MEDIUM SCALE MAPPING POSSIBILITY USING LFC DATA AND SPOT IMAGE NEAR MT. FUJI

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ABSTRACT

Large Format Camera(LFC) data and SPOT image enable us to make topographic maps from space. In order to investigate the possibility of making or revising medium scale maps, the accuracy of orientation and terrain measurement are studied for both LFC and SPOT near Mt. Fuji. As for LFC, standard deviation of control points' residuals derived from aerial triangulation are around 30m for both horizontal and vertical, the accuracies of DTM are around 14m. As for SPOT, standard deviation of control points' residuals derived from exterior orientation are around 21m and 13m for horizontal and vertical, and accuracies of DTM are around 15m for flat area and 34m for mountainous area.

The possible scale of mapping may be about 1:50,000 to 1:100,000 for both LFC and SPOT.

1. Introduction.

Geographical Survey Institute of Japan (GSI) covered all of Japan with 1:25,000 topographic maps in 1983. In order to make the cost of revising these maps lower, the possibility of making medium scale maps using LFC and SPOT are investigated. This study is also helpful for mapping a rural area in developing countries which have not yet be covered by medium scale maps.

2. Large Format Camera

The following investigations were made for LFC to evaluate the potential of data for medium scale mapping.

1) The absolute orientation was done by aerial triangulation with the bundle adjustment. Standard deviations of the control points' residuals were derived.
2) Several stereo models of different overlaps were plotted on the scale of 1:25,000 by analytical plotter and the results were compared with existing maps.

2.1 Large Format Camera data

The Large Format Camera, constructed by Itek/Nasa, was borned into space on Shuttle Mission STS 41-G, on October 1984. A total of 2160 frames were exposed at altitude of 363km to 230km. The parameters of camera are as follows (Doyle,1985):

Large Format Camera

Lens

- Focul length 30.5cm, aperture f/6.0
- Resolution 80 line pairs/mm AWAR
- Maximum distortion less than 20um
- Interchangeable haze and minus blue filters
- Rotary capping and chopping shutter
- Automatic exposure control, 1/250 to 1/30sec.

Magazine

- Format 23x46cm, long dimension in direction of flight
- 12 illuminated fiducial
- Back illuminated 5x5cm reseau
- Adjustment forward motion compensation (FMC)
- Film capacity 2400 frames
- Automatic data recording

Several characteristics may be found from the list of above. First, the FMC system causes no image motion on the film and hence enables the exposure time to be long enough for a slow speed resolution film. Second, the camera frame format of 23x46cm yields forward overlap of 20%, 40%, 60% and 80% (Figure 1) which will permit high precision in the determination of topographic elevation. From the frame, three parts of 23x23cm square (i.e. left, center and right part) can be cut out, and each part, having at least 6 fiducial marks, is available for ordinary analytical plotters.

The Large Format Camera was in operation when the shuttle was flying over Japan on the orbit no. 44, and took 7 frames (no. 0792 to 0798) of Honshu island, the largest island of Japan (Figure 2), with Kodak 3412 panchromatic black/white film. The flight altitude and solar illumination angle at the exposure time were about 230km and 40 degrees, respectively.

The contact diapositives of first generation were available only with the center part of each frame, so those of second generation were produced from the first generation negatives.

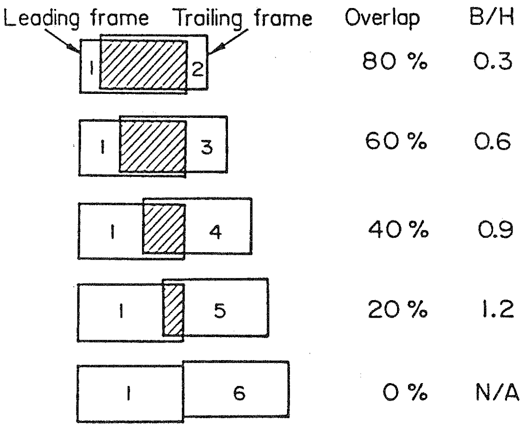


Figure 1. Overlap and B/H ratio for LFC frames

2.2 Aerial Triangulation

a) Ground control points

A number of ground control points, which were distinguished clearly on both the photos and 1:25,000 topographic maps, like national control points on the top of mountains, dams, bridges, corners of rivers, crosses of road or railways, and so on, were selected for aerial triangulation. After preliminary execution of the aerial triangulation, several control points with extremely large residuals were rejected, and the following 69 points were used as control points of good quality :

Horizontal and vertical control points	24
Horizontal control points	32
Vertical control points	13
TOTAL	69

UTM coordinates of the 54th system were used for the control point coordinates, but taking the earth curvature correction into consideration, the coordinates were first transformed to the local Cartesian coordinates before the aerial triangulation and then transformed to UTM afterwards.

