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6.3 MAP ACCURACY REQUIREMENTS: THE CARTOGRAPHIC POTENTIAL OF SATELLITE IMAGE DATA*

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The topic of this presentation is map accuracy requirements. I am going to try to relate map accuracy requirements to the cartographic potential of satellite image data. The objectives are to consider, first, if resolution will be adequate for the identification of control and for the compilation of map products. Then, second, to define map accuracy standards and to determine the potential for meeting these standards with image data from the film camera, scanner and linear array systems of the 1980s.

Cartographic products fall into a variety of classes. We have topographic maps that are concerned with planimetric information and elevations or heights. We have thematic maps, which might be used for geology, vegetation, water, or to display these subjects. We have digital elevation maps that would be produced from digital terrain data, and finally we have image maps. In terms of satellite applications, we've dealt primarily with thematic maps and with image maps, and in the future we would like to be able to develop some digital terrain models and topographic map products.

Table 1

EARTH SATELLITE PROGRAMS--1980s

SATELLITE	SENSOR	IFOV	SWATH
Shuttle/Spacelab (1982)	Film Cameras (LFC, MC)	5m*	225 km
Landsat-D (1982)	Mechanical Scanner (TM)	30	185
SPOT (1984)	Line Array (HRV)**	20	60
MOS (1985)	Line Array (MESSR)	50	200
Stereosat (?)	Line Array**	15	61
Mapsat (?)	Line Array**	10-30	185

*Equivalent IFOV
**stereo

We would like to be able to develop an array of points for which we know the X, Y, and Z coordinates and then interpolate from these points the contours or the elevations. I might point out that the accuracy with which we interpolate may be a problem here. In addition, sensor resolution must be considered.

Table 1 summarizes the terrain imaging satellite programs for the 1980s. It is important to note the Shuttle/Spacelab film cameras. These film cameras have an equivalent IFOV of about 5 m and represent the baseline against which the other sensor systems will have to be compared.

*Edited oral presentation.

The conventional 1:250,000 scale map contains contours and considerable planimetric detail. One can see the outline of towns, the different classes of roads, and the vegetation patterns. This is typical of a 1:250,000 scale map product. Now, I'll talk about well-defined points. By well-defined points I mean the intersection of roads or where a bridge crosses a river, things of this nature. Well-defined points don't exist in any great frequency in undeveloped areas, so this is a problem if we are going to extract control from maps.

With the Skylab Earth Terrain camera photograph we can detect the highways, the urban development, the airfields and so on. This is about the best resolution data that we've had to-date and is representative of what we will get with the Shuttle cameras. This is our baseline information. How good a map can we prepare with an approximate equivalent 5 m IFOV? Well, we can prepare quite a good map as a matter-of-fact. We can delineate the outlines of the urban areas, we can show most of the roads, we can pick-up the vegetated areas, we can obtain quite a bit of information. If we go to the map compiled from a RBV image of Landsat-3, it in no way compares to a 1:250,000 scale map, nor does it compare in any way to a map which was compiled from the Skylab photography. So if we're talking about Thematic Mapper data which may be of slightly better resolution than the RBV, it's very unlikely that we're going to be able to compile maps in the traditional sense of the word.

Now, what are U.S. National Map Accuracy Standards (NMAS, Table 2)? First of all we can divide them into horizontal and vertical accuracy standards. For horizontal accuracy, the U.S. standards say that 90% of well-defined points should be plotted at the map scale to within ± 0.5 mm of the correct position. For example, if we have a map scale of 1:100,000, the bridges, road intersections, and so on, must be correct to ± 0.5 mm on the map. Thus, we can say that 90% of the points must be within ± 0.5 mm on the map and ± 50 m on the ground. For spot heights, 90% of the elevations that are determined from contours shall be correct to within one-half the contour interval. Thus, if we have a contour interval of 100 m, ninety percent of the interpolated elevations should be correct to within ± 50 m.

