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Some observations of Melting Band in Radar Precipitation Echoes at Poona

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1. Introduction

The melting band is a phenomenon frequently observed in radar echoes from widespread steady precipitation. It appears as a narrow band of intense echo in the vicinity of the 0°C level, separating a relatively steady echo obtained from the snow above the melting region and a rapidly fluctuating echo of often rather greater intensity from the rain below. It has also been observed in the dissipating stages of thunderstorms. The appearance of the melting band was first explained by Ryde (1946) to arise from the coalescence and melting of snowflakes near the 0°C level. Austin and Bemis (1950) and Browne (1952) have modified Ryde's theory to include factors such as the aggregation of snowflakes near the melting region, vertical draughts and variation of the radar pulse-length. Because of its great significance the melting band has been the subject of considerable research during recent years, but observations in tropical latitudes have been very meagre.

Melting band observations have been made at Poona both during the southwest monsoon (June to September) and during thunderstorms in the months preceding the monsoon (March to May) and following the monsoon (October to November). Some features of the radar observations at Poona have been summarised in two previous papers (Gupta, Mani and Venkiteshwaran 1955, Gupta and Venkiteshwaran 1958). The present paper deals with the observations of the melting band in the radar precipitation echoes at Poona during the years 1953—1955, and an attempt is made to examine the special features, if any, associated with the occurrences of these bands at Poona.

2. Equipment and Operational Procedure

The equipment used was a search radar, type 717C, operating on 9·1 cm, installed on the roof of the Meteorological Office, Poona. The peak power of the transmitter is approximately 40 KW, the pulse duration 1·125 μ secs and it has five ranges of 4, 10, 20 ,50 and 100 nautical miles. With this radar, a precipitation rate of 0·02 inch per hour can be expected to be just detected at a range of 10,000 feet (Day 1953), if it is assumed that the rain storm completely fills the radar beam and has a size distribution as given by Laws and Parsons (1943). Also drops of 1 mm diameter and a density of 100 drops per cubic metre would be just visible at the range of 10,000 feet; those of 0·5 mm diameter would be just visible at the same range, if their density were 10^4 drops per cubic metre.

The radar antenna which is a dipole-fed paraboloid, was mounted in the manner first adopted by Bowen and his collaborators (Day 1953) in Australia, *i.e.*, the radar beam scans a path from horizon to horizon through the zenith. This results in a representation in the cathode ray display unit, of a cross-section through the atmosphere about the point of observation. In this method of scanning, the range and height are maintained in true

TABLE 1

Summary of bright band measurements at Poona in different seasons

No.	Date	Time (IST)	Ht. of freezing level a.s.l. (ft)	Distance of bright band below freezing level (ft)	Ht. of bright band a.s.l. (ft)	Thickness of bright band (ft)	Lapse rate immediately below freezing level (°C/1000 ft)	Weather at time of observation
				(a) Pre-monsoon season				
1	22-3-55	1930	15100	2700	12400	3100	1·0	Light rain
2	23-3-55	1820	13500	1800	11700	2200	1·4	Drizzle
3	21-4-54	1920	15900	3800	12100	2800	2·3	Light rain
4	22-4-54	1850	17300	4700	12600	2900	2·8	Light drizzle
5	24-4-54	1340	15100	3900	11200	1800	1·8	Light drizzle
6	10-5-54	1640	16900	3900	13000	1800	1·8	Light drizzle
7	19-5-54	1720	17000	4000	13000	2500	2·7	Light drizzle
8	5-5-55	1900	15700	4100	11600	1100	3·0	No data
Mean			15800	3600	12200	2300	2·1	
				(b) Monsoon season				
1	5-6-54	1630	19200	4600	14600	3600	1·6	No data
2	6-6-54	2010	20200	5200	15000	2200	1·3	Drizzle
3	7-6-54	1750	18400	3200	15200	2000	1·6	Light rain
4	16-6-55	1650	16700	3200	13500	2500	1·3	Drizzle
5	28-6-55	1350	16600	2200	14400	1700	2·6	Drizzle
6	15-7-54	1600	17100	2400	14700	2500	1·3	Light rain
7	7-8-54	1620	19800	4800	15000	2200	1·3	Light drizzle
8	9-8-54	1620	18400	3500	14900	2100	1·8	Light rain
9	17-8-55	1140	16500	2100	14400	1800	1·3	Light rain
10	30-8-55	1630	18500	4100	14400	1800	1·4	Light rain
11	2-9-54	1150	17800	2800	15000	1700	1·8	Light rain
12	21-9-55	1430	15900	5500	12400	2200	1·3	Drizzle
13	22-9-55	1510	17300	3900	13400	3400	1·5	Light rain
Mean			17900	3700	14400	2300	1·5	
				(c) Post-monsoon season				
1	6-10-53	1740	16900	4600	12300	1100	1·0	Rain
2	7-10-53	1750	14500	2500	12000	1500	1·9	Light rain
3	18-10-54	1640	15300	1600	13700	3400	0·5	Light rain
4	24-10-55	1855	15000	2400	12600	1800	1·2	Rain
Mean			15400	2800	12700	1900	1·1	

