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Errors in the operational gridding of APT pictures

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(*Received 16 March 1970*)

ABSTRACT. The accuracy of geographical location of cloud formations in satellite pictures is dependent on the operational methods used in gridding. It is of critical importance when the centres of storms and depressions are to be based on satellite pictures. The gridding errors arise mainly due to errors in spacecraft attitude and the lens and electronic distortions of the satellite camera system. These types of errors were determined in the APT satellite pictures received and gridded at Bombay during 1969. The results show that in extreme cases an error as high as 100-200 km can occur in the gridding of pictures without land marks; however, in a majority of cases it is estimated to be about 60 km.

1. Since the middle of 1966, satellite pictures are being received regularly at the APT ground station (APTGS) at Bombay*; after the pictures are gridded, the picture information is passed on to all the forecasting offices in India for use in operational work. The accuracy of determination of the geographical location of the cloud formations on the APT pictures, is dependent on the operational gridding methods employed. This assumes considerable importance and often becomes critical when the centres of tropical depressions and storms as reported by the satellite pictures are used for framing operational bulletins and forecasts.

2. The accuracy of the location of the centres of tropical depressions and cyclones from satellite pictures has been discussed by Hubert and Timchalk (1964), Frank (1966) and Haraguchi (1967). Errors in the satellite location of storm centres arise from the errors in the gridding of the picture as well as from the deficiencies in the methods employed to locate the centres on the satellite pictures, particularly where no well-defined 'eye' is noticed. Hubert and Timchalk noted in their study that there was no indication that any one error source was dominant. Arnold and Fujita (1964) have discussed the errors in gridding due to incorrect input information for the pictures from the earlier TIROS satellites which were not earth-oriented. In this paper it is proposed to examine the errors in the gridding of the APT pictures and present some numerical estimates of the same.

3. The gridding errors arise from three causes, *viz.*, (a) lens and electronic distortions of the satellite camera system, (b) errors in noting the time of the pictures, and (c) errors in spacecraft position and attitude.

(a) *Lens and electronic distortions*—These result in minor distortions of landmarks and cloud forms. On account of these errors it will not be possible to have a perfect fit between the picture and grid over the entire area of the picture. If we adjust the grid to fit exactly one landmark, some other landmark may slightly go out. Where more than one landmark can be clearly identified on the picture, the grid lines are usually drawn in such a way as to get an optimum fit with all the landmarks.

(b) *Time error*—For noting the time of the picture accurately, the clock at the APTGS is checked against a master clock or chronometer before tracking the satellite. A stopwatch is also used to note the actual time of the picture correct to a second. A time error of 10 sec will result in a gridding error of nearly 60 km, for a spacecraft at a height of about 1400 km. The shift will be more in latitude than in longitude. Our experience is that after a little practice, the operators have no difficulty in noting the picture time correct to a second. Thus this source of error can be safely eliminated.

(c) *Errors in spacecraft attitude*—The location of the spacecraft in space is obtained through the ephemeris predict messages, 24 to 48 hrs in advance. The predicted locations are taken as accurate. The gridding techniques employed assume that the spacecraft is looking vertically down at the time of picture-taking, so that roll, pitch and yaw are all zero. In actual practice, there is always some attitude error. The stablization of the spacecraft is claimed to be within about $\pm$ 1° for pitch and roll axes, although yaw error may exceed two degrees. A pitch or roll error of half a degree for a spacecraft at 1400 km will mean about 12 km shift in

*Since 1 April 1970, APT ground stations are functioning at Calcutta, Madras and New Delhi also—*Editor*

TABLE 1

Errors in	Range (in degrees) 0·0 to 0·2	0·3 to 0·5	0·6 to 0·7	0·8 to 1·0	1·1 to 1·2	1·3 to 1·5	1·6 to 2·0	2·1 to 2·5	Total No. of occasions
(a) Errors due to satellite attitude deviations (Period: Jan—Dec 1969)									
ESSA 8									
Lat.	158	53	5	—	—	—	—	—	216
Long.	171	41	1	2	—	—	1	—	216
ESSA 6									
Lat.	49	11	—	—	—	—	—	—	60
Long.	46	14	—	—	—	—	—	—	60
Nimbus III									
Lat.	46	24	8	11	6	5	7	8	115
Long.	33	35	25	18	3	1	—	—	115
(b) Errors due to lens and electronic distortions (Period: Jan — Dec 1969)									
ESSA 8									
Lat.	138	65	10	3	—	—	—	—	216
Long.	129	76	9	2	—	—	—	—	216
ESSA 6									
Lat.	44	15	1	—	—	—	—	—	60
Long.	39	17	3	1	—	—	—	—	60
Nimbus III									
Lat.	94	18	2	—	1	—	—	—	115
Long.	65	47	1	2	—	—	—	—	115

the picture, which is not normally discernible. Yaw error will result in different corrections in different parts of the picture, being a minimum near the central fiducial point. Errors due to larger attitude deviations become apparent when the grids are checked against landmarks on the picture.