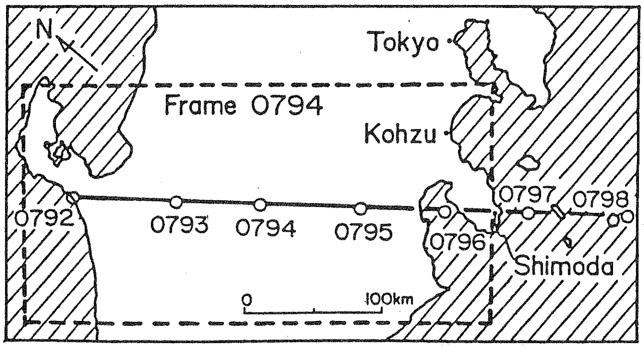


Figure 2. Index map of LFC over Japan

b) Inner orientation

According to the inner orientation procedures offered by NASA, the film distortion should be corrected with the reseau. But unfortunately, the reseau is not available with those frames used, so the conformal transformation was used for the film distortion correction. The displacement of th point of symmetry, and radial and tangential distortion was corrected by using the calibration parameters offered by NASA.

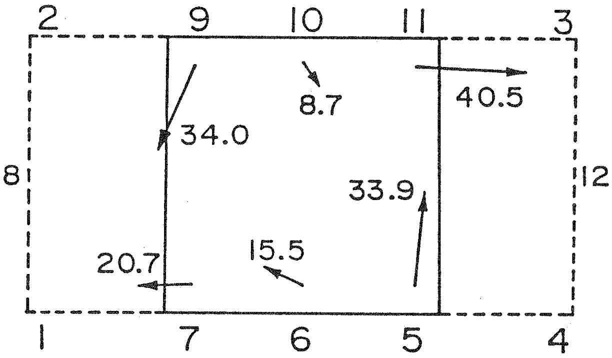


Figure 3. Pattern of residuals at fiducials (μm)
(for first generation positive of 0796)

The r.m.s. of residuals at the fiducial marks were about 20um for the first generation positives, and the pattern of the residuals (Figure 3) were almost the same as each other.

Table 1. Residuals of block adjustment

Self-calibration	NOT USED	USED
Residual at photo coord.		
R.M.S.(μm)	27	25
Max.((μm)	35	31
Residual at control points		
R.M.S. (m)	29.47	26.76
Max. (m)	77.92	66.12
R.M.S. (m)	30.85	24.02
Max. (m)	-71.50	65.11
Convergent difference of bundle (m)	11.32	9.53

c) Aerial Triangulation with bundle adjustment

The bundle adjustment was used for those five photos of frame (0794 to 0798). The adjustment was applied for two cases, with self-calibration (Murai, et al., 1981) and otherwise. The residuals for both horizontal and vertical control points are much the same, because the base to height ratio of 1.2 at the largest could make the vertical accuracy high. Despite good precision in the convergent of bundle, the residuals of the control points are not so good. It was because there were some difficulties in identifying the control points on the photos.

2.3 Plotting

a) Plotting areas

Two areas, Shimoda and Kohzu, were selected for plotting on the scale of 1:25,000 by analytical plotter. The shimoda area is located at almost the center of the frames (i.e. the area was just below the orbit of the shuttle), and the Kohzu area is located near the side edge of the frames. Figure 4 shows the 1:25,000 topographic map of the Kohzu area (reduced to about 1:50,000). Roads, railways, coast lines, large buildings, vegetation limits, and contours were plotted for those areas. The frame numbers used for the plotting are listed in Table 2.

