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CHAPTER 6

SPACE SHUTTLE IMAGING RADAR AND ITS APPLICABILITY TO MAPPING, CHARTING, AND GEODESY[†]

F. Leberl, J. Jensen [1976] Applications Review for a Space Program, Remote Sensing Research Unit. David Simonett [editor], Univ. of California at S. Barbara, 1976, pp 597-611

SUMMARY

The most significant Mapping, Charting, and Geodesy (MC&G) applications of Space Program Imaging Radar will include:

* continued small scale planimetric mapping (1:50,000)
* small scale map revision
* geoscience applications of radar imagery geometrically merged with other multispectral data (e.g. Landsat D & Space Shuttle Radar)
* positioning of maritime floating aids, ships, and icebergs
* mapping of lake and polar sea ice
* contingency flood mapping

RECOMMENDATIONS

Space Program Imaging Radar Program should:

* conduct more intensive research on classical mapping tasks such as stereoradargrammetry, block adjustment, and absolute/relative point positioning. Space Shuttle will serve as an excellent testbed to develop these techniques and expand radar's capability beyond reconnaissance type mapping.
* be geometrically correct (orthoradar), radiometrically correct, and partially theme processed to a mapping projection (e.g. UTM) for maximum user application. Space Shuttle will provide a testbed for the creation of such data prior to a dedicated orbital satellite.

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INTRODUCTION AND BACKGROUND

The Federal Mapping Task Force (Donelson, 1973) identifies Mapping, Charting, and Geodesy tasks as being:

- Land Surveys (point positioning for geodesy, cadaster, engineering)
- Land Mapping (planimetric, topographic, thematic)
- Marine Mapping (nautical chart, bathymetry, floating aid, hazard)

This can serve as a general cartographic requirements list for most countries of the world. Such tasks are carried out within the United States' national mapping programs primarily by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration. These and other agencies are further involved in a number of additional MC&G tasks. However, this federal MC&G task force cannot presently meet the requirement for maps, charts, and geodetic information; for example, the U.S. Geological Survey can satisfy only about 16% of the first priority needs for new mapping and 39% for revision of outdated maps (Donelson, 1973). In addition to these domestic mapping constraints, the United States cannot get by just inventorying and mapping its own natural resources. It is in the national interest to know exactly the world situation with respect to renewable and non-renewable resources because the U.S. uses so much of them and is heavily involved in international trade and aid.

It is against such a background that the United States and foreign MC&G communities are investigating alternatives to effectively meet the expanding cartographic challenge. In this context, space imaging radar will be evaluated to determine its potential applicability to MC&G tasks.

LAND SURVEYS

Radar block adjustments is a field of study that has not attracted the attention of many research workers. The comparatively weak geometry of all dynamic (kinematic) or line-perspective imaging systems does not present great promise for control network densification based on image blocks. From airborne radar, accuracy of relative point positioning cannot be expected to be better than about 10 meters (see Table 6.1). The only figure thus far available for orbital radar concerns the Apollo Lunar Sounder Experiment (ALSE) which resulted in a low accuracy of relative positioning of 100 to 200 meters due primarily to the steep look angles (Leberl, 1975). It is possible that the accuracy of point positioning from orbital radar could be dramatically better than the results obtained from the Apollo Sounder data. Space Shuttle Imaging Radar could play a key role in the research to establish accuracy models for orbital radar.

However, the accuracy of point positioning to be expected from radar images is not competitive with modern ground based methods employing observation of navigation satellites, nor with aerial or spaceborne photogrammetry based on metric photography. Therefore, radar could only be of marginal use for the densification of terrestrial nets of geodetic points.

LAND MAPPING

Planimetric

The most significant operational imaging radar application has been the planimetric reconnaissance-type mapping of pervasively cloudy, remote areas at scales of 1:100,000 and smaller. Vast areas of the world have been mapped in this way with the majority of these efforts taking place since 1972. For example, although Brazil began its extensive Radar Mapping of the Amazon--RADAM--in 1971 (Azevedo, 1971; Moreira, 1973), it only recently (in spite of available LANDSAT-MSS coverage) completed the acquisition of radar imagery of its entire territory of 9 million km^2. All Latin American countries sharing the Amazon Basin have now obtained radar coverage of this area (see Figure 6.1).

TABLE 6.1: MAPPING ACCURACIES ACHIEVED IN SINGLE IMAGE RADARGRAMMETRY (after Leberl, 1976)

Source	Year	Mapping Acc. (m) in Check-points:		Topogr. Relief (m)	# Control Pts. per 100 km^2	Radar Ground Resolu. (m)	Antenna Stabilited	Type of Radar	Image Scale	Remarks
		Along	Across							
Gracie et al	1970	20	14	217 to 302	10	17	yes	Synth. Ap. An-APQ 102		Atlanta, Georgia
Leberl	1971	50	23	flat	10	30	no	Real Ap.EMI	1:200,000	N.E. Netherlands
Bosman et al	1972	47	60	flat	10	30	no	Real Ap.EMI	1:250,000	Netherlands
Konecny	1972	152	255	mount.		16	yes	Real Ap. Westinghouse	1:250,000	New Guinea Conformal Transf.
Greve et al	1974	35				3	yes	Synthetic Ap. Topo II	1:100,000	Digital mono plotting
Goodyear	1974	38	30	flat	3	12	yes	Synth. Ap. GEMS 1000	1:400,000	Phoenix, Arizona
Derenyi	1974	89	111	0 to 150	1.1	16	yes	Real Ap. Westinghouse	1:250,000	Washington, D.C.
DBA Systems	1974	51	26		0.5	3	yes	Synth. Ap. An-ASQ142	1:100,000	Radar interferometer
Konecny	1975	80	79	flat		12	yes	Synth. Ap. GEMS 1000	1:400,000	Phoenix, Arizona
Derenyi	1975	30	28	flat		12	yes	Synth Ap. GEMS 1000	1:400,000	Phoenix, Arizona
Tiernan et al	1976	209	257	flat	0.7	30 to 150	no	ALSE orbit radar	1:1,000,000	Apollo 17 mission to moon steep look angles
Leberl	1976	147	233	flat	0.27	20 to 150	no	ALSE orbit radar	1:1,000,000	Apollo 17 mission to moom, steep look angle
Hirsch et al	1976	120		flat	3	30	no	Real Ap. EMI	1:100,000	Netherlands
Leberl et al	1976	140	170	flat	0.27	25 to 150	no	Synth. Ap. JPL-L-Band	1: 500,000	Alaskan tundra Steep look angles

