REGISTRATION WORKSHOP REPORT

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I. INTRODUCTION

The following is a brief report on the NASA Workshop on Registration and Rectification held in Leesburg, Virginia during November 17-19, 1981. Sponsored by NASA Headquarters, the workshop was attended by over a hundred representatives from NASA and other government agencies, universities and private industry. The purpose of the workshop was to examine the state-of-the-art in registration and rectification of image data for terrestrial applications and make recommendations for further research in these areas.

The workshop was organized into plenary session presentations and panel/subpanel meetings. There were three panels-Registration, Rectification and Error Analysis-with seven subpanels as shown below.

- o Registration - Image Sharpness, Feature Extraction, Inter-Image Matching

- o Rectification - Remapping Procedures, Resampling Functions
- o Error Analysis - Error Characterization and Error Budgets, Methods of Verification

Initially, presentations were made on user's needs, space and ground segment errors, and systems. Representatives from each of the subpanels provided tutorial presentations on their respective topics. Separate subpanel meetings were held to identify the state-of-the-art and make recommendations on further work needed in each of the subareas. These recommendations were then presented to the members-at-large by the respective subpanel chairmen to pursuit general discussions. Next the subpanels reconvened and reworked the recommendations accounting for inputs from the members-at-large. The results of these meetings were again presented in a final plenary session.

The following is a summary of the information gathered during the workshop. It is not meant to be comprehensive. It will probably not provide equal emphasis to all the topics covered. It is, rather, a condensation of my notes from the workshop and the information from a number of references handed out. The list of handouts referred to in preparing this report is given in Section IX. A more complete bibliography on registration will be available with the detailed workshop report (to appear in Spring 1982)

II. USER'S NEEDS

The requirements of the users are dependent on the discipline and applications. The following disciplines were represented at the workshop with corresponding applications:

1. Land Use, Land Cover and Hydrology:

   a. Generation of land use and land cover maps

   b. Merging with ancillary data in a geographic information system

   c. Finding the effect of land use on hydrological budget

   d. Estimation of water usage via modelling

   e. Identification of residential land use.

2. Agriculture and Forestry

   a. Foreign crop forecasting

   b. Domestic crop acreage estimation

   c. Forestry information

d. Rangeland evaluation

3. Geology

a. Structural mapping

b. Material type identification

c. Linear mapping

d. Generation of small (quadrangle size) and large (state/country wide) mosaics

e. Hydrological studies

f. Comparison of mosaics with topographic maps

g. Monitoring temporal changes in vegetation for soil type information and soil erosion.

h. Albedo monitoring in arid lands

i. Land slide/erosion potential mapping

4. Oceanography

a. Sea-ice dynamics and ice-flow tracking

b. Ocean pattern analysis

c. Motion measurements

d. Biological estimates

5. Meteorology

a. Severe storms prediction

b. Measuring atmospheric motion and cloud growth

c. Generation of time-lapse displays

d. Cloud height estimation

Typical requirements indicated by the users are:

1. Accuracy

a. It is sufficient if the "system" (i.e., the central data distribution facility) performs as well as the users themselves do, so that the users can avoid spending the effort in registering their images.

b. Root-mean-squared errors of less than one pixel are satisfactory in applications involving extraction of summary data for polygons.

c. Many Landsat users are satisfied with fitting the data to standard maps at 1:250,000 or 1:500,000 scale (implying errors less than 127 or 254 meters at more than 90% of the locations).

d. Errors of less than .5 pixel at (90% of the location) for temporal registration and digital mosaicking are satisfactory for most applications in geology and meteorology.

e. For applications involving visual interpretation (for example, making linears from large area mosaics) errors of the order the "width of a pencil line" (1.5 pixels) are acceptable.

f. One forestry application involving combination of Landsat data with other data for regions containing irregular features required an absolute accuracy of 20 meters at more than 95% of the locations.

g. It is necessary to have 50% of the "multitemporal energy" from the same ground area. This implies that (in the absence of rotational errors) the shift in the X (or Y) direction should be less than or equal to $(\sqrt{2}-1)/\sqrt{2}$ = .29 pixels.