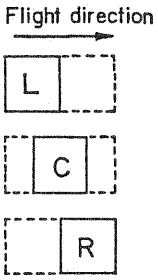
b) Contours

Figure 5 shows the contour plotting result for the Kohzu area by using 60% overlapped photos. The following were

Table 2. Frame number used for plotting

Area	Overlap	Photo Number Left	Photo Number Right
Kohzu	80%	0796C	0797C
	60%	0795C	0797C
	40%	0794R	0797C
	20%	0794R	0797L
Shimoda	80%	0796C°	0797C°
	60%	0795R	0797C

°: First generation positive



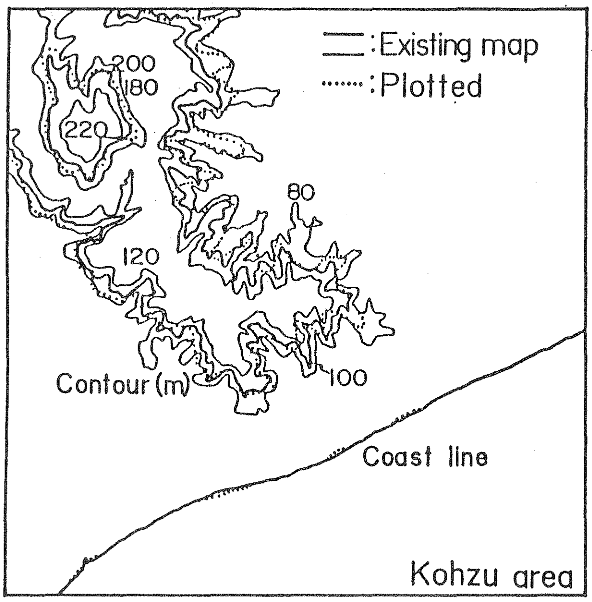


Figure 5. Result of plotting (Contour and Coast line)

pointed out for the contour plottings.

1) Contours of 20m interval were almost impossible to draw but the interval of 40m to 50m seemed possible.
2) In comparison with 1:25,000 topographic maps, the results were rather indistinct for small folds.

c) DTM

A digital terrain model (DTM) of 30 points was derived from the models for the Kohzu area and compared with a DTM which was obtained from the 1:25,000 topographic map (Fig4). R.M.S. and minimum values for the residuals at the points are listed for each overlap in Table 3. The results show that the model with 40% overlap (base to height ration is 0.9) has the highest precision. The model which uses 20% overlap near the edge of the frames does not suitable for practical use.

Table 3. Height observation error

Overlap	R.M.S(m)	Max.(m)
80%	21.7	45.0
60%	15.7	44.0
40%	13.9	29.8
20%	14.1	30.7

(Kohzu area)

3. SPOT

The following investigations were made for SPOT HRV (level 1A) to evaluate the potential of data for medium scale mapping.

1) The following orientation method was applied for SPOT image near Mt. Fuji. Exterior orientation parameter is the function of scan line number and ground control point, projection center and image satisfies colinearity equation.
2) DTMs were acquired using analytical plotter. DTMs from space was compared with DTM from 1:25,000 topographic maps.

3.1 Exterior orientation of SPOT HRV

a) Exterior orientation method for SPOT HRV

The position and attitude of SPOT satellite changes with time and scan line number, so the exterior orientation parameters are given as the function of time or scan line number. They can be approximated well enough with polynomials of line number because of slow and continuous changes of a satellite position and attitude.

$$\overline{X} = \overline{X_0} + \overline{X_1} * L$$
$$\overline{Y} = \overline{Y_1} + \overline{Y_1} * L$$
$$\overline{Z} = \overline{Z_0} + \overline{Z_1} * L$$

Satellite attitude

$$\omega = \omega_0 + \omega_1 * L + \omega_2 * L^2 + \omega_3 * L^3$$
$$\phi = \phi_0 + \phi_1 * L + \phi_2 * L^2 + \phi_3 * L^3$$
$$\kappa = \kappa_0 + \kappa_1 * L + \kappa_2 * L^2 + \kappa_3 * L^3$$

Where

L : Line Number
$(\overline{X}, \overline{Y}, \overline{Z})$: Sensor Position(Projection Center)
(ω, ϕ, κ) : Sensor Attitude(roll,pitch,yaw)

The order of these polynomials varies with the length of an orbit, the stability of attitude, and so on.

In this case, the total number of unknown parameters is 18. These unknown parameters satisfies the following equations.