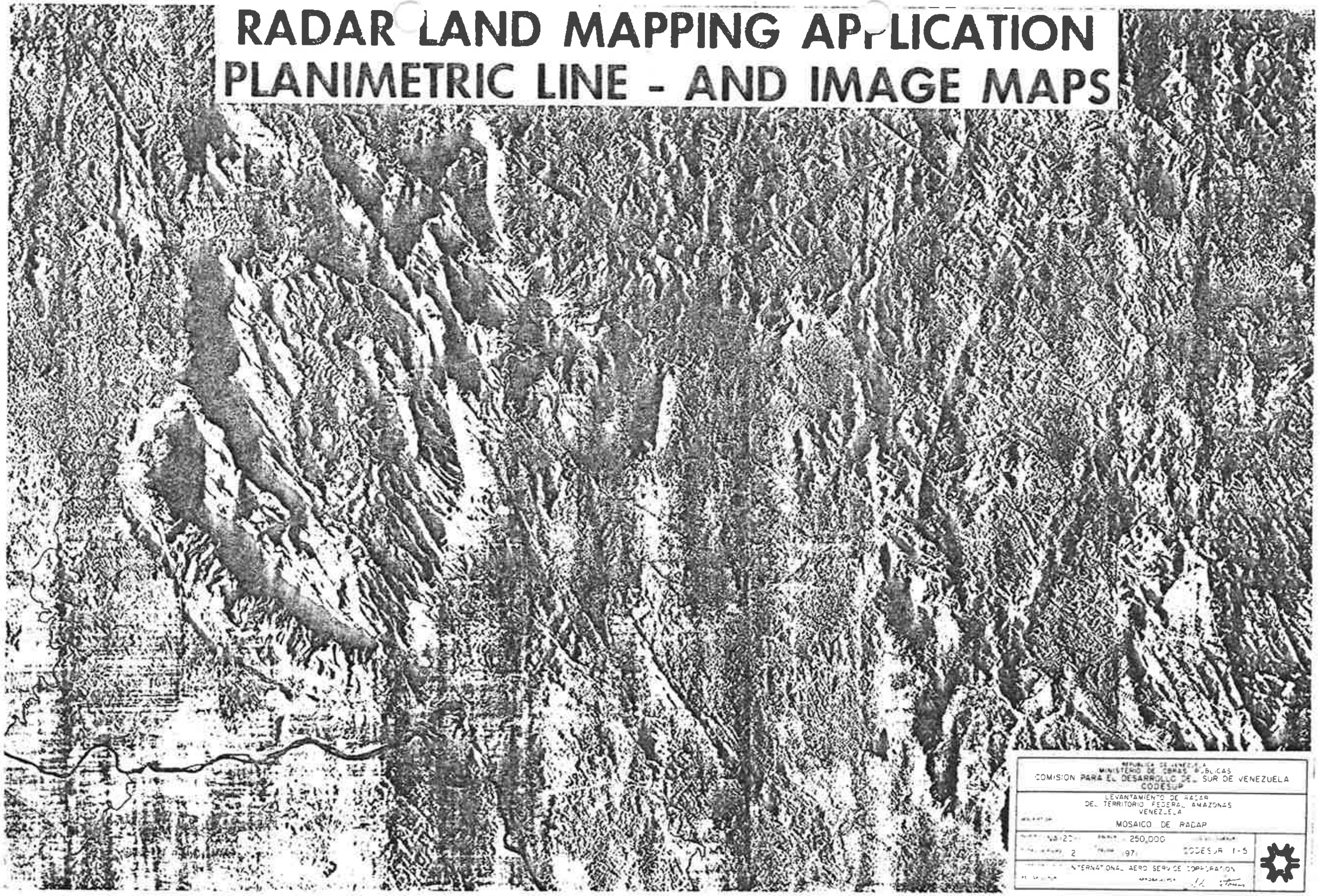


Figure 6.1. This is a semi-controlled radar mosaic of a portion of Venezuela compiled and published at a reconnaissance scale of 1:250,000. It is one of a series of sheets that provide the first overview of much of this perennially cloud-covered country.

In addition, Peru mapped a large portion of the Andes by radar, Colombia its Pacific coast, and Nicaragua its entire territory. Other mapping projects include portions of the Philippines, Indonesia, New Guinea and Australia.