2. Other

a. The "system" should provide information on image geometry, such as listings of ground control points.

b. The "system" should provide more quality information.

c. Software for transformation of coordinates from one projection to another and a convenient means of converting from geodetic to image coordinates and vice versa should be available.

d. The images should be rotated to north to facilitate inclusion into geographic information systems.

e. Pixel sizes which are multiples (and submultiples) of 50 meters are preferred.

f. For oceanographic applications, a well organized, easily accessible file of coastline and landmarks is useful.

g. Applications-specific, rather than data-source-specific, packaging of techniques for users is needed.

It is to be noted that there were no user-expressed needs for band-to-band registration. It was assumed that this was easily satisfied as in the case of Landsat MSS and was considered a non-problem. Also, some of the needs were obviously tempered by the user's perceptions of the capabilities of the present Landsat systems.

There are at least two recent quantitative studies addressing this topic. The first, by Swain (1980) uses simulated Thematic Mapper data sets using aircraft multi-spectral scanner data. Classification accuracies are evaluated for various simulated band-to-band registration errors. It is found that a misregistration of .3 pixel causes a classification change of over 10%. The second study, by Billingsley (1981) treats band-to-band and multitemporal registration similarly. Using a first order analysis and modeling the multispectral classification process, this study concludes that the difference between .3 and .5 pixel errors in registration are insignificant and greater gains will be realized with increased spatial resolution than with increased registration accuracy at a given resolution.

III. SYSTEM ERRORS

Several presentations were made regarding the sources of distortions in images from various types of sensors. The sensors considered were space- and air-borne scanners, Synthetic Aperture Radar and Multispectral Linear Array. Of primary interest is the error remaining after correcting for known/measured system-induced distortions. This represents the error that can only be removed using ground control points.

In the presentation by Ungar, examples of simulated aircraft scanner errors, their effects on images, and the correction of those errors were shown. However, no quantitative estimates of the residual errors after systematic corrections were given (even though in an experiment with ground control points and systematic corrections an RMS error of .29 pixel was obtained at a pixel size of 30 meters).

The main sources of error in such "Systematic Corrections" are the uncertainties in measuring ephemeris and attitude of the spacecraft and the alignment of the sensor relative to the spacecraft body. The present Landsats (up to 3) use the Goddard Spacecraft Tracking and Data Network (GSTDN) for deriving the ephemeris data. The accuracy of the attitude measurement system is .1 degree. The initial operation of Landsat-D will use GSTDN for ephemeris. Even though the operational post-processing of the ephemeris data can reduce the error to 105m (Root-Sum Squared of along-track, across-track and radial 1σ errors), the ground processing is designed for the worst case errors of 510 meters associated with two-day predicts of orbit data. It is expected that with TDRSS in operation, the RSS error will be reduced to 90 meters and with the Global Positioning System the error will be further reduced to 12 meters (1σ with 4 satellites in view) to 60 meters (with poor visibility). The presentation on GPS indicated, however, that the ephemeris data may be intentionally degraded to greater errors than indicated here. The attitude measurement accuracy on Landsat-D is .01 degree. Table I shows the approximate errors in the systematic correction data for Landsats.

Tests on Seasat SAR processing have indicated that systematic corrections leave residual errors in the neighborhood of 200 meters.

Note that the errors remaining after systematic corrections, even with the better ephemeris and attitude measurements anticipated, are greater than acceptable as indicated by user's needs. This clearly implies that some amount of ground control (or relative control for multitemporal registration) will be required at least for the foreseeable future.