Table 2

U.S. NATIONAL MAP ACCURACY STANDARDS

A. HORIZONTAL - 90% OF WELL-DEFINED POINTS SHALL BE PLOTTED (AT THE MAP SCALE) TO WITHIN ± 0.5 mm OF THEIR CORRECT POSITION, e.g.,

MAP SCALE = 1:100,000
± 0.5 mm AT MAP SCALE = ± 50 m ON GROUND

THUS, 90% OF POINTS MUST BE WITHIN ± 0.5 mm ON THE MAP AND ± 50 m ON THE GROUND.

B. VERTICAL - 90% OF THE ELEVATIONS DETERMINED FROM CONTOURS SHALL BE CORRECT TO WITHIN 1/2 THE CONTOUR INTERVAL (C.I.), e.g.,

C.I. = 100 m

THUS, 90% OF ELEVATIONS REFERENCED TO CONTOURS SHALL BE CORRECT TO WITHIN ± 50 m.

In terms of horizontal accuracy now, let us introduce root mean square error (RMSE). By RMSE we mean that 68% of the points tested lie within the specified distance from the correct grid coordinates (Figure 1). For example, if the RMSE is ± 15 m, 68% of the points tested lie within ± 15 m of the correct location. For the 90% confidence level specified by NMAS, we must multiply 15 m by 1.65 which yields ± 25 m. Next, we want to determine the largest scale map (which is really what we want to know) that can be compiled from these data and still meet NMAS. As Figure 1 notes, the largest scale map compatible with horizontal errors of ± 25 m at the 90% level of confidence is 1:50,000.

Figure 2 reviews vertical accuracy (Z). If the $RMSE_Z$ is ± 15 m, that means 68% are to be within that value. But NMAS state that 90% of interpolated Z-values must be correct to within one-half the contour interval. So statistically, the closest contour interval which will meet NMAS is 3.3 times the $RMSE_Z$, or 50 m in this instance. From this discussion we can make the general observation that elevations are the problem, not the planimetric positions.

Figure 3a notes areas of the world with poor map coverage, and it is precisely these areas where satellite data are going to be most useful. These are also areas that have poor control nets.

Figure 3b indicates the standard contour intervals associated with maps around the world. The 1:50,000 scale maps normally have a 20 m contour interval. The contour intervals found on 1:100,000 scale maps range from 20 to 50 m and those on 1:250,000 maps from 50 to 100 m. If you are going to talk about compiling topographic maps at these scales, you have got to be able to meet the accuracy standards for elevations. For example, with a 1:100,000 scale map. planimetric accuracy requirements mean ± 50 m at 90% or ± 30 m RMSE. A 50 m contour interval requires an $RMSE_Z$ of ± 15 m.

The other subject which we have to consider is ground control and I'd like to make these points. First, ground control is normally required to establish the exterior orientation of the sensor system. Second, ground control will consist of well-defined points within the image data set for which the X, Y, Z terrain coordinates are known. Third, most ground control to be used to rectify satellite image data will be obtained from existing topographic map bases. Thus, the accuracy of the source maps may be an important factor (Table 3). Fourth, in the absence of ground control there must be an external means of establishing the X, Y, Z coordinates of the spacecraft or sensor system: e.g., orientation data from a star tracker and position and time from the NAVSTAR GPS. As satellite data are likely to prove most useful for mapping areas with poor control, the external means of determining spacecraft position, sensor attitude and time are extremely important.

Table 3

ACCURACY OF GROUND CONTROL POINTS OBTAINED
FROM MAPS MEETING NMAS

SCALE OF MAP	HORIZONTAL RMSE	CONTOUR INTERVAL	(C.I./3.3-C.I./2)
1:250,000	75 m	100 m	30-50 m
1:200,000	60	100	30-50
1:100,000	30	50	15-25
1:50,000	15	20	6-10
1:25,000	7.5	10	3-5

Future sensors will employ MLA technology in which a line array is pushed over the earth and there is a time element involved. You are not recording the entire frame at one instant in time. You are recording one line of data at a time. There are several sources of error with MLAs. We have pointing, attitude stability, satellite velocity, measurement precision and accuracy, reliability of ground control, earth curvature refraction, processing equipment, adjustment procedures, and relief displacement.