The small scale (i.e. $\leq$1:100,000) is basically the result of the geometric ground resolution of radar images. Because radar ground resolution in range depends only on angle and on pulse length rather than upon distance from the antenna to the ground (Doyle, 1975), orbital radar and photography approach each other in range resolution as illustrated by Figure 6.2. Similarly, for a synthetic aperture system azimuth resolution is range independent. By comparing the ground resolution in Figure 6.2 with the percent of potential users satisfied in Figure 6.3 (after Donelson, 1973), it is clear that radar can play a role in future small scale planimetric mapping particularly with resolution of $\leq$ 30 meters and geometric rectification. This can further be confirmed in the context of National Map Accuracy Standards. According to these, 90% of check points measured on the final map must lie within 0.02" of their correct position for class A, within 0.04" for class B, and within 0.08" for class C-1 maps. This converts to the following meter-values on the ground, specifying 90% limits and standard deviations (1σ) of coordinate errors, σx, σy, as opposed to point-errors $\sigma p = (\sigma x^2 + \sigma y^2)^{\frac{1}{2}}$:

Scale	90% of coord. errors(m)			Stand. deviation of coord. errors (m)		
	Class			Class		
	A	B	C-1	A	B	C-1
1:250,000	90	180	359	54	110	218
1:100,000	36	72	143	22	44	87
1:50,000	18	36	72	11	22	44

Comparison of these requirements with the mapping accuracies shown in Table 6.1

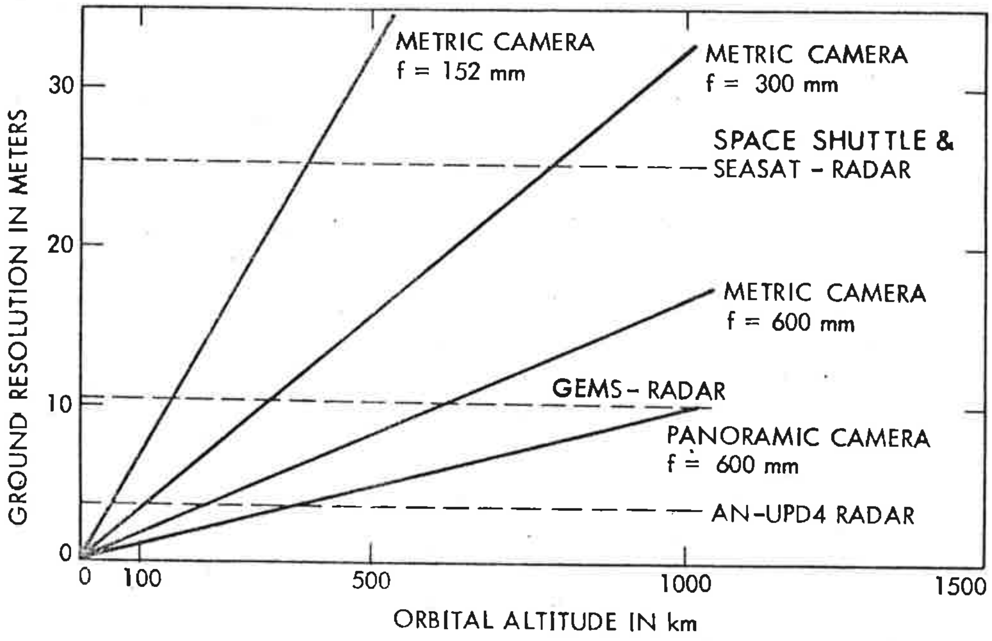


Figure 6.2 Comparison of orbital radar and photographic system resolution. Note how the radar resolution remains constant for a given synthetic aperture system.

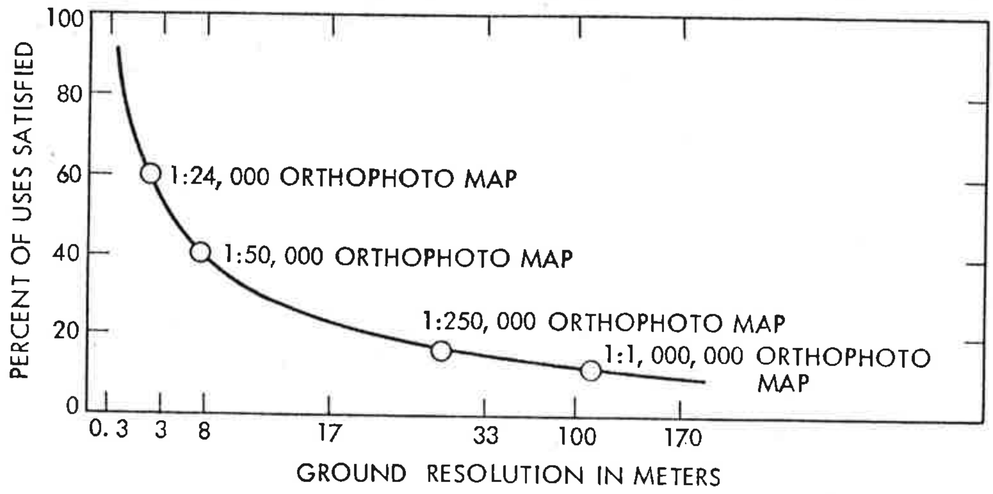


Figure 6.3 Relationship between resolution, mapping scale, and percent of users satisfied for orthophoto map products (adapted from Donelson et al., 1973).

indicates that airborne radar can satisfy class A mapping standards at scales up to 1:100,000, *depending on the amount of ground control* used for rectification (or gridding); scales of 1:50,000 can be met at class B levels. This leads one to hope that satellite radar will be useful at similar mapping scales.

Rectification

The along track and across track coordinates of radar images are generated independently of each other. There is, therefore, the possibility of inconsistencies in along and across-track scales. In the case of synthetic aperature radar images these can, if known, be removed in the process of converting the raw sensor output (the signal-histories) into the "map" film. The method employs a variable scale setting in the optical correlator (Jensen, 1975; Petersen, 1976). However, there are many more image deformations possible than just those due to a differential scale. Possible sources of such deformation were described by Van Roessel (1971), Leberl (1972a), Van Roessel and de Godoy (1974). Methods of rectification are numerical-graphical (Hockeborn, 1971); electro-optical (diCarlo et al., 1968, 1971; Yoritomo, 1972; Masry et al., 1976); or purely digital (Van Roessel, 1971; Thompson et al., 1972; Leberl et al., 1976).

