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On the estimation of upper winds from satellite cloud pictures

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ABSTRACT. The direction of upper tropospheric flow was estimated from the cirrus plumes associated with *Cb* clouds seen on satellite television pictures. The estimated directions were compared with actual wind directions at the 300 and 200 mb, and also with the directions of the shear between winds at (a) 700 and 200 mb and (b) 500 and 200 mb. The results of the comparison are presented in this paper.

1. Introduction

Estimation of upper tropospheric winds is now possible with the help of meteorological satellite photographs. The method has been described in National Environmental Satellite Centre, U. S. A., Technical Memorandum No. 8, published in October 1968, and some simple rules have been suggested for the estimation of wind direction and wind speed based on satellite cloud pictures.

The estimation of winds from satellite pictures for operational use has not been undertaken in India so far. It is evident however, that such information will be useful for filling up the large data gaps in our observational net work, and in data sparse regions. This will be not only helpful in supplying upper wind data with greater confidence to aircraft along routes which lie almost entirely over ocean areas (such as the Bombay-Nairobi and Madras-Singapore routes); but will also help in the analysis of weather charts used for numerical weather prediction. Preliminary work on a few occasions suggests that an estimate of upper tropospheric winds using the APT pictures received at Bombay can be made with reasonable accuracy. Further, it was noticed that cloud structures which are highly useful for wind estimation like the *Cb* clouds, are generally plentiful in large data holes, like the north Indian Ocean.

2. Method

2.1. *Method of Evaluation* — It is well known that tops of large convective clouds are blown off when they penetrate to heights where strong winds are present. This gives the familiar anvil shaped form to these clouds. Such 'anvils' or cirrus plumes have characteristic features on satellite TV-pictures which make them easily recognisable. The general geometry of cloud tops is nearly egg-shaped. The broad end is regular, bright and solid looking, while the narrow end appears frayed, translucent and fibrous. Along the length, the brightness gradients are gradual, indicating that most of the cloud top is being drifted downstream, while the brightness gradients are strongest at the lateral edges. Therefore, the orientation of an egg shaped cloud gives an estimate of the wind direction at the cloud top level.

2.2. Fig. 1(a) gives an example of large *Cb* clusters with their tops getting blown off by winds. The schematic profile of a 'plume', as seen on a satellite TV-picture, is shown in Fig. 1(b). Fig. 1(c) is an APT picture received at Bombay of the north Indian Ocean area, which shows a number of *Cb* tops which can be utilised for wind estimates.

2.3. In the above discussion, it was assumed that only the *Cb*-tops are moving and *Cb*-cloud itself is sationary. Such an assumption is generally satisfactory for the tropical regions, where the mean wind (along the vertical) is small. If the cloud itself was moving as an entity, with a speed equal to or comparable with the speed of the wind at the cloud top level, and if the directions of the two were different, a cirrus plume would still form but the orientation of the plume would lie in the direction of the shear vector, between the velocity of the cloud and the wind at the cloud-top level. In the present study, comparisons were made between the directions of the cirrus plume with the directions of wind at 300 and 200 mb. Comparisons were also made between the plume directions and the directions of the shear vector between the winds at 700 and 500 mb, and those at 200 mb.