4. Since the time error is usually not present, it is the other two that affect the gridding of the pictures. The order of magnitude of these errors based on an examination of the APT pictures received at Bombay and gridded operationally during the year 1969 has been examined. In each day's picture the frames in which the Arabian Peninsula appears, were examined so that we have well-defined landmarks to check the gridding. In all, nearly 400 frames were looked into. The pictures examined include those from ESSA 6, ESSA 8 and Nimbus III.

5. Fig. 1 shows a sample of the APT picture frame used in the study; this picture is for 6 September 1969, and the picture-time was 11 *h* 44*m* 13 *s* IST. The satellite was looking vertically down at this instant and the central fiducial mark (+) on the picture represents the sub-satellite point at the instant when the picture was taken. In Nimbus picture there is no central fiducial mark, instead we locate the image principal point, which is uniquely determined, slightly offset, from the geometric centre of the picture. The central fiducial point in ESSA picture and the image principal point in Nimbus III picture are the basic reference points for the subsequent gridding of the picture. The geographical co-ordinates of the reference point

which is the sub-satellite point at the picture-time, are calculated by interpolation from the two-minute interval positions of the satellite, available in the ephemeris predict messages. Thus, picture-time becomes an important input information in the gridding procedure. Since the frames selected for the present study contain well-defined landmarks, the APT analyst would have used these landmarks and adjusted the grids. Any difference noticed between the geographical location of the sub-satellite point as determined from the picture-time and its co-ordinates as read from the grids drawn on the picture, represents the correction applied by the APT analyst while gridding. This correction is due to the errors* in satellite attitude since as already stated there is usually no time error. In the present study this correction in gridding was noted correct to 0·1 degree of Lat./Long. for every frame. For instance, in the picture given in Fig. 1, the co-ordinates of the central fiducial point are —

(*i*) as read from the grid—16·6°N, 47·2°E

(*ii*) as determined from picture-time—16.7°N, 48·8°E and the difference between (*i*) and (*ii*) is Lat. 0·1, Long. 1·6. The difference is the correction to the gridding applied by the APT analyst. Had no landmarks** been present in the frame, the error would have remained uncorrected in the gridding. The distribution of these corrections in the various ranges of latitudes and longitudes for all the cases examined, is given in Table 1 (a).

6. Table 1(a) shows that the same magnitudes of errors in latitude as well as in longitude occur with nearly the same frequency. It confirms the earlier statement that there is practically no error due to picture-time, for if picture-time had been incorrect, the error would have been more in latitude than in longitude. For ESSA series satellites (ESSA 6 and ESSA 8), the error was within 0·2 degrees of Lat./Long. on 75 to 80 per cent of the occasions and within 0·5 degrees on practically all the occasions. For Nimbus III, however, the errors were somewhat spread out†; they did not exceed 0·5° Lat./Long. on 60 per cent of the occasions and 1·0° on nearly 90 per cent of the occassions. A simultaneous correction of 0·5° in latitude as well as in longitude for any point

