THE APPLICABILITY OF SATELLITE REMOTE SENSING TO SMALL AND MEDIUM SCALE MAPPING

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ABSTRACT / RESUME

There are unclear prospects regarding the usefulness of satellite remote sensing images to the generation and updating of general purpose maps at scales 1: 50 000 to 1: 100 000. There is a world-wide need for such mapping. This paper examines space imagery of current and future projects to determine in how far it can satisfy these needs. It conventional medium and small scale mapping will simply not be satisfied by space imagery. A pre-condition for the applicability is the need to develop either new attitudes and value systems in the mapping world, or to generate space imagery at higher geometric resolution of about 3 m or better.

Keywords: Planimetric and topographic mapping, photogrammetry, radar imaging, scanning, space photography.

1. INTRODUCTION

Medium and small scale mapping is here meant to concern general purpose maps at scales 1: 50 000 to 1: 100 000. The scales of 1: 250 000 and beyond are considered to belong to the realm of atlas cartography.

Remote sensing imagery from satellites is with microwaves (side-looking radar), with scanning or push-broom scanning, and with cameras. From aircraft we also have radar and scanning. Air - photography, however, would more appropriately be kept apart from remote sensing and called the topic of photogrammetry.

A mere 35 % of terrestrial land areas are mapped at scales 1: 100 000 and larger (Schwidefsky, Ackermann, 1976, Konecny et al. 1979) or 25 % at scales 1: 50 000 and larger, and revision cycles are widely seen to be inappropriate. This clearly leads to the conclusion that some change has to occur in the ways that mapping is currently being done. The question is often raised whether satellite remote sensing is appropriate to solve this problem.

This paper makes the point that space imaging cannot be the basis of general purpose non-thematic mapping at medium and small scales in the current value system. It thus follows the view expressed in an early paper by PETRIE (1970). Currently available satellite images of LANDSAT, SEASAT and SKYLAB are proof to this claim. Currently planned satellite missions will also not be appropriate for the establishment of conventional maps.

Therefore, if space remote sensing is to significantly contribute to general purpose mapping then there must either be a change in the value system attached to maps or much higher geometric resolution imagery must be generated. Both avenues are open.

Space remote sensing so far has only been experimental. However, many studies have proposed with some optimism that space platforms will be appropriate to generate imagery sufficient for 1: 50 000 scale mapping and smaller (ITEK, 1981, COLVOCORESSES, 1981; DUCHER, 1980, SPOT, 1981, KONECNY et al., 1981). In order to obtain a clearer view of the arguments to support or discard these hopes, this paper will first review the thinking that dominates current map and image scale considerations in the map-making world. This is then contrasted with the capabilities offered by current and proposed satellite remote sensing missions.

The conclusion is then obvious that c o n v e n t i o n a l general propose mapping cannot be a "driver" for future space missions. Some significant change of attitudes in the map-making world would be required to lead to medium scale mapping applications of satellite images.

2. CURRENT MEDIUM AND SMALL SCALE MAPPING

In industrialized countries the small scale maps often derive from generalized larger scale maps. Original mapping may thus be at scale 1: 10 000 or 1: 25 000. In developing countries it is the smaller scale that is subject of direct mapping.

A certain map scale is considered to require a certain image or photo scale for satisfactory accuracy and interpretability. Regarding accuracy the standards are easily verifiable. Height and planimetric accuracy must be considered separately. Image scales are a function of flying height and type of camera.

Flying height is limited by the ceiling of a survey aircraft. The current limits towards small imaging scales are near 15 - 16 km. Special aircraft may reach 20 km and more.

Cameras have standard formats and focal (principal) distances. For small scale photography these are principal distances of 8.5 cm (super-wide angle camera) and 15 cm (wide-angle camera), given a format of 23 x 23 cm^2 for the images. A resolution of 40 lp/mm is considered to be achievable. This limit results from the need for highly sensitive films to image in an enviroment that is poor in contrast. Geometric resolution must be combined with great accuracy and stability. The latter requirement may be relaxed in a computer-controlled and thus flexible photogrammetric mapping system when compared to more traditional analog systems.

2.1 Geometric Accuracy Considerations

(a) Height

Medium and small scale maps contain height information in the form of contour lines at height intervals, CI, of 10 to 20 m. This converts to the required height accuracy, σ_H, of measuring an individual point as follows:

$$\sigma_H \;/\; CI \approx 1/4 \text{ to } 1/5 \quad \text{in Europe}$$
$$\sigma_H \;/\; CI \approx 1/3 \quad \text{in U.S.A.} \qquad .....(1)$$

A 10 to 20 m equidistance leads thus to a required accuracy σ_H of 4 to 7 m.