IV. GEODETIC ERRORS

Given that it is necessary to use ground control to achieve the required geodetic accuracy, it is relevant to examine the availability and accuracy of geodetic data throughout the world. Presentations on geodetic data indicated that within the U.S., the geodetic control data were quite good with datum points known to within 15 meters (absolute accuracy) (per NAD27) and expected to be known to within .5 meters (per NAD83). The estimated absolute accuracy in the worldwide geodetic data, however, was 200 meters. Also, the data are generally not available due to security classification and the available data are not current. It may well prove that, for many of the non-U.S. areas, the satellite data will provide better mapping information than currently available and relative registration will be the best that can be expected.

The U.S. National map accuracy standards call for "errors of less than 0.02" (90%) at any scale smaller than 1:20,000. This is equivalent to approximately 12.2 meters at the scale of 1:24,000 used for the 7 1/2 minute quadrangle sheets. This means that many of the control points used for geodetic registration could be in error by as much as 0.4 pixels at the TM resolution. Therefore, to achieve the desired 1/2 pixel accuracy, (i) all the other procedures used in registration must have a tight subpixel error budget, and (ii) unless the errors tend to compensate each other the accuracy may not be achievable.

V. REGISTRATION

The tutorial papers on registration addressed the issues related to automatic matching of images and the preprocessing needed to achieve better results. Preprocessing steps useful for manual determination of control point coordinates from a displayed image are: enlargement using cubic convolution, least-squares estimation for given (or assumed) modulation transfer function (MTF) and noise characteristics and other enhancements to sharpen the image. Even though enlargement, as a preprocessing step, may be useful in automatic matching of local image areas, it has not been used much.

The most common approach to image matching is to:

(i) Store a local patch (control point chip) from a reference image in a control point library

(ii) Extract a neighborhood, from the registrant image, large enough to assure inclusion of the control point chip

(iii) Preprocess the chip and the neighborhood using gradient filters and/or binary edge determination

(iv) Compute a "correlation surface" to define the match between the chip and neighborhood for all integral pixel displacements of the chip.

(v) Find the integral coordinates of the location of maximum correlation.

(vi) Interpolate the correlation surface around its maximum using a linear or quadratic model and estimate the fractional coordinates of the correlation peak.

(vii) Repeat the procedure for several patches and find displacements between expected and actual locations of match.

(viii) Find a global mapping function to fit the registrant image to the reference image.

Studies have shown that matching gradient or edge images, rather than grey level images directly, is more likely to succeed especially in cases of multitemporal scenes. It is important to suppress cloudly areas prior to matching and techniques exist to find matches in slightly cloudy neighborhoods. Various correlation methods have been used including Fast Fourier Transforms, binary "AND" and bit counting, Sequential Similarity Detection, etc.

Generally, criteria are needed for automatic rejection of control points so that the final mapping will not be affected by erroneous matches. The usual creteria are: peak threshold, primary to secondary peak ratio, offset magnitude threshold, errors in least squares fitting to find the global mapping function.

Since control point correlation is a computationally intensive process, it is desirable to minimize the number of control points required. The number of control points necessary to achieve a given registration accuracy depends on the accuracy with which their individual locations are known, their distribution and the accuracy to which the physical model used to describe the imaging process is known.

The above image-matching procedure assumes that the local patches suffer only translational errors. This is a reasonable assumption over small neighborhoods of multitemporal satellite imagery. However, for matching aircraft images or multisensor images where local distortions can be significant, or for direct "full-image matching" other techniques are used. Of note in this regard are (i) finding affine distortions in the Fourier domain and (ii) least-squares estimation of the coefficients of a parametric distortion model.

VI. RECTIFICATION

The problems associated with handling large quantities of image data and the fidelity of resampled digital images were the major topics considered by the rectification panel and its tutorial presentations.

Alternatives to representing "output space to input space" mapping functions are: direct functional method gridded approximation, dope vectors and combinations thereof. The direct functional method is suitable only for simple transformations applied to small images (for example, affine transformation and images less than 1000 by 1000). The more common approach is to use a gridded approximation taking advantage of the low spatial frequency of the mapping functions. The functions are fully evaluated over a very sparce grid. The mapped coordinates for non-grid points are computed by suitable interpolation using the nearest grid-points. When the distortions are functions of a single variable (for example, the non-linear mirror velocity profile on the Landsat MSS, or the earth skew offsets and sensor readout delay) they can be stored in "dope vectors" and used as table-look-up corrections to computed coordinates. When high-frequency corrections are present (such as jitter on Landsat-D TM) it is necessary to use combinations of the above methods.