Colinearity equation is

$$x = -f\,\frac{a_{11}(X-\overline{X}) + a_{21}(Y-\overline{Y}) + a_{31}(Z-\overline{Z})}{a_{13}(X-\overline{X}) + a_{23}(Y-\overline{Y}) + a_{33}(Z-\overline{Z})}$$

$$y = -f\,\frac{a_{12}(X-\overline{X}) + a_{22}(Y-\overline{Y}) + a_{32}(Z-\overline{Z})}{a_{13}(X-\overline{X}) + a_{23}(Y-\overline{Y}) + a_{33}(Z-\overline{Z})}$$

Where

x, y : Image Coordinate

X, Y : Ground Coordinate

The observed satellite position (ephemeris) data and attitude velocity data are provided in SPOT image CCT. Following equations are observed satellite position and attitude velocity data.

Satellite Orbit

$$\overline{X} = \overline{X}_0 + \overline{X}_1 * L$$

$$\overline{Y} = \overline{Y}_1 + \overline{Y}_1 * L$$

$$\overline{Z} = \overline{Z}_0 + \overline{Z}_1 * L$$

Satellite Attitude

$$\omega = \omega_0 + \omega_1 * L + \omega_2 * L^2 + \omega_3 * L^3$$

$$\phi = \phi_0 + \phi_1 * L + \phi_2 * L^2 + \phi_3 * L^3$$

$$\kappa = \kappa_0 + \kappa_1 * L + \kappa_2 * L^2 + \kappa_3 * L^3$$

b) Test area

The exterior orientation was carried out for three SPOT images of a mountainous area near Mt. Fuji. Figure 6 shows the topographic maps of the test area and distribution of 38 ground control points. Their ground control points were measured on 1:25,000 scale topographic maps with 10m interval contour lines, while the image coordinates were measured on a graphic display. Figure 7 shows the dates and the sensor angles of SPOT images.

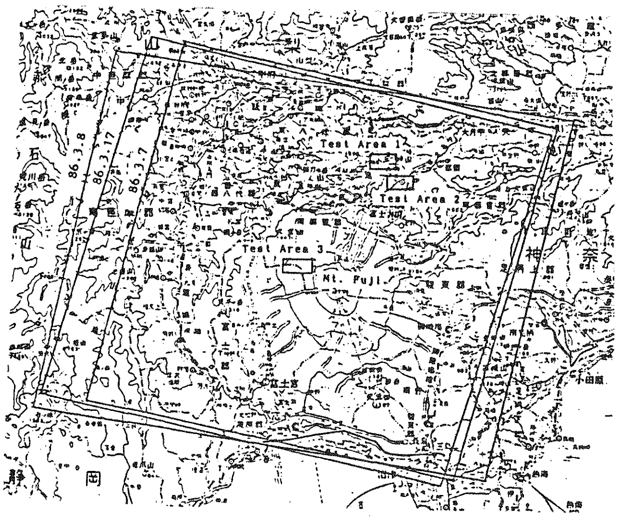


Figure 6(a)

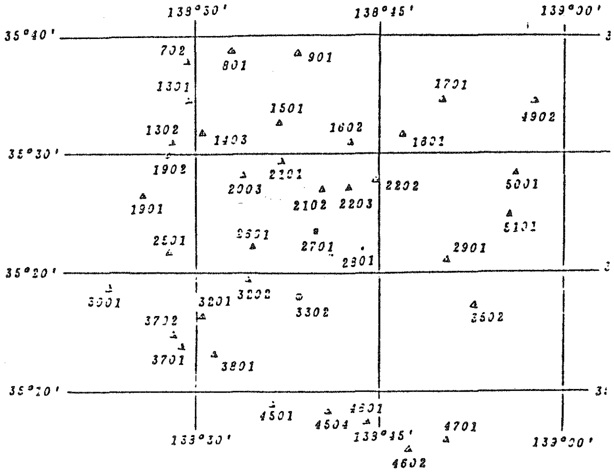


Figure 6(b)