For the numerical-graphical method, an ordered set of image-points ("tick-marks") is first transformed into a map system. Square shaped image patches are then rectified graphically using the four surrounding tick-marks and an anamorphic viewer as described by Ambrose (1967).

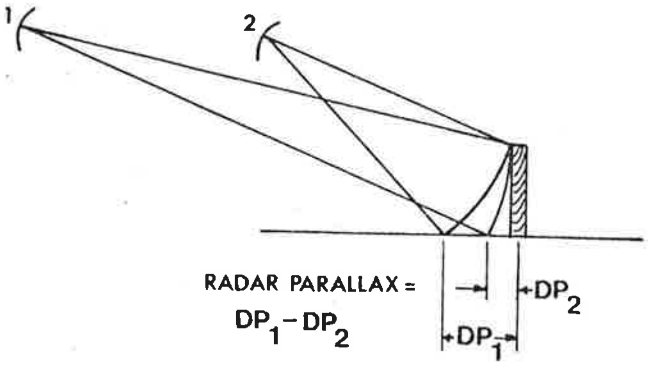
The electro-optical method uses a set of ground control points to compute the empirical relationship between the raw and rectified image. The settings of an electro-optical differential rectifier (Gestalt Radar Restitutor) are then calculated and the radar image is rectified. In the purely digital approach, the radar image is rectified in a digital image processing routine, using knowledge about systematic corrections and a set of ground control points to determine the coefficients of a "rubbersheet" stretch of the radar image. The use of rubber sheeting will enable Space Shuttle Imaging Radar to overcome spatial distortions in gentle relief without stereoscopy. Space Shuttle will provide a valuable testbed for this research.

The most satisfactory rectification program would not only employ a minimum of geodetic ground control points, but also R.B.V. images from LANDSAT-D and future LANDSATS, and a few satellite fixes for an adjustment of whole blocks of radar images.

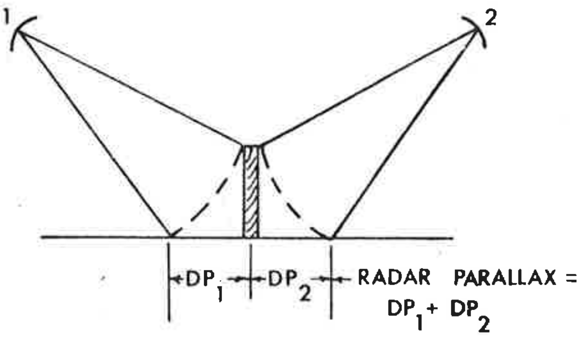
Stereo Configuration

For areas of significant relief, the unique stereo capability of Space Program Imaging Radar will be important for generating differentially rectified orthoradar products. The normal case of stereo radargrammetry consists of two parallel flight lines on the same side of the imaged area (same-side stereo; see Figure 6.4A). Other configurations, e.g. parallel flight lines on opposite sides of the imaged area (opposite-side; see Figure 6.4B), or at right angles (cross-wise; see Graham, 1975) can create difficulties in visually perceiving a stereoscopic model, to the point that such configurations cannot be employed. This exhausts the possibilities for synthetic aperture radar. For real aperture radar, there are still a number of possible stereo configurations, which can be generated along a single flight-line, for example imaging with convergent scanning planes (Leberl, 1972a; Bair and Carlsson, 1975), and with both radar and infrared scanner (Moore, 1969).

Experimental stereo analyses have been performed by a number of authors. An overview of the results is given in Table 6.2. In some cases the accuracies quoted are optimistic, particularly if they concern opposite-side stereo configurations. Opposite-side stereoscopic viewing may be mainly possible



A: SAME SIDE-SAME ALTITUDE RADAR CONFIGURATION



B: OPPOSITE SIDE-SAME ALTITUDE RADAR CONFIGURATION

Figure 6.4 AB. Radar relief displacement is an inherent characteristic of side-looking imaging systems and is towards the nadir if the object is above the datum and away from nadir if the object is below the datum. The relief dispacement, therefore, is in the opposite direction from the displacement in optical camera systems. When one object is imaged twice at two different look-directions, i.e., either same side (A) or opposite side (B) configuration at the same altitude, then radar parallax can be measured and radar stereoscopy attained.

TABLE 6.2: MAPPING ACCURACIES ACHIEVED IN STEREO-RADARGRAMMETRY
(after Leberl, 1976)

Source	Year	Mapping Acc. (m) in Checkpoints			Control Pts. per 100 km^2	Radar Ground Resolution (m)	Antenna Stabilized	Type of Radar	Remarks
		Along	Across	Height					
Gracie	1970	12.1	7.7	13.2	35	17	yes	Synth. Ap. AN-APQ 102	Atlanta, Georgia
Konecny	1972	68	138	240		16	yes	Real Ap. Westinghouse	New Guinea, opposite side stereo
		130	428	1548					New Guinea, same side stereo
DBA-System	1974	26.8	21.9	16.7	1.2	3	yes	Synth. Ap. AN-ASQ 142	Opposite side
		29.5	25.6	19.7	1.2				Same side
Goodyear	1974			93	3	12	yes	Synth. Ap. GEMS 1000	Phoenix, Arizona, Opposite side stereo
Derenyi	1975			33		12	yes	Synth Ap. GEMS 1000	Phoenix, Arizona, Opposite side stereo
				177					Phoenix, Arizona, same side stereo
Leberl	1975	173	510	109	0.27	30-150	no	Synth. Ap. ALSE-UHF	Apollo 17 orbital radar stereointersection angles 2°

in the case of fairly flat terrain or only isolated mountains surrounded by flat terrain. In other cases, lay-over, shadowing, and general differences in the contents of overlapping image pairs may not permit opposite-side stereo measurements to be taken, although geometrically, the opposite-side stereo arrangement is superior, because of greater parallax differences.