Converting this required value σ_H to an image scale of conventional photogrammetry, we use a rule of thumb for wide-angle cameras:

$$\sigma_H \approx 0.2 \text{ ‰} \cdot H \qquad .....(2)$$

Thus a photogrammetric system base on wide-angle photography allows one to achieve height accuracies of 2 parts in 10 000 of the flying height. This in turn leads to image scales as follows:

$$\sigma_H = 4 \text{ m} \rightarrow H_{wa} = 20 \text{ km} \approx 1:130\ 000 \rightarrow H_{swa} = 11 \text{ km}$$
$$\sigma_H = 7 \text{ m} \rightarrow H_{wa} = 35 \text{ km} \approx 1:230\ 000 \rightarrow H_{swa} = 20 \text{ km}$$

H_{wa} is the acceptable flying height with wide-angle cameras, H_{swa} for super wide-angle cameras. This implies an accuracy of WA- and SWA cameras that is equal at equal image scales.

(b) Planimetry

In a map one presents graphical accuracy on a printing base. The commonly accepted accuracy standard in large scale maps is 0.1 mm to 0.2 mm. However, in a small scale map one needs a considerable degree of generalisation, symbolisation and prioritizing. This in turn leads to geometric displacements in a map of up to 0.5 mm. Planimetric accuracy is thus far less stringent than height accuracy.

2.2 Considerations of Interpretability

The interpretability of images is the decision factor in judging the usefulness for medium and small scale mapping. Various rules exist that relate a map scale number, m_m, to the required image scale number m_i. According to standard photogrammetric text books, a common rule is (e.g.Schwidesfsky and Ackermann, 1976):

$$m_i \approx 250 \cdot m_m^{1/2} \qquad ......(3)$$

For ortho-photo maps, a standard, f.e. in Germany, is acc. to Hobbie (1974):

$$m_i \approx 17 \cdot m_m^{0.85} \qquad ....(4)$$

This leads to required image scales of about 1:100 000 for maps 1:50 000, and image scales of about 1:200 000 for maps 1:100 000. However, the above rules essentially apply to larger scales. At map scales 1: 50 000 one often uses image that are much larger than the rules (3)and(4) would suggest.

This is justified by relaxed requirements for field completion and represents a "safety factor" to ensure that all significant details are presented in the maps.

2.3 Discussion

The comparison of the various considerations to define a required image scale for mapping reveals that i n t e r p r e t a b i l i t y is the most limiting factor. In order to define a geometric resolution figure, a, instead of scale, λ, and to compare aerial photography with digital remote sensing images, one needs to relate line-pairs per millimeter to pixel sizes on the ground. This can be achieved employing the well-known Kell factor or Shannon-theorem. According to these, n lp/mm are resolved by at least 2 n, better about 2.8.n pixels.

This leads to the conclusion that on aerial film with 20 to 40 lp/mm resolution an equivalent pixel diameter is between 9 μm and 25 μm or, to take but a single value, about 17 μm. Figure 1 presents the pixel diameter on the ground as a function of image scale. An obvious conclusion is that a 1 m resolution or better is usually considered necessary for medium to small scale mapping.

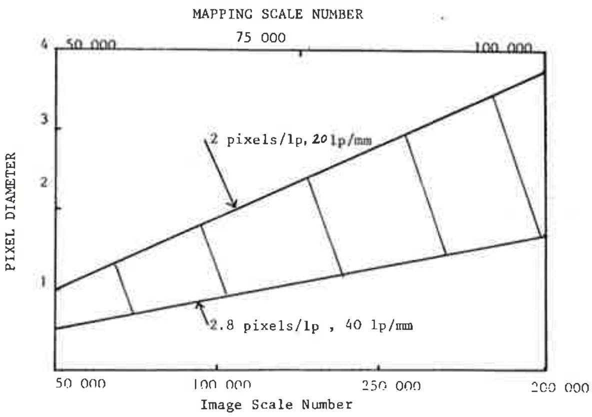

Figure 1:

Required photoscale number for a given mapscale, and resulting equivalent pixel diameter on the ground.