Pointing and attitude control are a major problem. If we are going to map we require stereo coverage, and most of the stereo systems such as Mapsat or Stereosat are going to take coverage with a forward-looking camera and with an aft-looking camera. The time interval between the fore- and the aft-looking coverage is on the order of 90 to 100 seconds (B/H = 1.0). During that 90- to 100-second period, the attitude of the spacecraft has to be very stable. If one assumes for the moment that we have a combined error due to pointing errors and attitude errors on the order of five seconds of arc, the error in X,Y is $\pm$ 10 m and the Z error is going to be about $\pm$ 20 m. The elevation component is the critical aspect, and attitude control is absolutely essential.

A hypothetical combination of errors is reviewed in Figure 4. Given the assumption that sensor attitude is maintained to five seconds of arc, the errors in X,Y and in Z are about $\pm$ 10 m and $\pm$ 20 m respectively. Let's also assume we have a measurement or correlation error equivalent to a half of a pixel. That's about $\pm$ 8 m. Additional miscellaneous errors may equal another $\pm$ 10 m. If we combine these errors by taking the square root of the sum of the squares, we obtain $\pm$ 15 to $\pm$ 20 m for planimetry, and about $\pm$ 25 m for spot heights. The largest scale map that we can reproduce from such data, working in even increments, comes out to about 1:100,000 scale and the contour interval that meets NMAS is on the order of 100 m.

In conclusion then, I think that we can say that, first of all, for topographic mapping at scales of 1:100,000 and larger, an IFOV of 10 m or less will be required, as will geometric accuracies of $\pm$ 20 m or better. Secondly, the film cameras to be employed on the shuttle missions will provide baseline data against which the scanner, line array and radar systems can be evaluated. Third, automated mapping will require error-free image data. Thus, in my opinion, it appears reasonable to emphasize satellite positioning and attitude control rather than to rely solely on the availability of dense ground control and on costly image processing techniques to create rectified image data sets. Finally, satellite systems which provide data meeting rigorous topographic mapping requirements will also satisfy the accuracy requirements for thematic mapping.

ROOT MEAN SQUARE ERROR (RMSE) -68% OF POINTS TESTED LIE WITHIN THE SPECIFIED DISTANCE WITH REFERENCE TO THE CORRECT GRID COORDINATES, e.g.,

$RMSE = \pm 15$ m

THUS 68% OF THE POINTS TESTED LIE WITHIN $\pm$ 15 m OF THE CORRECT LOCATION.

FOR A 90% CONFIDENCE LEVEL AS SPECIFIED BY NMAS, IT IS NECESSARY TO MULTIPLY THE RMSE BY 1.65, e.g.,

$+ 15 \text{ m} \times 1.65 \approx + 25 \text{ m}$

THUS, THE LARGEST SCALE MAP WHICH CAN BE COMPILED AND STILL MEET NMAS IS:

$$\text{MAP SCALE FACTOR} = \frac{\text{RMSE} \times 1.65}{0.5}$$
$$= \frac{25000 \text{ mm}}{0.5 \text{ mm}}$$
$$= 50{,}000$$

FIGURE 1. HORIZONTAL ACCURACY (X,Y)

e.g. $RMSE_Z = \pm 15$ m (68%)

NMAS STATE <u>90%</u> OF ELEVATIONS TO $\pm$ <u>1/2</u> C.I.

STATISTICALLY,

$$\begin{aligned} \text{C.I.}_{\text{NMAS}} &= 3.3 \times RMSE_Z \\ &= 3.3 \times 15 \\ &= 50 \text{ m} \end{aligned}$$