Based on a general evaluation of Table 6.2, height mapping from orbital stereo radar is only possible with an accuracy in the range of 100 meters. From orbital altitudes of about 1000 km, radar heights would be competitive with heights derived from metric photography but hardly useful in terrestrial mapping except in the last unmapped mountain regions of the Earth (Cordilleras, Himalaya). This indicates that orbital stereo mapping may not for some time come ~~to~~ be the way to derive terrestrial topographic height, whether it be from photography or other types of images. However, in all fairness to the capability of stereo radar it has only been investigated in the context of reconnaissance type mapping rather than classical mapping approaches (Leberl, 1976). For example, contouring from radar stereo models has been reported on only two occasions; Norvelle (1972) demonstrated the use of the analytical plotter AS-11-A to directly plot contour lines from a deformed radar model. Leberl (1975) produced a radar contour plot of a lunar feature, however not by directly tracing the contour lines, but by first acquiring a digital height model, from which the contours were interpolated numerically.

Considerable research is required before a definitive statement can be made about orbital radar's contribution to topographic mapping. Space Shuttle will certainly further this research. However, it should be stressed that there is no doubt about the value of stereo-radar for purposes other than terrestrial topographic height mapping. For example, Koopmans (1973) demonstrated clearly the dramatic improvement in the mapping of drainage if stereo radar rather than monoscopic radar is employed. The first significant use of stereo-radar for drainage mapping was in 1970 in studies for Kennecott Copper Corporation in West Irian (Simonett and McCoy, Earth Satellite Corporation, unpublished memorandum, 1970).

Merging Radar with other Multispectral Data

A major radargrammetric application is the merging of radar image data with imagery from other sensors. Attempts to merge data from different sensors are presently being undertaken (Harris and Graham, 1976). No specific conclusions have been reached as to a geoscience application of such techniques. However, there seems to be a growing awareness among remote sensing specialists that ultimately remote sensor data from many sources have to be combined for optimum interpretability. Stereo capability may be required for all areas except extensive plains, in order to merge both the radar and M.S.S. images. Because of the improved resolution of LANDSAT D MSS, strictly speaking, the MSS should also have stereo capability to achieve a satisfactory ortophoto/projection-based merge. Rubber sheet adjustments can of course be made for both images in the absence of stereoscopy, but the latter is preferred.

Figures 6.5, 6.6, and 6.7 give a good indication of the potential of geometrically merging multispectral sensor products. When the LANDSAT color composite (Blue, Band 4; Green, Band 5; Red, Band 7) is combined with the X-band radar image, a definite improvement in overall image information and interpretability is produced. Extrapolate the capability of this technique to combining LANDSAT-D ($\leq$ 30 meters) and Space Program Imaging Radar ($\leq$ 30 meters) and we will potentially have a powerful resource analysis product. Such data will be of great importance to the next topic which considers SPIR's role in thematic mapping.

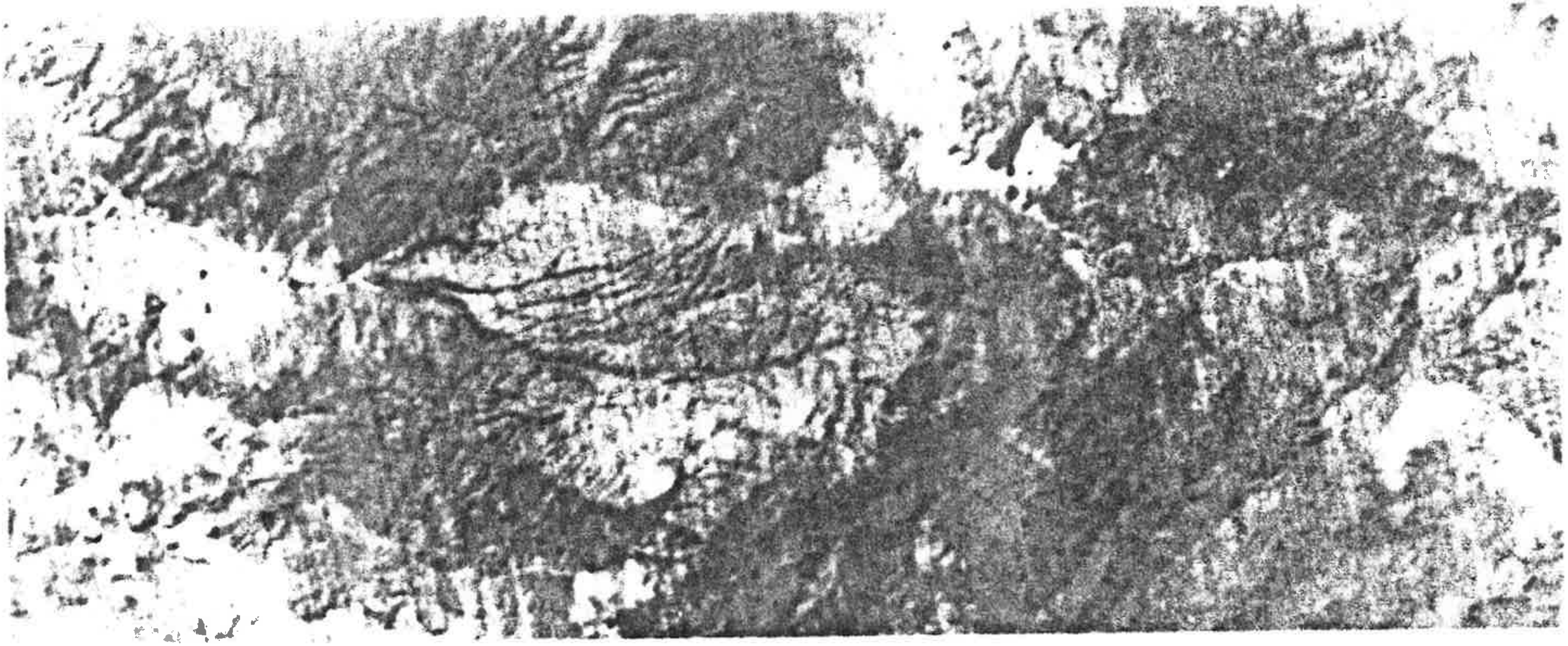
Figure 6.5 LANDSAT color composite of an area near Tucson, Arizona. Bands 4, 5, and 7 were filtered (blue, green, red respectively) and optically combined to produce the 1:1,000,000 (original scale) image. Note the lack of spatial and spectral detail present in the open pit mine areas shown by the absence of small color contrasts. (Courtesy of Goodyear Aerospace Corporation)