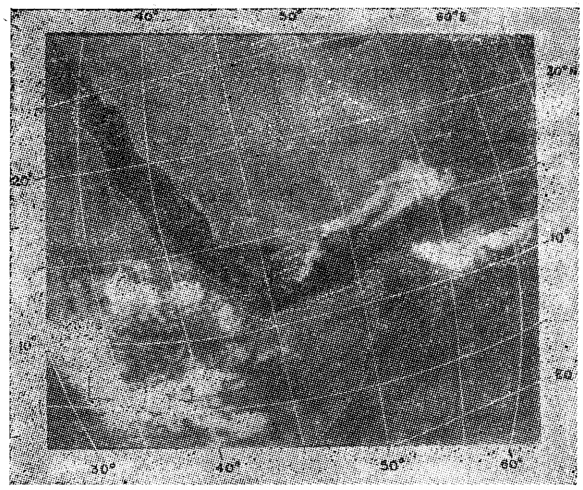

Fig. 1

ESSA 8 APT picture on 6 Sep 1969 at 11*h* 44*m* 13*s* IST

in the picture would amount to a net correction of about 0·7°, *i.e.*, approximately 70 km. However, simultaneously significant corrections for both latitude and longitude were rare (simultaneous corrections of 0·3° or more for both latitude and longitude were noticed hardly on 10 per cent of the occassions in the ESSA pictures). Even assuming a 0·5 degree correction for both latitude and longitude for ESSA pictures and a similar 1·0° correction in the case of Nimbus pictures, the maximum error in the gridding of pictures without landmarks may be of the order of 70 to 140 km. On a large majority of occasions it is much less, probably about half this value.

7. It has already been pointed out that due to combined lens and electronic distortion it is not possible to fit the Lat.-Long. grids accurately all over the frame even when land marks are noticed; thus there will be some error even in the best-gridded pictures. To obtain an estimate of this type of error, a prominent landmark was chosen at random on each frame; its latitude and longitude were read off from the grids on the picture as well as from an atlas. The difference between the two readings gave an estimate of the error on account of pictures distortion. Results of the analysis of this type of error are presented in Table 1 (b).

*Since the grids are drawn manually on the APT pictures on an operational basis, very minor displacements of the Lat-Long. lines while tracing them on to the picture, cannot be ruled out. Similarly, a fixed grid magnification for the mean height of the satellite is used at APTGS, Bombay in the case of ESSA pictures, neglecting the small day-to-day variations in the height. However, these are assumed not to lead to any significant error in gridding.

**Sometimes the same cloud mass seen in overlapping portions of two consecutive frames (one with the landmarks and the other without landmarks) are also used for checking the grids on the frame without landmarks.

†Incorrect equatorial crossing times on some occasions are also partly responsible for the large spread out.

8. Table 1(b) shows that the distortion error exceeds 0·5 of Lat./Long. hardly on 3 to 5 per cent of the occasions in the case of all the three satellites examined. The distortion error was simultaneously 0·3 degree or more in latitude and longitude in nearly 15 per cent of the cases. It was also noticed that the distortion was less near the picture centre and increased away from it.*

9. A combination of the results presented in Table 1(a) and 1 (b) will give the order of error one may expect in the location of any cloud feature (for instance the centre of a storm) on an APT picture, arising out of the limitations involved in the operational gridding procedures. In frames where landmarks are clearly seen, the error is due to lens and electronic distortion only, and it is very small near the centre of the picture and increases away from the centre. It is not more than 50 km to 70 km on any occasion. However, in frames in which no landmark is noticed, errors due to both deviations in satellite attitude as well as lens and electronic distortion will have to be taken into account. In the geographical location of any cloud feature, therefore, these two errors may either add up or cancel out. In the extreme case where both are of the same sign, the maximum error that may be expected will be atmost 100 to 200 km, adding up 70-140 km due to attitude correction and 50-70 km due to distortion correction. On a majority of occasions these two errors individually do not exceed 0·2° in Lat./Long., which will amount to a net error of about 30 km. We may, therefore, normally expect no more than an error of the order of 60 km, even if the two errors become additive.

10. A study of the errors in the satellite location of storm centres over Indian Sea areas cannot be undertaken till aircraft reconnaissance flights become available to verify the satellite derived information. However, in some rare cases where ship observations very close to the centre of the storm were available, the position of the centre derived from the APT picture was found to be quite acceptable.

11. It is necessary that users of satellite information are aware of these errors in the geographical positioning of the cloud features on the APT pictures. As these errors are inherent in the system itself, it is not possible to eliminate them in the operational methods. Therefore, even in storms where well defined 'eye' is noticed, the location of the centre in a picture without any landmark is subject to an error which may be in extreme cases as high as 100 to 200 km. On a majority of cases, however, it may be only about 60 km; and it compares very favourably with the accuracy of centres located with ship observations alone available on operational basis.

12. *Acknowledgements* — The author is thankful to Shri Y. P. Rao, Deputy Director General of Observatories (Forecasting) for his encouragement and for the facilities provided to carry out this study. The assistance given by Shri V. Sadasivan in the preparation of this paper is also acknowledged.

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*Gridding of Nimbus pictures can be improved by using more refined procedures to minimize the lens and electronic distortions. However, in operational work the simpler procedure is preferred.