proportion and easier interpretation of the rain echoes immediately above the point of observation is possible.

Austin and Bemis (1950) made measurements at Cambridge, U.S.A. with a TPS-10A radar operating on a wavelength of 3 cm with RHI (Range-Height-Indicator) presentation. With this radar they attempted to measure (1) the height of the centre of the bright band, (2) the vertical thickness of the bright band and (3) the radar reflectivity, in the bright band, above it and below it. From radiosonde ascents at stations in the vicinity, they obtained the heights of the freezing level and the lapse rate of temperature in a layer two or three thousand feet thick, just below the freezing level.

Because of the RHI presentation and the ground clutter at close range, Austin and Bemis found it difficult to make observations at ranges nearer than 10 miles. At this range, the apparent thickness of the bright band was often the same as the beam width. Therefore they could not measure the thickness of the bright band accurately. The bright bands studied were, therefore, divided into two groups —(1) those which appeared to be less than 1000 feet thick at a range of 10 miles and (2) those which seemed to be 1000 feet or more in thickness at 10 miles. They also rounded off the heights of the centre of the bright bands to the nearest 500 foot level, as a result of the uncertainty of the observations.

Hooper and Kippax (1950) used a vertically directed 3·2-cm radar to investigate the relationship between the heights of the melting band and the 0°C level being obtained from simultaneous radiosonde ascents. Browne (1952) used a similar arrangement to determine the height of the melting band below the 0°C level. Uncertainties due to the beam width present in the RHI presentation do not appear in their arrangement and in the mode of observation employed at Poona with the SCR-717 radar. Errors in the measurement of the heights of the melting band are comparatively small, where vertical scanning is used and where the distance of the band above the station is small and its height and thickness are greater than the pulse length in space of the radar. Difficulties in determining the melting layer depths with sufficient accuracy remain since inaccuracies in determining heights from radar and radiosonde data are of the order of 500 ft.

3. Analysis of Observational Data

Table 1 summarises the measurements of the bright band made at Poona on 25 days in different seasons during the years 1953 to 1955. The height of the freezing level and lapse rate below this level were obtained from the radiosonde ascents of the day, at Poona taken usually at about 2000 IST. The heights and thickness in Table 1 have been rounded off to the nearest 100 feet. The overall accuracy in the measurement of the thickness of the melting layer and the distance of the band below the 0°C level is of the order of $\pm$ 500 ft.

3·1. *Bright bands in thunderstorms and the variation of their heights with time*

At Poona, during the pre-monsoon months of March to May, and the post-monsoon months of October and November, rain mostly occurs in association with thunderstorms. During the monsoon period, June to September, thunder is rarely heard. The pre-monsoon period of thunderstorms is the hottest part of the year and the lapse rates in the lower layers are appreciably greater than those in other seasons.