Figure 6.6 X-band synthetic aperture radar image of the area near Tucson, Arizona produced by the Goodyear Gems APS-102 system. (Courtesy of Goodyear Aerospace Corporation)

Figure 6.7 Optically combined X-band radar/LANDSAT image (see Figures 6.5 and 6.6) of the area near Tucson, Arizona. Note the increase in detail produced when the high resolution synthetic aperture radar image is merged with the low resolution (i.e. 80m pixels) LANDSAT image. More importantly, note also that this spatial detail is accompanied by parallel changes in color indicating that the radar image is providing additional spectral as well as spatial information.

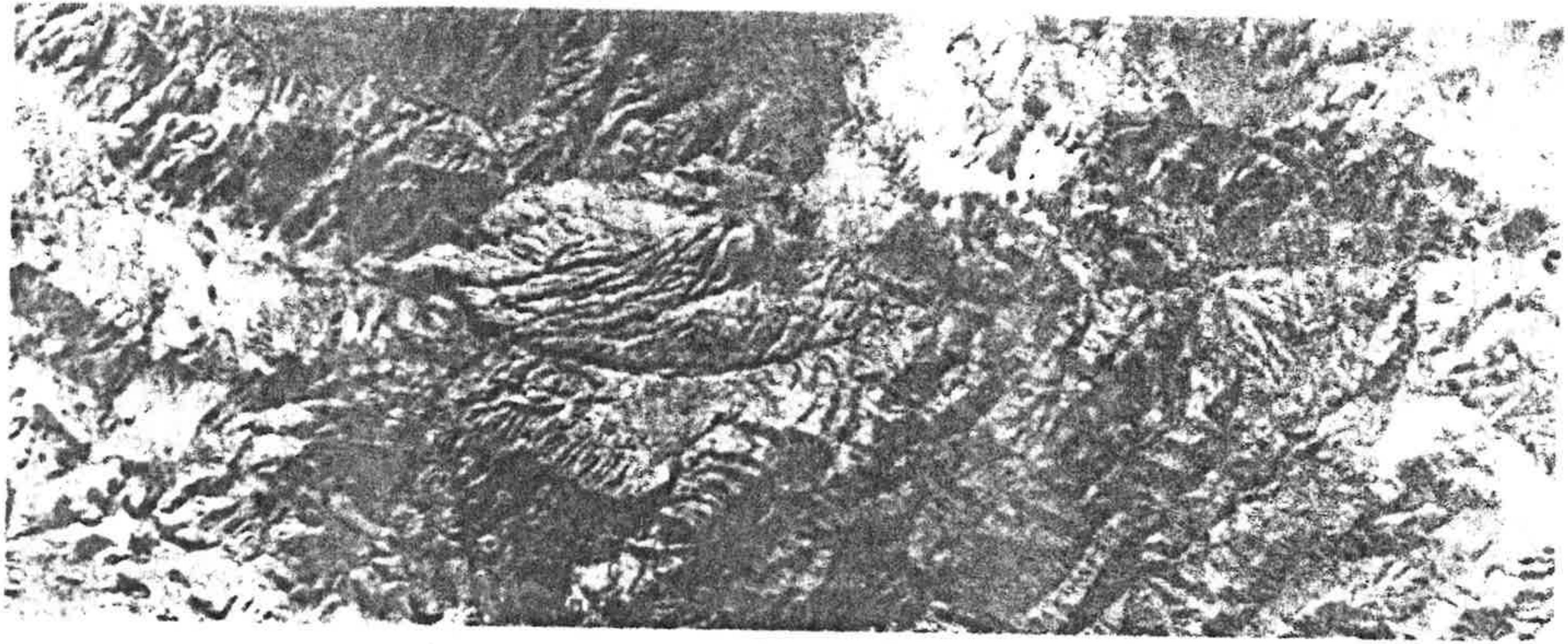
RADAR LAND MAPPING APPLICATION
THEMATIC MAPPING

LANDSAT



RADAR LAND MAPPING APPLICATION
THEMATIC MAPPING

RADAR & LANDSAT



Thematic Mapping

Thematic maps emphasize themes symbolized on a basemap which contains reference information. One of the primary strengths of Space Program Imaging Radar will be its unique capability to generate thematic data which may be unobtainable from any other sensor configuation. For example, Table 6.3 summarizes some of the radar capabilities and their general significance to thematic mapping.

