikaner/Jaisalmer to central bay of Bengal, this is the reason that in sector-2 around Jaisalmer in the month of July, the maximum concentration of echoes found and later on as the trough position shift downward, average concentration of echoes in sector-3, in the month of August and September increases as compared to sector-2. The onset period of monsoon for Jaisalmer is 24-26 June and withdrawal of monsoon on an average is 10^{th} September every year. Sector-wise echoes study around 200 km of Jaisalmer gives an idea, in which particular month and sector the different type of echoes exist in its place. Total number of echoes observed for 16 years period was 28918.

In sector-1, echoes observed and analyzed were 5441 (18.8%), in sector-2, echoes observed and analyzed were 9554 (33.0%), sector-3, echoes observed and analyzed were 9479 (32.8%) and in sector-4, total number of echoes observed and analyzed were 4444 (15.4%). Sector-1, echoes observed, mostly due to approach of western disturbances, pre-monsoon and monsoon activity. Sector-2, echoes observed due to western disturbances, pre-monsoon and monsoon activity. Sector-3 echoes observed mostly due to pre-monsoon and monsoon activity and sector-4 is showing the minimum echoes activity due to western disturbances and mixed activity of monsoon. Radar echoes classified month-wise and the highest percentage of echoes in the month of July was 30.1% followed by August 24.6%, June 17.2%, May 8.3%, April 6.3%, September 5.8%, January and February 2.0%, March1.6%, October 1.1%, November 0.5% and lowest in month of December was 0.4%. Echoes have been analyzed according to height-wise starting from 3 km and maximum height of echoes detected up to 16 km. The highest percentage found of 3 km echoes in all the four sectors were 29.0% followed by 4 km of 21.0%, 5 km of 18.9%, 6 km of 11.9%, 7 km of 4.2%, 8 km of 4.8%, 9 km of 1.6%, 10 km of 1.9%, 11 and 12 km of 0.9%, 13 km of 0.8 %, 14 km of 0.6%, 15 km of 0.4% and the minimum 16 km of 0.2%.

Acknowledgements

Author is sincerely thankful to AVM (Dr.) Ajit Tyagi (Retired) Director General of Meteorology, India Meteorological Department, New Delhi and Dr. O. P. Singh, Dy. Director General of Meteorology, Regional Meteorological Centre, New Delhi for encouragement and interest in carrying out this research activity. Author is thankful to Shri Anand Nagar and Shri Kalu Ram Sharma, Scientific Assistant for collection of data and rendering help in carrying out the analysis work. Author is also thankful to the anonymous reviewer/referee for the valuable suggestions and comments to improve the paper.

References

Battan, L. J., 1953, "Duration of convective radar cloud units", *Bull. Amer. Met. Soc*., **34**, 227-228.

Blackmer, R. H., 1955, "The life time of small precipitation echoes", Proc, Fifth Weather Radar Conf., Fort Monmouth, N. J. signal Corps, Engineering Lab, 103-108.

Chatterjee, R. N. and Prakash, Prem, 1990, "Some aspect of convective clouds around Delhi", *Mausam*, **41**, 3, 475-482.

Choudhary, A. K. and Mazumdar, A. B., 1983, "Norwester and the synoptic climatology of hot weather season in northeast India", *Vayu Mandal*, **13**, 48-55.

Manohar, G. K. and Kesarkar, A. P., 2003,"Climatology of thunderstorm activity over Indian region : A study of East-West contrast", *Mausam*, **54**, 4, 819-828.

Manohar, G. K. and Kesarkar, A. P., 2004,"Climatology of thunderstorm activity over Indian region : II spatial distribution", *Mausam*, **55**, 31-40.

Riehl, H. and Malkus, J. S., 1958, "On the heat balance in the equatorial trough zone", *Geophysica*, **6**, 503-537.

Sharma, J. K. and Srivastava, K., 2009, "Thunderstorm activity around Ranchi Airport-A case study", *Mausam*, **60**, 2, 221-224.