Data handling is a significant problem in the rectification of images. For example, the rotation of a 2340x3240 MSS image by 14.4 degree (the approximate angle to orient to North a Landsat 3 image at 35 degree latitude) requires 835 lines of input image to generate one line of output. The problem is worse with TM images where the nominal line length is 6176 pixels. It is for this reason that the ground processing systems for Landsat have chosen not to orient the images to North, but use a fixed angle from North for all images of a given scene such that the buffer size for resampling is minimized. In general, it is necessary to segment an input image, resample and reassemble the output image. The strategies for doing this are varied depending on the hardware configuration.

Geometric transformations involving small angles of rotation can be treated as separable and the horizontal and vertical resampling can be performed independently with no significant difference in the output image values. Separable transformations also have the potential of being implemented with intermediate 90 degree rotations (or transpositions) for which efficient methods exist.

Nearest neighbor, bilinear, cubic convolution, sin x/x interpolation, spline interpolation, and least-squared error with respect to a desired point-spread function are among the approaches to deriving the resampled output images.

The advantages and disadvantages of these methods are discussed sufficiently in the literature. The cubic convolution method is used in the ground processing systems for Landsat due to its balance between performance and computational complexity.

VII. VERIFICATION AND VALIDATION

The error analysis panel was concerned about the procedures for characterizing the errors as well as verification and validation of geometrically corrected products. It was indicated that in the present production system for Landsat images there was insufficient verification of geometric accuracy.

Verification can be a labor-intensive process depending on the extent of output images to be checked. Geodetic accuracy of an image can be verified by converting the geodetic coordinates of selected points within a scene to image coordinates, displaying neighborhoods of these points, comparing them with maps, and checking whether features on the map and the image overlay as expected. The tools needed for this are identical to those for building a Control Point Library. The task is simplified if sections of maps are available in digital image format.

Verification with such digital maps (and verification of registration of two images) can be performed by using flickering displays. Registration can also be verified automatically by correlation of several test segments from the reference image with the corresponding segments of the resampled image registered to it. Such a procedure would, however, be insensitive to high frequency distortions.

VIII. RECOMMENDATIONS

The recommendations made by the various panels and the members-at-large can be summarized under three major headings:

1. Verification and Validation: It is necessary to have a capability to verify achieved registration accuracies and validate techniques appropriate to a given sensor using simulations. It is necessary to define the amount of quality control required and to design a system which permits efficient verification.

2. Advanced Registration System: Advanced concepts in registration such as sensors with inherent registration accuracy, pointable sensors with selectable/multiple resolution, on-board processing for registration, and "creation" of a few very accurate, possibly "active" ground control points per orbit should be studied. Analyst's capabilities should also be enhanced through interactive terminals with image enhancement and manipulation software, especially related to remapping to various projections. Such software should be modular and transportable.

3. Universal Control Point Library: A control point library system should be developed which receives, verifies and enters data from various sources. The library should be applicable to several sensors. It should provide world-wide coverage and have a database management system permitting distributed input/output access to users. Potential use of non-image format "control point patterns" should be considered.