As observed by Byers and Coons (1947) the bright band does not appear in thunderstorms during the developing phase, and are usually observed only during the dissipating stages. But in contrast to their observations the bright band was often observed at Poona for as long as three hours during the dissipating stages of thunderstorms. The bands were quite well-defined and the general thickness did not vary erratically. The variations were

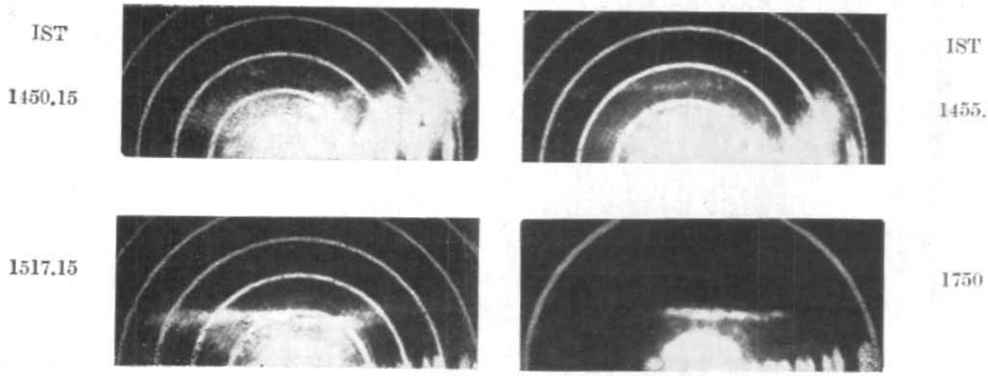

Fig. 1. Bright band on 7 October 1953

gradual, as could be visually observed. In Fig. 1, is shown a series of photographs of the radar echoes of a thunderstorm which occurred at Poona on 7 October 1953, showing the formation of a bright band during its dissipation stages. There was at first a stratification indicated in the radar echo at 1450 IST. A bright band formed later at a height of about 4·6 km a.s.l., and by 1511 IST it lowered to a height of about 3·8 km a.s.l., where it remained stationary till it disappeared at about 1810 IST. The rate of descent of the bright band from the level of the first formation to the level where it remained steady and dissipated, was of the order of about 2·5 km hr^{-1}. The freezing level on that day, as taken from the radiosonde ascent at about 2000 IST was about 4·4 km a.s.l.

While the height of the bright band remained almost steady during the monsoon season, the bright band associated with thunderstorms during the pre- and post-monsoon seasons, varied in height with time, on many occasions. They were generally higher in the initial stages, coming down to lower levels with time. In some cases the lowering was of the order of 1500 to 1000 feet; in others, smaller. According to Wexler (1955), the melting layer undergoes changes due to the effect of the melting precipitation on the air, in addition to larger scale synoptic conditions. The lowering of the melting layer due to cooling by melting snow has been discussed by Wexler, Reed and Honig (1954). The melting layer has also been frequently observed to rise due to the advection of warm air (Hooper and Kippax 1950). These changes are, however, generally relatively slow and the melting layer frequently remains at a constant height over a period of several hours; and the melting layer may be considered as a quasi-steady state, its depth depending on the lapse rate and on the sizes and fall velocities of the melting snow flakes (Wexler 1955).

3·2. *The thickness of the melting band and its freezing level*

In Table 1[(*a*), (*b*) and (*c*)] are given the heights of the "freezing level" and of the melting band above sea level, the thickness of the band and its distance below the freezing level, during the pre-monsoon, monsoon and post-monsoon seasons. The weather at the time of observation and the lapse rate immediately below the freezing level are also given. The mean thickness of the band is of the order of 2200 ft and its mean distance below the freezing level of the order of 3600 ft.

During the monsoon months (June to September), the mean height of the freezing level is higher than that in the pre-monsoon thunderstorm months (March to May), by about 2100 feet. The centre of the bright band is also higher in the monsoon months by almost the same amount, 2200 feet. The mean thickness of the bright band and its distance below the freezing level are, however, the same during the monsoon and pre-monsoon periods.