Processing of radar image data for the preparation of thematic maps involves the rectification of images, compilation of semi-controlled or other image mosaics, and registration of images from different sources, followed by the compilation of the thematic content on the rectified and mosaicked base.

Along with the significant federal and state requirements for thematic products already presented in this report, the U.S. business community has definite thematic radar requirements (Archibald Park, General Electric Corporation (personal communication)). In particular, private industry finds that almost all client requirements are cartographic. Dr. Park recommends that NASA establish a specialized processing facility and carry the processing a long way to widen the user base. Three options are proposed (see Table 6.4). The first is raw data and CCT. This has a high cost to the user and substantially cuts the number of users down and means that there is an immense amount of redundant work in the user community. The second is to take the raw data, radiometrically and geometrically correct it, and then give it to the user as a CCT. This still has a moderate cost to the user and much redundancy which in the long run is not cost-effective.

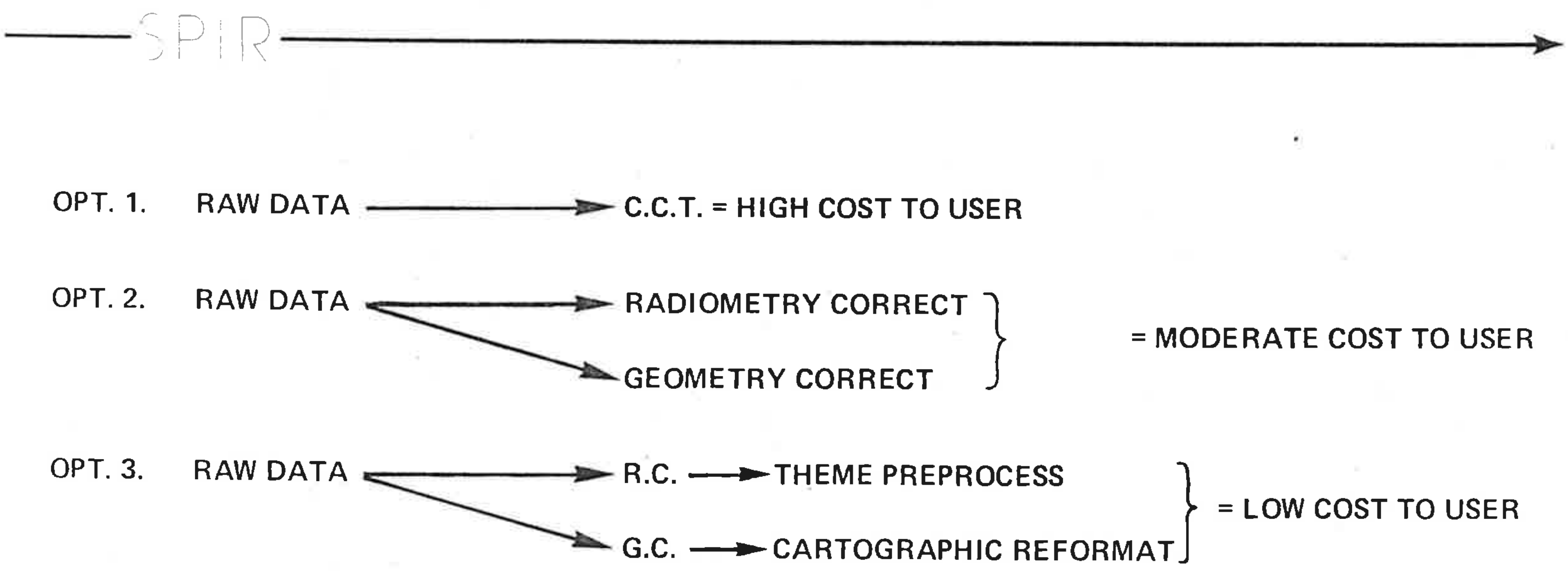
The third and recommended option is that NASA radiometrically correct, geometrically correct (i.e. to orthoradar), theme pre-process, and then place the image into a cartographic format such as a UTM projection. This has the lowest cost and most benefit to the user community. All image

Table 6.3: Radar Capabilities and their Significance in Thematic Mapping Applications

CAPABILITY	COMMENTS
Provides its own illumination	Timeliness enables thematic data to be obtained at all times and in inhospitable regions.
Penetrates clouds and rain	
Penetrates vegetation	Potentially important geologically; improves land/water delineation.
Permits control of illumination angle	Enhances topography.
Permits control of illumination direction	For emphasizing geologic structures. In space will occur as orbits precess, and between ascending and descending orbits.
Resolution independent of distance	Can make satellite radar complementary to satellite photography.
Multifrequency capability	Combined image may reveal greater content of information than single frequency.
Multi-Polarization capability	Significant differences exist between like images (HH vs VV) and between them and cross images (HV).
Employs EM spectrum different from visible	Records dielectric properties of targets.
Sensitivity to surface roughness	Significant for geological and engineering studies.
Sensitivity to surface soil moisture	Valuable for watershed runoff, agricultural yield.
Stereoscopy	Provides 3-dimensional terrain model for thematic data extraction.

TABLE 6.4

INDUSTRIAL IMPACT ON DATA PROCESSING DESIGN



SPIR

OPT. 1. RAW DATA → C.C.T. = HIGH COST TO USER

OPT. 2. RAW DATA → RADIOMETRY CORRECT
GEOMETRY CORRECT
= MODERATE COST TO USER

OPT. 3. RAW DATA → R.C. → THEME PREPROCESS
G.C. → CARTOGRAPHIC REFORMAT
= LOW COST TO USER

FOR INDUSTRY OPT. 3 = MORE CLIENT INTEREST = LARGER USER BASE

NOTE: THIS APPLIES TO ALL USERS FOREIGN & DOMESTIC and derived thematic data of all dates could then be laid on top of one another to create geobase information systems with congruent geometry.