IX. REFERENCES

Workshop Presentations (November 17-19, 1981)

1. Allen, R., USDA Registration and Rectification Requirements.
2. Ananda, M., Navstar/Global Positioning Systems.
3. Ando, K. J., MLA Imaging Systems.
4. Anuta, P. E., Image Sharpness.
5. Beyer, E., Geometric Error Characterization and Error Budgets (Landsat-D Thematic Mapper Processing).
6. Billingsley, F. C., Data Versus Information: A System Paradigm.
7. Chavez, P. S., Jr., Registration and Rectification Needs of Geology.
8. Curlander, J. C., Geometric and Radiometric Distortion in Spaceborne SAR Imagery.
9. Dalton, J. T., Data Registration and Integration Requirements for Severe Storms Research.
10. Driver, J. M., A Case for Inherent Geometric and Geodetic Accruacy in Remotely Sensed VNIR and SWIR Imaging Products.
11. Dye, R. H., A Quantitative Assessment of Resampling Errors.
12. Engel, J., Thematic Mapper Performance.
13. Gaydos, L., Needs for Registration and Rectification of Satellite Imagery for Land-Use and Land-Cover and Hydrologic Applications.
14. Grebowsky, G. J., Geometric Verification.
15. Haralick, R., Feature Extraction.
16. Heuberger, H., Spacecraft Induced Error Sources.
17. Nichols, D., Oceanographic Satellite Remote Sensing: Registration and Data Integration Requirements.
18. Prakash, A., Spaceborne Scanner Imaging System Errors.
19. Ungar, S. G., Aircraft Scanner Imagery System.
20. Wolfe, R. H., Jr., and R. D. Juday, Inter-Image Matching.
21. Zobrist, A. L., Computational Aspects of Remapping Digital Imagery.

Other

1. Anuta, P. E. and C. D. McGillem, A Two-Dimensional Filter Design for Isotropic Reconstruction of Track-Type Airborne Geophyscial Surveys, IEEE Acoustics, Speech and Signal Processing Conference, Washington, D. C., April 1979.

2. Billingsley, F. C., Modeling Misregistration and Related Effects on Multispectral Classification, JPL Report #81-6, 1981.

3. Colvocoresses, A. P., Control and Stability of Earth Sensing Satellites, Memorandum for the Record, U.S. G.S., Reston, VA, July 9, 1980.

4. McGlone, J. C., and E. M. Mikhail, Accruacy, Precision and Reliability of Aircraft MSS Block Adjustment, to be published in Photogrammetic Engineering and Remote Sensing.

5. McGlone, J. C., and E. M. Mikhail, Geometric Constraints in Multispectral Scanner Data, Presentation at the Annual Convention of the American Society of Photogrammetry, 1982.

6. McGillem, C. D., et al, Resolution Enhancement of ERTS Imagery, Symposium on Machine Processing of Remotely Sensed Data, Purdue University, 1975.

7. McGillem, C. D., and N. Y. Chu, A Simplified Design Procedure for Image Restoration and Enhancement Filters, LARS Technical Report 091577, Purdue University, 1977.

8. Mikhail, E. M., and J. C. McGlone, Current Status of Metric Reduction of (Passive) Scanner Data, 14th Congress of the International Society of Photogrammetry, Hamburg, July 1980.

9. Snyder, J. P., Map Projections for Larger Scale Mapping, Presentation at the Workshop (adapted from paper in Proceedings of the 1981 ACSM Fall Technical Meeting).

10. Svedlow, M., et al, Experimental Examination of Similarity Measures and Preprocessing Methods Used for Image Registration, Symposium Machine Processing of Remotely Sensed Data, Purdue University, 1976.

11. Swain, P. H., A Quantitative Applications - Oriented Evaluation of Thematic Mapper Specifications, LARS Grant Report 121680, Purdue University, Dec. 1980.

TABLE I

APPROX. ERRORS (METERS, 1σ) IN SYSTEMATIC CORRECTION DATA

	LANDSAT-2	LANDSAT-D <TDRSS	LANDSAT-D >TDRSS, <GPS	LANDSAT-D >GPS
EPHEMERIS				
A.T.	500	500	80	10*
C.T.	100	100	30	6*
ATTITUDE				
A.T.	1580	125	125	125
C.T.	1580	125	125	125
ALIGNMENT				
A.T.	-	855	205+	205+
C.T.	-	427	205+	205+
RSS	2292	1098	350	340
RSS/80	28.7	13.7	4.4	4.2
RSS/30	-	36.6	11.7	11.3