The depth of the melting zone, measured from the 0°C level, to where it merges into the rain echo below, corresponds to the distance through which the snow flakes will fall before melting and will therefore depend upon the lapse rate and on the sizes and fall velocities of the melting flakes. It should be greater for larger flakes and smaller lapse rates. Since the observations during both the periods from March to September show no variation either in the distance below the freezing level or the mean thickness of the bright band, one may infer that the size of snow flakes are similar. The lapse rates in the region below the freezing level were obtained at about 2000 IST, while the radar observations were made a few hours earlier. While this observed lapse rate may be considered to be representative of the conditions prevailing at the time of the bright band observations during the monsoon, this may not be so in the summer pre-monsoon thunderstorm season, since thunderstorms are short lived and even during the thunderstorm the conditions inside the cell may be very different from those outside. It is, therefore, not feasible to draw any inference on the effects of lapse rate measured during radiosonde ascents on the distance of the bright band below the freezing level, during the thunderstorm seasons.

The few observations in the post-monsoon month of October seem to indicate that both the mean thickness of the bright band and its distance below the freezing level are lower. This has, however, to be confirmed by more observations.

4. Discussion

Measurements designed to locate the height of the melting band relative to the 0°C level and to determine the vertical thickness have been made by Austin and Bemis (1950), Hooper and Kippax (1950), Browne (1952) and Mason (1955). The results of ten observations made by Hooper and Kippax gave the depth of the melting band below the freezing level to be 330±150 ft. They also reported the thickness of the bright band to be about 750 ft, which would indicate a melting depth of that order. Austin and Bemis found the average distance between the feeezing level and the peak of the bright band to be 830 ft but they admit errors of perhaps 500 ft in the location of this level and of the melting band. Since the thickness of the bright band was about 1000 ft, a melting layer of about 1300 ft is indicated. On one occasion with a vertically pointing radar with a $0{\cdot}5\mu$ sec pulse, the apparent thickness of the band was found to be about 500 ft. More recent measurements in Cambridge show a melting depth of 1500 ft accurate to within about 150 ft. Browne found the peak of the melting band to be 600±200 ft below the freezing level (but his observations included some cases of unsteady rain), and that in warm fronts the band was generally 300—400 ft thick. Mason analysing the records obtained by Browne for twelve further occasions of steady rain, found the depth of the melting zone to lie between 50 and 500 ft with a mean value of 225 ft. The corresponding value for Poona is about 4700 ft, a value 3 to 4 times that obtained by some of the earlier observers.

Rough calculations of the melting layer depth have been made by Austin and Bemis (1950), Atlas (1953) and Mason (1955). Assuming a snowflake aggregate of 5 mm radius falling with a velocity of 1 m/sec, with a resultant raindrop of 1 mm in radius, Austin and Bemis calculated the distance between the freezing level and the level at which the melting is complete (the bottom of the bright band), to be about 1200 ft. Mason calculated that a flake of mass 1 mg composed of dendritic crystals and falling through an atmosphere with lapse rate 6°C/km would melt completely after a fall of about 150 metres. Wexler (1955) has carried out more extensive calculations and determined theoretically the change in fall velocity of the melting snowflake and the depth of the melting layer in saturated air for different sizes of raindrops. He found that for a 3 mm drop, which may be considered as a maximum for continuous stratiform rain, the melting distances range from 800 to 1200 ft for a lapse rate of 6°C/km and 1050 to 1480 ft for 4°C/km. He also found that the melting depth for a snowflake in the shape of a disc to be 24 per cent higher than that of a sphere of the same mass, and attributes the greater melting depth to the smaller rate of diffusion of water vapour or heat to a disc than a sphere, and the greater rate of increase in the fall velocity of a disc, despite the fact that its fall velocity is initially less than that of the sphere.

As mentioned earlier, it is difficult to compare these theoretical melting layer depths with observations, due to the inaccuracies inherent in the radar and radiosonde measurements and lack of information of the drop size distribution. The results obtained by Hooper and Kippax indicate values of melting depth of the order of 900 ft and for normal lapse rates of 4—6°C/km, maximum drop diameter less than 2 mm, in agreement with the kind of rain common in England. Austin and Bemis obtained a melting layer depth of about 1300 ft and, for their average lapse rate of 5·5°C/km, indicate an aggregation of dendrites with maximum melted diameters between 2·5 and 3 mm. The values obtained at Poona are very much higher than what would be expected from Wexler's calculated values, but these are presumably due to the very much larger size of the snow flake aggregate.

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