Marine Mapping

Increased point positioning and planimetric mapping capability developed through Space Shuttle Radar experiments could be potentially useful for acquiring planimetric data (original or updated) for four of the five basic types of NOAA/NOS nautical chart programs including:

Type	Scale Range
Sailing	1:600,000 and smaller
General	1:100,000 to 1:600,000
Coastal	1:50,000 to 1:100,000
Harbor	1:50,000 and larger

While general charts are designed for coastal navigation well offshore they still require planimetric reference to coastal landmarks, lights, and bouys. Area coverage of this chart series is about 95 percent complete, with an updating interval governed by the rate of change in a particular area which ranges from 6 months to 4 years. However, there are major inadequacies such as the incomplete coverage of Alaskan waters (Donelson et al., 1973). Because radar creates its own illumination it is not perturbed by the low level of illumination of the polar regions nor the frequent, dense cloud cover which has hampered photographic data collection. Therefore, for many inhospitable regions radar could provide data to complete or update nautical map series.

Probably the most significant marine impact of Space Program Imaging Radar will be the mapping of point man-made features (such as ships, floating aids), natural features (such as icebergs) and area extensive features such as ice. The timely monitoring of point features becomes increasingly important in view of a growing density of ship movement and the extension of national fishing zones. In addition to its all-weather capability previously mentioned, microwave sensing is especially capable of resolving many marine features because of the relative ease with which it is possible to signalize features on a specularly reflecting water surface. In fact, the application of radar to tracking icebergs is now considered near-operational (Schertler et al., 1975).

The application of radar to mapping area extensive lake ice is also considered to be near-operational (Super and Osmer, 1975). This application to polar sea ice, however, seems only to have been developed to this status in the U.S.S.R. (Glushkov et al., 1972). A major future task, particularly well suited to Space Program Imaging Radar will be the capability to map the polar sea ice and its associated ice motion (Ice dynamics). Although Shuttle Radar will only be on 7-day sorties, certain experiments could capitalize on the system's multipolarization, frequency, and look angle capability to suggest improvements in point feature identification and ice monitoring from future orbital microwave systems.

CONCLUSIONS: ROLE OF SHUTTLE IMAGING RADAR IN MC&G

The 7-day missions of the space shuttle are well suited to provide radar data that permit an evaluation of their applicability to MC&G tasks under near-operational conditions. The data acquired during a specific sortie could be evaluated to recommend parameter changes for dedicated microwave orbital systems.

Application of radar to classical mapping tasks has been limited to reconnaissance mapping of remote areas. The radar images have not been used to their full potential in these projects. It is recommended that the Space Shuttle Imaging Radar be applied to specific radargrammetric mapping projects to determine the true capability of orbital planimetric mapping, map revision, stereo radargrammetry, block adjustment, and the relative/absolute point positioning. In the realm of thematic mapping, Space Shuttle can only satisfy the requirements for monitoring slowly changing phenomena, perhaps providing only a few complete coverages per year. Nevertheless, the geometric merging of radar with other multispectral data and the techniques of theme pre-processing could be significantly advanced via the shuttle sortie concept.

Timeliness and costs of Mapping, Charting and Geodesy (MC&G) products are such an overriding concern that a significant number of MC&G tasks have evolved in the past for airborne side looking radar. However, when arguing the case for orbital radar it is appropriate to consider the relative merits of airborne versus orbital systems. Apart from the requirements for repetitive imaging of dynamic features such as those associated with marine mapping, where the low variable cost of orbital mapping soon results in an advantage over airborne mapping, there is even an argument for orbital radar imaging in the case of single coverage. This is demonstrated in Figure 6.8, which relates the fixed and variable cost of airborne and orbital radar imaging. In this context, Space Shuttle Imaging Radar will allow a rigorous analysis to be made concerning the cost effectiveness of orbital radar mapping applications. We recommend that this be examined specifically in later shuttle studies.

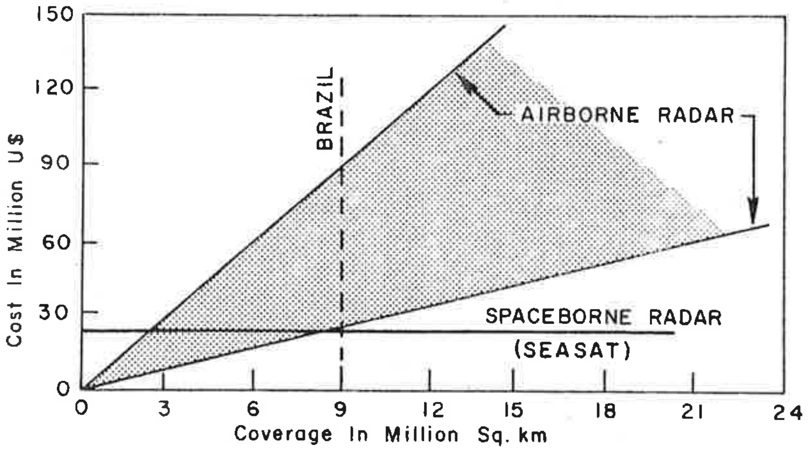


Figure 6.8 Estimate of costs versus coverage with airborne and orbital imaging radar. For airborne radar, prices per square kilometer can be about $3-10. The SEASAT synthetic aperture radar will cost approximately $14 million with mission and ground support being approximately $6 million. Radar data processing costs are rather small if the development costs of processing technology are not considered. (Jet Propulsion Laboratory).

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