*VALUES MAY BE GREATER DUE TO INTENTIONAL DEGRADATION

+EXPECTED AFTER POST-LAUNCH CALIBRATION

REGISTRATION WORKSHOP SUMMARY

- NASA HQ SPONSORED (A. VILLASENOR)
- N. BRYANT (JPL) CHAIRMAN
- LEESBURG, VA.
- NOVEMBER 17-19, 1981

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NASA GSFC
CODE 932

- o PRESENTATIONS
  - USER NEEDS
  - SPACE SEGMENT ERRORS
  - GROUND SEGMENT ERRORS
  - SYSTEMS
  - PROCESSING & VERIFICATION
- o PANEL MEETINGS
  - REGISTRATION
  - RECTIFICATION
  - ERROR ANALYSIS
- o DISCUSSIONS AND RECOMMENDATIONS

TYPICAL REQUIREMENTS

- ACCURACY
  - GOOD IF SYSTEM CAN DO AS WELL AS USERS
  - RMS ERROR $\leq$ 1 PIXEL; EXTRACTION OF PIXELS IN A POLYGON
  - FITTING TO A MAP - 1:250,000 OR 1:500,000 SATISFACTORY TO MANY USERS (<127M OR 254M; 90%)
  - (<1/2 PIXEL; 90%) SATISFACTORY FOR TEMPORAL REGISTRATION & DIGITAL MOSAICS
  - "WIDTH OF PENCIL LINE" FOR VISUAL INTERPRETATION
  - ONE FORESTRY APPLICATION - (20M; 95%)
  - 50% MULTITEMPORAL ENERGY FROM SAME GROUND AREA ($\Delta X, \Delta Y \leq (\sqrt{2}-1)/\sqrt{2} = .29$ PIX.)
  - NO "USER ANSWERS" ON BAND-TO-BAND REGISTRATION
  - SWAIN STUDY: BAND-TO-BAND REGISTRATION ERROR OF .3 PIX. SIGNIFICANT
  - BILLINGSLEY STUDY: BAND-TO-BAND & MULTITEMPORAL REGISTRATION ERRORS TREATED SIMILARLY; INSIGNIFICANT DIFFERENCE BETWEEN .3 & .5 PIXEL REGISTRATION FROM CLASSN. POINT OF VIEW

- OTHER
  - INFO. ON GEOMETRIC CORRECTIONS (PROJECTION CONVERSIONS, QUALITY, ETC.)
  - GCP LISTS
  - ROTATION TO NORTH
  - COAST-LINE & LANDMARKS FILE FOR OCEANOGRAPHY

APPROX. ERRORS (METERS, 1σ) IN

SYSTEMATIC CORRECTION DATA

	LANDSAT-2	LANDSAT-D <TDRSS	LANDSAT-D >TDRSS, <GPS	LANDSAT-D >GPS
EPHEMERIS				
A.T.	500	500	80	10*
C.T.	100	100	30	6*
ATTITUDE				
A.T.	1580	125	125	125
C.T.	1580	125	125	125
ALIGNMENT				
A.T.	-	855	205+	205+
C.T.	-	427	205+	205+
RSS	2292	1098	350	340
RSS/80	28.7	13.7	4.4	4.2
RSS/30	-	36.6	11.7	11.3

*VALUES MAY BE GREATER DUE TO INTENTIONAL DEGRADATION

+EXPECTED AFTER POST-LAUNCH CALIBRATION

RECTIFICATION

- o RESAMPLING
  - RESTORATION
  - RESOLUTION ENHANCEMENT
  - NN, BL, CC, SPLINE, PSF
  - USER ACCEPTANCE
- o DATA HANDLING
  - RESAMPLING GRIDS
  - SEPARABILITY (HORIZ. & VERT.)
  - EFFICIENT I/O

VERIFICATION

- o CHECKING SATISFACTION OF SPECS.
- o LACIE SEGMENTS FOUND TO SATISFY SPECS. MOST OF THE TIME
- o USERS HAVE COMPLAINED ABOUT MDP REGISTRATION
- o HOW EXTENSIVE SHOULD QUALITY CHECKS BE?
- o WHAT KIND OF VERIFICATION SYSTEM?