c) Accuracy of exterior orientation

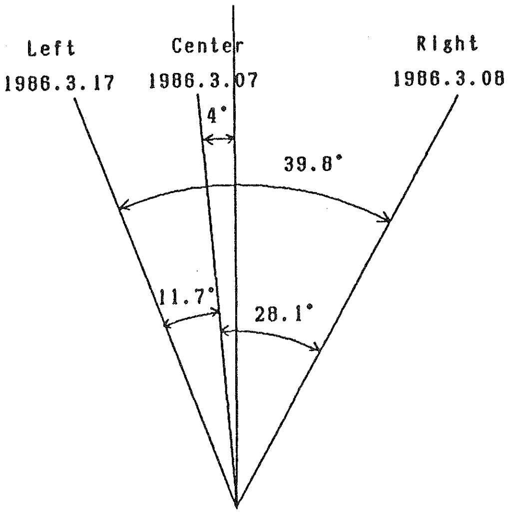


Figure 7 Stereo Angles of SPOT Image

Table 4 shows the accuracy of exterior orientation in terms of residuals on the image plane. For case 1 and 2, the order of attitude polynomials are assumed to be zero. From case 3 to 6, the order of attitude polynomials are assumed to be third. The observed satellite position and attitude velocity data are used in case 5 and 6. The accuracy of the orientation in terms of residuals is best in case 6.

Table 5 shows the accuracy of orientation in terms of pointing error (X Y Z) on the ground in case 1 and 6. The pointing error data were obtained from nine GCP. The accuracy in case 6 is much better than that in case 1. This fact implies that the utilization of observed satellite data is useful to improve the accuracy of orientation.

Table 4(a) Cases of exterior orientation

Case	Order of Attitude			Order of Orbit			Observed Satellite Data		Earth Curvature Correction
	ϕ	κ	ω	X	Y	Z	Atti	Long	
1	0	0	0	1	1	1	-	-	-
2	0	0	0	1	1	1	-	-	done
3	-	3	3	1	1	1	-	-	-
4	3	3	3	1	1	1	-	-	-
5	3	3	3	1	1	1	used	used	-
6	3	3	3	1	1	1	used	used	done

Table 4(b) Residuals of Exterior Orientation

Case	3/7 Center			3/8 Right			3/17 Left		
	RMSE		Max	RMSE		Max	RMSE		Max
	line	pixel	(mm)	line	pixel	(mm)	line	pixel	(mm)
1	0.016	0.015	0.044	0.015	0.012	0.036	0.013	0.012	0.041
2	0.018	0.016	0.046	0.015	0.011	0.039	0.012	0.015	0.047
3	0.021	0.014	0.050	0.038	0.145	0.393	0.034	0.016	0.067
4	0.014	0.013	0.040	0.094	0.199	0.575	0.010	0.013	0.036
5	0.015	0.018	0.044	0.023	0.045	0.069	0.013	0.030	0.056
6	0.015	0.014	0.036	0.014	0.011	0.029	0.012	0.012	0.028

Pixel size = 0.013mm x 0.013mm

Table 5 Pointing error on the ground

unit(meter)

	3/7-3/8 (B/H=0.52)				3/17-3/8 (B/H=0.72)			
	Control Point		Check Point		Control Point		Check Point	
Case	σ xy	σ z	σ xy	σ z	σ xy	σ z	σ xy	σ z
1	11.7	19.9	19.9	20.4	10.5	12.8	17.7	16.5
6	10.9	13.7	21.4	13.9	9.8	11.8	20.9	12.9

3.2 DTM

a) Test area

We made photocopies of three SPOT images for plotting with analytical plotter. The reseau marks which connect photo coordinate and image coordinate were also printed on the films to correct film deformations. Two test areas for stereo plotting are shown in Figure 8. Test area A is a relatively flat area whereas test area B is a mountainous area with steep slopes.