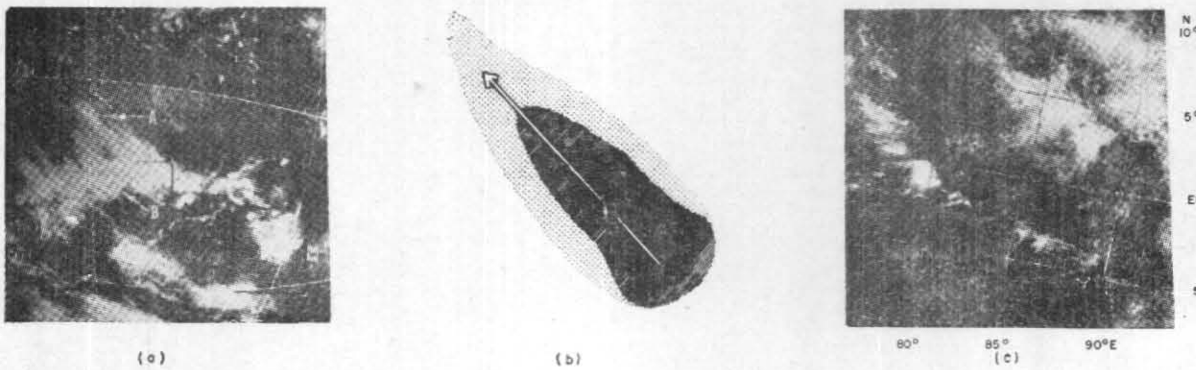

Fig. 1

(a) is taken from WMO Tech. Note, 75. It shows *Cb* tops getting blown off by strong winds aloft. At 'A' can be seen the frayed ends of the *Cb*-plumes and at 'B' the well defined edges of the main cloud. (b) gives the schematic representation of the brightness gradations of *Cb* tops plumes. (c) is an APT picture received at Bombay on 8 Dec 1969 showing the area 75°-95°E and 5°S-10°N where large number of *Cb*-clouds with plumes can be seen.

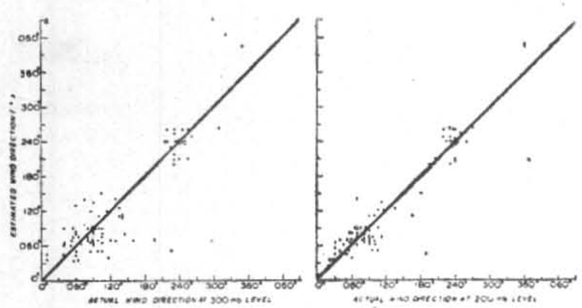

Fig. 2(a) Fig. 2(b)

Scatter diagrams showing the relationship between estimated wind directions and the actual wind directions at 300 & 200 mb levels

TABLE 1

Level of the observed wind (mb)	No. of observations	Deviation of estimated wind directions from the the observed wind			
		Average	Mean	Standard	Correlation coefficient
300	86	—7°	31°	43°	·9
200	81	+3°	21°	28°	·9

3. Data utilised

The data utilised pertains to the months of January, July, September, October and December 1969. Satellite cloud data were taken from the APT mosaics prepared by the Indian Ocean and Southern Hemispherical Analyses Centre at Poona. For comparison, only those *Cb* tops which lay within two hundred kilometres of an upper air station were taken into consideration. The time of reception of TV-pictures utilised in this study varied from 0230 GMT to 0530 GMT, while the upper wind data were from 00 GMT observations. Thus, there was a time difference of 2 to 6 hours between the compared elements.

4. Results

4·1. Figs. 2(a) and 2(b) are two scatter diagrams to show the correlation between direction of the actual winds at the 300 and 200 mb, and estimated wind directions from the *Cb*-top plumes. To facilitate an estimate of the amount of scatter in this diagram, the $x = y$ line was also drawn on the two diagrams.

4·2. The data of Figs. 2(a) and 2(b) are shown in a slightly different form in Fig. 3. This is a frequency diagram of the deviations of estimated wind directions from the observed wind directions at 300 and 200 mb. The average, mean and standard deviations have been worked out and are given in Table 1. The correlation coefficients between the estimated wind directions (plume directions) and observed wind directions at the two levels are also given in the same table. The data suggest that the plume directions correlate better with the 200 mb wind directions. But the difference is not much, as seen from the data in Figs. 2 and 3 and Table 1. This suggests that at least in the area under consideration, the flow directions at 300 and 200 mb do not differ by much on most occasions. The average and mean deviation between the plume and the wind directions at the two levels are within 10°, which is about the limit of accuracy of wind data at higher levels.