IMAGE MATCHING

- o LOCAL NEIGHBORHOODS (SHIFT WILL DO)
- o CONTROL POINT CHIPS-SIZE & DISTRIBUTION
- o CLOUD SUPPRESSION
- o CORRELATION
  - GRAY LEVEL
  - GRADIENT
  - EDGE
  - FFT, SSDA, 'AND' + BIT COUNT
  - NORMALIZED/UNNORMALIZED
  - SUBPIXEL PEAK FINDING
  - PEAK REJECTION
- o MAPPING FUNCTIONS
  - SENSOR MODELS
  - AFFINE/POLYNOMIALS
  - COMBINATION

IMAGE MATCHING (CONT)

- o OUTLIER REJECTION
  - LEAST SQUARES & HIGH RESIDUAL
  - "ALL-BUT-ONE" SOLUTIONS
  - RANDOM SAMPLE CONSENSUS
- o FULL-IMAGE MATCHING (ACCOUNT FOR WARP)
  - AFFINE (FOURIER TRANSFORM)
  - PARAMETER ESTIMATION (LEAST SQUARES)

RECOMMENDATIONS

MAIN AREAS NEEDING ATTENTION:

- o VERIFICATION & VALIDATION
  - DEFINITION OF EXPERIMENTS
  - HOW MUCH QUALITY CONTROL?
  - SYSTEMS TO HELP EFFICIENT VERIFICATION
- o ADVANCED REGISTRATION CONCEPTS
  - BUILD SENSORS WITH INHERENT REGISTRATION ACCURACY
  - ON-BOARD PROCESSING
  - POINTABLE SENSORS, SELECTABLE RESOLUTION
  - SYSTEM SIMULATION MODELS TO HELP ERROR ANALYSES
- o UNIVERSAL CONTROL POINT LIBRARY
  - FEASIBILITY STUDY
  - MULTISENSOR
  - NON-IMAGE FORMATS
  - DISTRIBUTED ACCESS
  - ACHIEVABLE ACCURACIES

NON-NASA SENSORS

MULTISPECTRAL IMAGING SCIENCE WORKING GROUP

IMAGE SCIENCE TEAM

INFORMATION EXTRACTION SCIENCE TEAM

MAY 10, 1982
MARVIN S. MAXWELL

"METEOR" EARTH OBSERVATION (AND METEOROLOGY) SPACECRAFT

LAUNCHED BY THE USSR IN JUNE 1980

589→678 KM ALTITUDE, 98^{o} INCLINATION

BASIC PARAMETERS ON THE METEOR SATELLITE SENSORS

INSTRUMENTS

PARAMETER	BIK-E		"FRAGMENT"	RTVK	
	MSU-E	MSU-SK		MSU-S	MSU-M
FOV (KM)	30	600	85	1,400	2,000
IFOV (M)	30	170	80	240	1,000
BANDS (μM)	0.5-0.7	0.5-0.6	0.4-0.8	0.5-0.7	0.5-0.6
	0.7-0.8	0.6-0.7	0.5-0.6	0.7-1.0	0.6-0.7
	0.8-1.0	0.7-0.8	0.6-0.7		0.7-0.8
		0.8-1.0	0.7-0.8		0.8-1.0
			0.7-1.1		
			1.2-1.3		
			1.5-1.8		
			2.1-2.4		
	ELECTRONICALLY SCANNED ARRAYS	CONICAL IMAGE SCANNER	OPTICAL-MECHANICAL SCANNER	OPTICAL-MECHANICAL SCANNER	OPTICAL-MECHANICAL SCANNER