We may thus summarize that conventional mapping standards dictate the following image performance:

height accuracy	± 5 m
plan accuracy	± 15 m
pixel diameter	1 m

2.4 Cost of Conventional Small and Medium Scale Mapping

The cost of aerial photography is a varying entity. It tends to become more economical as the area to be covered increases. To acquire aerial photography at small scales may cost US$ 10.--per photograph or an amount of less than US$ 1.-- per sqkm.

In order to obtain an estimate of the cost for photogrammetric plotting one needs to know the number of stereo models required for a given area and image scale. Based on a usable stereo overlap, a stereomodel covers 8 x 10 sqcm. Therefore the effective ground coverage at scale 1: 50 000 is 40 sqkm. Table 1 presents the area per stereomodel, flying height and image scale, and number of models per 100 000 sqkm.

Image Scale number	Ground area covered(sqkm)	Flying height (km)		Nr. of stereo models 100 000 sqkm	Man years of plotting for 100 000 sqkm
		f=15cm	f=8.5cm		
50 000	40	7.5	4.2	2 500	4 - 10
100 000	162	15	8.5	620	1 - 2
150 000	364	22.5	12.7	300	1/5-1
200 000[1]	648	30	17	150	1/4-1/2

Table 1: Relating image scale to ground coverage, number of stereo models and plotting effort, based on stereo models with effective stereo coverage of 9 x 18 sqcm. One stereo instrument with 2 shifts.
1) currently not available from aircraft.

Regarding cost for plotting at small scales, current photogrammetric literature (Schwidefsky, Ackermann, 1976) reports that up to 1 to 2 stereomodels can be plotted per shift in natural, non-built-up areas on an instrument. This converts to an overall cost of US$ 5.-- per sqkm for the preparation of a manuscript. Cartographic work is not included.

We now find, at US$ 5.-- per sqkm, the cost per equivalent image pixel with a ground resolution of 1 m to be US$ 0.00005.

3. PERFORMANCE OF REMOTE SENSING SYSTEMS

3.1 Side-Looking Radar

SEASAT-satellite side-looking radar offered a ground resolution of 25 m. From aircraft common resolutions are 10 m with a mapping system such as that of Goodyear-Aerospace. Higher resolutions of up to 3 m are available to civilian users but not practicable at this time.

This resolution leads to image scales of about 1: 500 000. Geometric accuracies over large areas and without dense ground control are ± 100 m and poorer.

These figures make it apparent that both the resolution and geometric accuracy may approach required accuracy levels; height does not. Interpretability is certainly insufficient for conventional mapping.

It has become common practice to generate special radar map series at scale 1: 250 000. This scale reflects the capabilities of radar at this time: it cannot be a replacement for aerial photography for mapping, but merely an addition with a special purpose outside that of conventional medium and small scale maps.

Many areas of the world have been mapped by radar, essentially for thematic purposes, but also in some cases with a distinct general thematic purpose in mind. Brasil, Venezuela, Guatemala, Togo, Nigeria, Japan, Nicaragua and others have been completely covered by radar maps. Colombia, Peru, Ecuador, USA, Indonesia, Philippines, Australia and others have obtained partial coverage. At a cost of US$ 3.-- to US$ 15.-- per sqkm one must assume that in excess of US$ 100 Mio. have been spent on the aquisition of these radar coverages.

The rules of conventional mapping at scale 1: 250 000 would require images with pixel diameters of about 1.5 m. The fact that merely images with up to 10 m resolution are employed with current radar maps is indicative of the fact that radar is justified by other considerations than those of conventional mapping. A distinct factor is the logistics advantage: images can be obtained when and where desired.

3.2 Satellite Scanning

LANDSAT is the only satellite series that generated significant scan-data for mapping. Other satellites are or were for meterological purposes or of short-lived, experimental purposes (SKYLAB, HCMM).

The geometrical resolution of LANDSAT multispectral scanning (MSS) is currently 80 m and will improve to about 30 m. The geometric mapping accuracy in planimetry is commonly reported to be in a ± 50 m range with the MSS, and in the ± 12 to ± 15 m range with the vidicon imagery (RBV). Height measurements have been reported with accuracies of ± 700 m.

Clearly these values of resolution and accuracy are entirely unacceptable for 1: 50 000 to 1: 100 000 scale mapping. The only application to mapping is for atlas-cartography at scales 1: 500 000 to 1: 1 000 000

3.3 Space Photography

Photogrammetric authors have both dismissed (PETRIE, 1970) and proposed space photography for 1: 50 000 scale mapping (KONECNY et al., 1979). Dismissal is based on considerations of scale and resolution, height accuracies, cost and the need for film recovery. Examples for space photography were obtained in the past by SKYLAB and the SOJUZ-series. With the former, two cameras produced photography at scales 1: 1 Mio. and 1: 3 Mio., where the former had equivalent ground pixel diameters of up to 6 m.