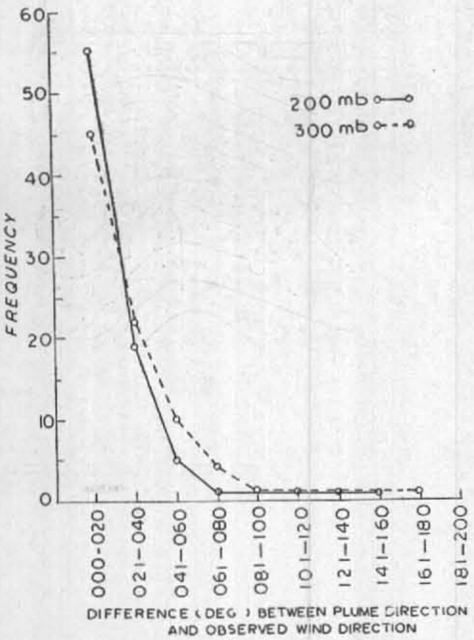

Fig. 3. Frequency distribution curves

TABLE 2

Levels of observed winds for which shear vector was calculated (mb)	No. of observations	Deviation of the plume directions from the direction of the shear vector: Average	Mean	Standard	Correlation coefficient
200—500	77	—2°	20°	27°	·9
200—700	81	—2°	18°	24°	·9

4.3. For comparing the direction of the plume with the shear vector, one should know the velocity of the cloud. Data on cloud velocities are not normally available for synoptic work. But it is known that large convective clouds move with the mean velocity of the winds in the layer in which they are imbedded. Thus, the mean velocity often agrees with the wind at some intermediate level, like 700 mb or 500 mb. Consequently, the shear vectors between 700 and 200 mb winds and 500 and 200 mb were calculated for all occasions. The directions of the shear vectors were compared with the plume directions. The frequencies of deviations of the plume directions from the directions of the shear vectors for two sets of data are shown in Fig. 4. The average, mean and the standard deviations of the plume direction from those of the two shear vectors are given in Table 2. The correlation coefficients between the plume and the

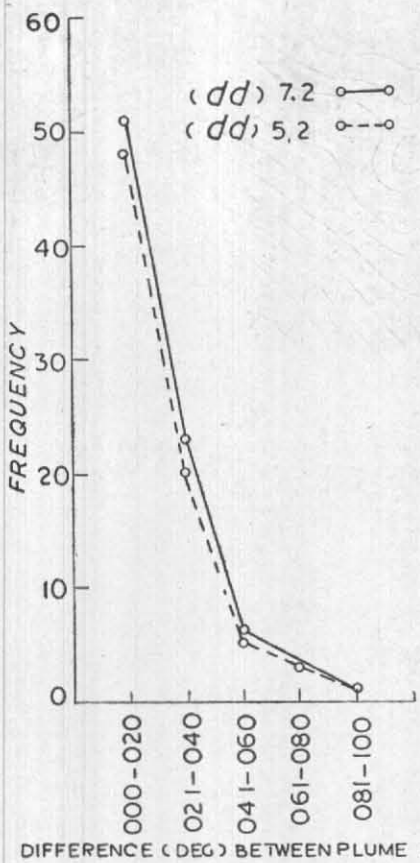

Fig. 4

Frequency Distribution of the differences between the plume direction of the shear vector (thermal winds) between 700 & 200 mb winds (dd 7,2) and between 500 & 200 mb winds (dd 5, 2)

directions of the two shear vectors are also given in the same table. It is seen that the plume directions agree better with the directions of the shear vectors. But, their agreement with the directions of actual winds at the higher levels is also fairly good, which indicates that the differences between the directions of the upper winds and of shear vectors are not large in the area under consideration. In most cases we can assume the plume directions as indicative of the direction of upper air flow.