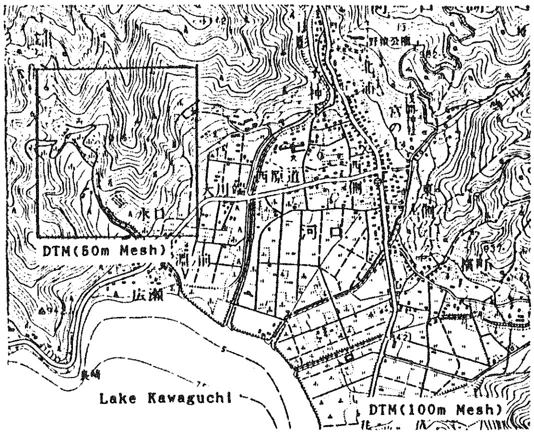


Figure 8(a) Test Area A

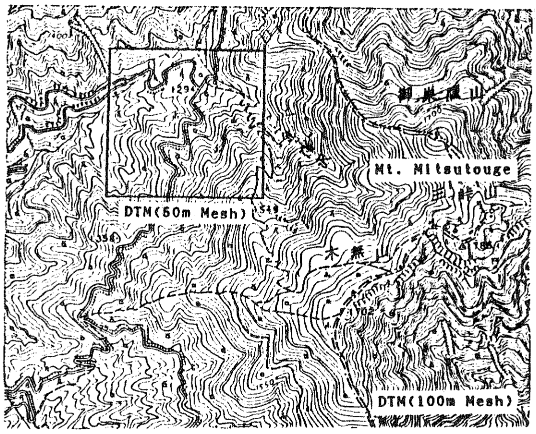


Figure 8(b) Test Area B

b) Accuracy of DTM

Irregularly spaced DTMs were obtained through stereo plotting. To evaluate their accuracy, grid spaced DTMs were acquired from 1:25,000 topographic maps with digitizer. For their comparison, the DTMs obtained from SPOT images were converted to grid spaced DTMs through interpolation.

The accuracy of the DTMs is shown in Table 6 in terms of height discrepancy between the DTMs obtained from SPOT image and those from 1:25,000 topographic maps. The height ddiscrepancy includes an altimetric error caused by the planimetric displacement. The DTMs in test area A (flat area) have better accuracy than those in test area B (mountainous area). The one reason is that planimetric displacement has more influence on height discrepancy in a mountainous area. To avoid planimetric error, DTM's were additionary measured from SPOT images on three profiles. They are road, ridges and so on. The RMSE of the discrepancy are from 9 to 15m. This result is better than that of the irregularly spaced DTMs.

Their is not much difference of accuracy between the DTMs from SPOT with higher B/H ratio (B/H=0.72) and those with lower B/H ratio (B/H=0.52). The accuracy of DTM in case 4 is the worst among four cases. This result may be caused by some other factors, such as th quality of stereo plotting operation.

From this result, 40 to 50m contour interval can be drawn using SPOT.

Table 6 Height Discrepancy of DTM's from SPOT Images

Case	Test Area	B/H Ratio	RMSE(m)		MAX(m)	
			100m Mesh	50m Mesh	100m Mesh	50m Mesh
1	A	0.52	16.8	13.7	72	42
2	A	0.72	15.1	11.7	99	68
3	B	0.52	17.9	16.7	-75	45
4	B	0.72	25.1	33.5	-102	113

4. Ground features

In making topographic maps from space, detection of ground features is important. Topographic maps usually has the information of road and vegetation. These informations are traditionary obtained from aerial photograph. But LFC and SPOT have limitation of the detection of ground features caused by their resolution.

Table 7 is a detectibility of ground features from LFC and SPOT in the test area shown in Figure 6.

Table 7 Ground features from LFC and SPOT

category	subcategory	LFC	SPOT	details
land use land cover	grass land	Yes	Yes	brighter than forest
	coniferous forest	Yes	Yes	LFC: almost impossible to find the difference between coniferous forest and broad leaf forest SPOT: coniferous forest is darker than broad leaf
	broad leaf forest	Yes	Yes	
	bamboo	No	No	
	upland field	Yes	Yes	LFC,SPOT: upland and paddy field have no difference
	paddy field	Yes	Yes	
	fruit orchard	No	No	
road	about 5m and more in width	Yes	Yes	LFC: detection of road in urban area is difficult
	road in forest	Yes	Yes	
	others	No	No	
railway		No	No	
river		Yes	Yes	

In our research, SPOT image is better than LFC. The one reason is that SPOT image can be changed by digital enhancement.

5. Conclusions

1) LFC
   a) The residuals of control points' derived from aerial triangulation are 30m for both vertical and horizontal.
   b) The accuracies of DTMs are around 14m.

2) SPOT
   a) The residuals of control points' derived from exterior orientation are around 21m and 13m for horizontal and vertical.
   b) The accuracies of DTMs are around 15m for flat area and 34m for mountainous area.

The purpose of this study was to investigate the possibility of mapping or revising the existing 1:25,000 topographic maps from space. The LFC and SPOT are not suitable for mapping or revising 1:25,000 topographic maps. The possible scale of mapping may be 1:50,000 or 1:100,000.