The specific choice of cameras and emphasis of accuracy -- or lack thereof -- has led to map accuracies of only ± 40 m in planimetry and ± 150 m in height. Space photography could certainly be better than that. In SKYLAB the main limitation to the mapping applicability was the failure to satisfactorily resolve man-made features (Mott,1975). The practicability of space photography is limited due to the need for film recovery and the advent of CCD-sensing cameras, where linear detector arrays may ulitmately not need to be configured in areal, two-dimensional form. From the point of view of conventional mapping, a 60 cm-camera in a 600 km orbit could still produce only SKYLAB-type image resolutions. Lower orbits are feasible, but create problems for long duration due to limited orbit life-times. Long duration is needed due to weather problems.

3.4 Future Satellite Remote Sensing Missions

One expects the following missions to be available in one form or another in the future:

LANDSAT
SPOT
SPACELAB
ERS - 1
MAPSAT/STEREOSAT

There may be other missions such as a tropical satellite for Indonesia or a Japanese land observation system etc.

None of these systems will offer a geometrical resolution in excess of 10 m. This automatically disqualifies the data for 1: 50 000 or 1: 100 000 conventional mapping. And this type of mapping is presented in certain cases as an important element in the application. As seen with conventional map-maker's eyes, one may expect the following:

- The planimetric accuracy, possibly also height accuracy, can be met for 1: 50 000 scales and 20 m contouring . In the MAPSAT-concept (ITEK,1981), this high height accuracy could be achieved by accurate stabilisation of the satellite. The 10 m pixel diameter of MAPSAT converts to a film resolution of 300 lp/mm in a wide-angle camera at the same altitude; consequently a higher accuracy results than one expects from film cameras in the same orbit.
- The near orthogonal projection of a push-broom CCD-image is of interst. Stereo may be helpful for interpretation.
- The ground resolution is insufficient.
- The logistics question is unclear. Effects of weather and data accessability/sovereignity may be a limiting factor to the application of the data.

This situation must be contrasted with the cost of conventional aerial photogrammetry using new cameras, higher flying aircraft,new films, dual exposures and computer-assisted analysis methods. This alternative must be borne in mind in any evaluation of satellite remote sensing applications.

4. CONCLUSIONS AND OUTLOOK

The above materials indicate that c o n v e n t i o n a l medium and small scale mapping in the range of 1: 50 000 to 1: 100 000 will not be served by satellite remote sensing unless:

- the cost of imagery is sufficiently low to make it competitive with small scale aircraft photography (1: 140 000);
- the ground resolution is high (3 m or better);
- there is a distinct logistics advantage of satellite image acquisition.

There is the possibility of changes in the attitudes towards maps and in the value systems of those ating and using them: for this a view would e.g. be taken that emphasises up-to-date map contents at the expense of map accuracy and completeness. In that case satellite data will have a role to play in this application.

In the industialized high-technology societies such changes may be provoqued by the advent of digital geo-information systems so that maps are just a tip of a digital iceberg. In that case it may be essential to have data that are up-to-date. A m o n i t o r i n g function for map-makers does not exist today but may emerge in the future. If it does, then an application for satellite map making would emerge with it.

In developing countries a change of attitudes toward maps may be provoqued by the space technology push and the proven insufficienty of current procedures and policies. However, there are hardly any efforts mad to alert those responsibile for it that time and money spent on space efforts could satisfy mapping needs possibly also with conventional aerial photogrammetry.

Until such changes of attitudes take effect, satellite remote sensing will -- for conventional medium and small scale mapping -- have no application or merely one following an attitude of "anything is better than nothing if it is for free".

In conclusion, this paper is an effort to make two points. The major of the two points is to emphasize that there is a current world of conventional map-making and values attached to it. Satellite remote sensing images are not the kind of raw material to fit this world and its values.

The minor second point of this paper is to draw attention to two facts:

(a) a change in the current value system is needed to resolve the misery of unavailable and out-of-data-maps;

(b) a totally new task could, should and will emerge for map-makers in the area of monitoring the environment in the framework of a digital information system.

It will be in the context of these two items that satellite remote sensing images will have a lasting and meaningful rule for general purpose map making.

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