4.4. Estimates of wind speeds can be obtained subjectively from APT pictures. NESC Technical Memorandum No. 8 gives some general principles for such estimates. Climatology, continuity in space and time and synoptic knowledge are the prime factors for such estimates. Estimates were made for some occasions but further work is necess.ry before conclusions can be drawn. Figs. 5 and 6 show the 200 mb charts of 8 and 11 December 1969 with the estimated wind directions plotted on the chart. We see that the additional data were useful for carrying out an analysis over ocean areas.

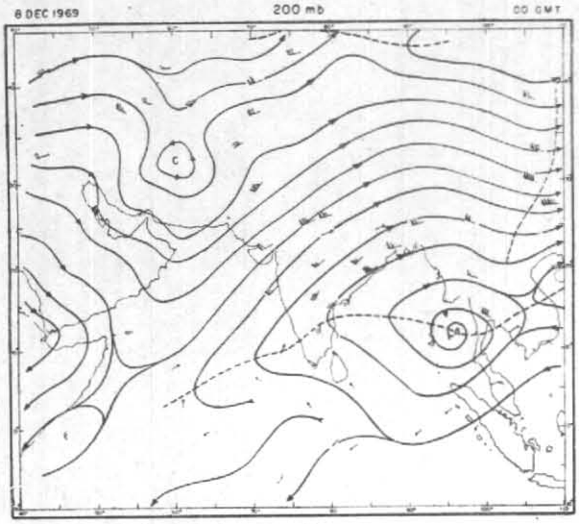

Fig. 5

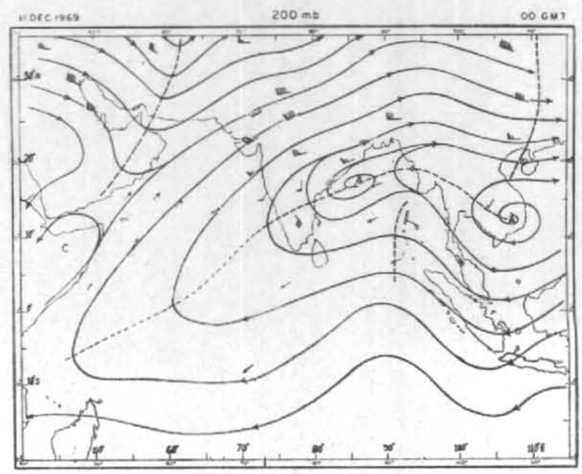

Fig. 6

Streamline analysis of the 200-mb chart where the observed winds are plotted in the conventional manner and estimated winds are indicated by arrows

4.5. During the course of this study, certain features were observed, which are given here as they are of practical importance—(1) Clusters of convective cloud create a diffluent wind field of their own (of meso-scale extent) at the cloud top level; especially in areas where the upper flow is weak. Plume directions in such cases may not represent the synoptic scale flow pattern. The analyst has to use his judgement in accepting or rejecting estimated winds in such cases. (2) Plumes of small clusters or isolated *Cb* cells appear faint in APT pictures, and tend to be overlooked when compared to the spectacular plumes from large clusters. But, the winds estimated from the former are much more representative of the general flow at the upper tropospheric level. (3) From TV pictures it is not possible to say whether plume directions represent the 300-mb flow or the 200-mb flow. The data seem to indicate that in the area under consideration they indicate the 200-mb flow better.

5. Conclusion

The result so far obtained indicate that useful estimates of upper tropospheric winds can be made using the APT TV-picture cloud data. Routine estimates can be made easily for operational work.

Acknowledgement

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DISCUSSION

(Presented by S. Mazumdar)

SHRI D. R. SIKKA : Have two independent estimates of winds been made in your study ?

SHRI S. MAZUMDAR : There is no room for divergence, as blow off from solitary cumulus has been utilised and not from cloud clusters.

SHRI D. R. SIKKA remarked that it was encouraging that the deviations of wind direction were within 20 degrees in 50 per cent of the cases. The winds fall into two main groups, one in the upper tropospheric easterlies and the other in the westerlies. In between the sub-tropical high due to the absence of clouds, wind estimation from satellite data is not possible.