THUS, THE CLOSEST C.I. WHICH CAN BE COMPILED TO MEET NMAS IS 50 m

FIGURE 2. VERTICAL ACCURACY

ORIGINAL PAGE IS
OF POOR QUALITY

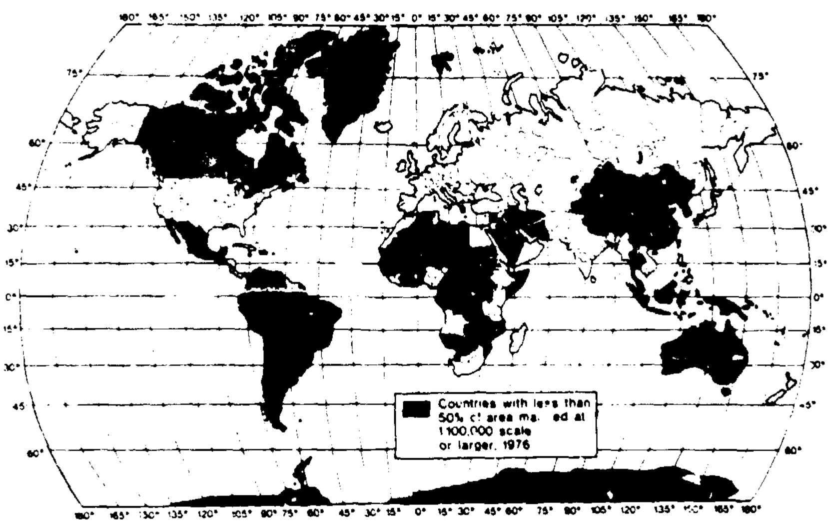

Figure 3a. The shaded areas represent countries or regions with 50 percent or less of their area mapped at 1:100,000 scale or larger in 1976 (United Nations, 1976).

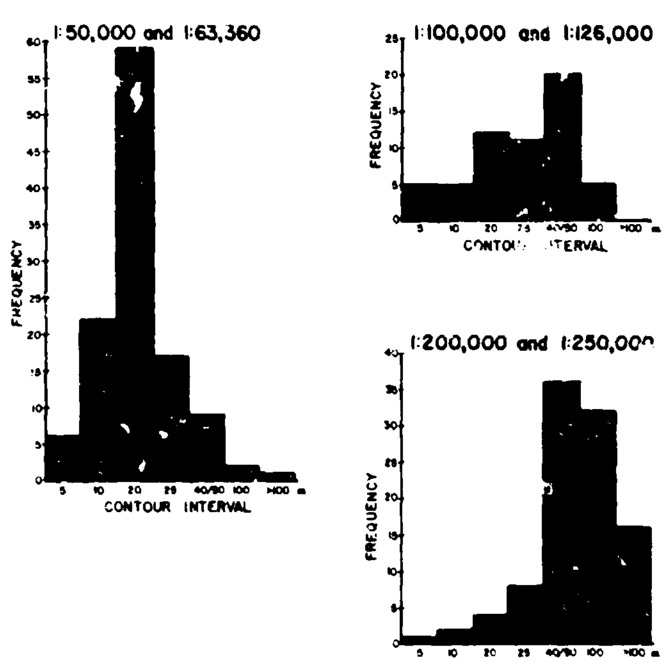

Figure 3b. Histograms of contour intervals for topographic maps at scales of 1:50,000, 1:100,000, and 1:250,000 (United Nations, 1976).

SENSOR ATTITUDE - $\pm$ 10 m IN X, Y
(e.g. $\pm$ 5 sec) $\pm$ 20 m in Z

MEASUREMENT ERROR - $\pm$ 1/2 PIXEL (e.g. + 8 m) in X, Y, Z

MISCELLANEOUS ERRORS - $\pm$ 10 m IN X, Y, Z
(DUE TO GROUND CONTROL, PROCESSING, REFORMATTING, RESAMPLING, ADJUSTMENT PROCEDURES ETC.

$$RSME_{X,\,Y} = \sqrt{10^2 + 8^2 + 10^2}$$

$$\simeq \pm 15 - 20 \text{ m}$$

$$RSME_Z \simeq \sqrt{20^2 + 8^2 + 10^2}$$

$$\simeq \pm 25 \text{ m}$$

MAPPING CONSIDERATIONS

$$\text{MAP SCALE FACTOR}_{X,\,Y} = \frac{20 \times 1.65}{0.5}$$

$$= \frac{33\ (000)}{0.5}$$

$$= 66{,}000 \simeq \underline{100{,}000}$$

$$C.I._{NMAS} = 3.3 \times 25$$

$$= 83 \simeq \underline{100 \text{ m}}$$

FIGURE 4. COMBINATION OF ERRORS (Based on H = 800 km, IFOV = 15 m)

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