MODULAR OPTOELECTRIC MULTISPECTRAL SCANNER - MOMS

SCHEDULED TO FLY ON SHUTTLE PALLET SATELLITE (SPAS-01) ON STS FLIGHT #7, MARCH 1982

TWO CHANNELS - 575 TO 625 NM, 825 TO 975 NM

6.912 PIXELS/LINE, IFOV - 67.5 μ RAD, FOV - 26.2^{0}

NOMINAL ALTITUDE - 296 KM, IFOV - 20 M, FOV - 140 KM

OPTICALLY BUTTED - 2 LENSES AND FILTERS PER SPECTRAL BAND

ON BOARD CORRECTION OF GAIN AND OFFSET OF THE DETECTORS

ON BOARD STORAGE OF 30 MINUTES OF DATA

7 BITS ENCODING, DATA RATE = 2 X 2.8M BYTE/SEC

	OPTICS MODULE	POWER BOX	LOGIC BOX	RECORDING SYSTEM	CONTAINER
SIZE (CM)	39X42X43	22X40X13	22X36X13	21X33X16	72X69X49
WEIGHT (KG)	48	24	15	54	35

TOTAL POWER - 350W

BUILT BY MEBSERSCHMITT-BÖLKOW-BLOHM GMBH (MMB)

FOR GERMAN MINISTRY OF RESEARCH AND TECHNOLOGY (BMFT)

HIGH RESOLUTION VISIBLE (HRV) IMAGER

SCHEDULED TO FLY ON THE FRENCH SPOT SATELLITE IN 1984

832 KM ALTITUDE, 98.7° INCLINATION, SUN SYNCHRONOUS, 10:30 AM EQUATOR CROSSING

TWO HRV INSTRUMENT ON SPACECRAFT, 2 TAPE RECORDERS

EACH HRV INSTRUMENT INDEPENDENTLY PROGRAMMED

FIELD OF VIEW - 60 KM, OFF NADIR POINTING ± 27° (± 525 KM) ALLOWS SIDE LAP STEREO AND OBSERVATIONS EVERY 5 DAYS ON SELECTED SITES

EACH INSTRUMENT - TWO MODES:	MULTISPECTRAL (HRV-XS)	PANCHROMATIC (HRV-P)
SPECTRAL BANDS	.50-.59 μM .61-.68 μM .79-.89 μM	.51-.73 μM
FOV	4.13°	4.13°
IFOV	20M X 20M	10M X 10M
PIXELS/LINE	3,000	6,000
PIXEL CODING	8 BITS	6 BITS, DPCM
DATA RATE	25 MB/S	25 MB/S

REAL TIME AND STORED TRANSMISSIONS - XBAND - SIMILAR TO LANDSAT-D.

COMMERCIAL SALE OF PRODUCTS - IMAGES AND DIGITAL TAPES

IMAGES ON 241 MM FILM - SCALE - 1:400,000

RADIOMETRIC CALIBRATION IS ROUTINE, GEOMETRIC AND TERRAIN RELIEF COMPENSATION AVAILABLE.

MULTISPECTRAL ELECTRONIC SELF SCANNING RADIOMETER - MESSR

SCHEDULED TO FLY ON THE MARINE OBSERVATION SATELLITE (MOS-1) IN 1985 - FOR LAND AND OCEAN OBSERVATIONS

909 KM ALTITUDE, INCLINATION 99.1^{o}, 17 DAY COVERAGE CYCLE, SUN SYNCHRONOUS, 10 AM TO 11 AM DESCENDING NODE

THE MOS-1 ALSO CARRIES:

- A VISIBLE AND THERMAL INFRARED RADIOMETER TO MEASURE SEA SURFACE TEMPERATURE
- MICROWAVE SCANNING RADIOMETER TO ALSO MEASURE ATMOSPHERIC WATER VAPOR

THE MESSR CONSISTS OF FOUR GAUSS TYPE TELESCOPES (LENSES)

A PRISM DICHROIC BEAM SPLITTER IMAGES TWO SPECTRAL BANDS

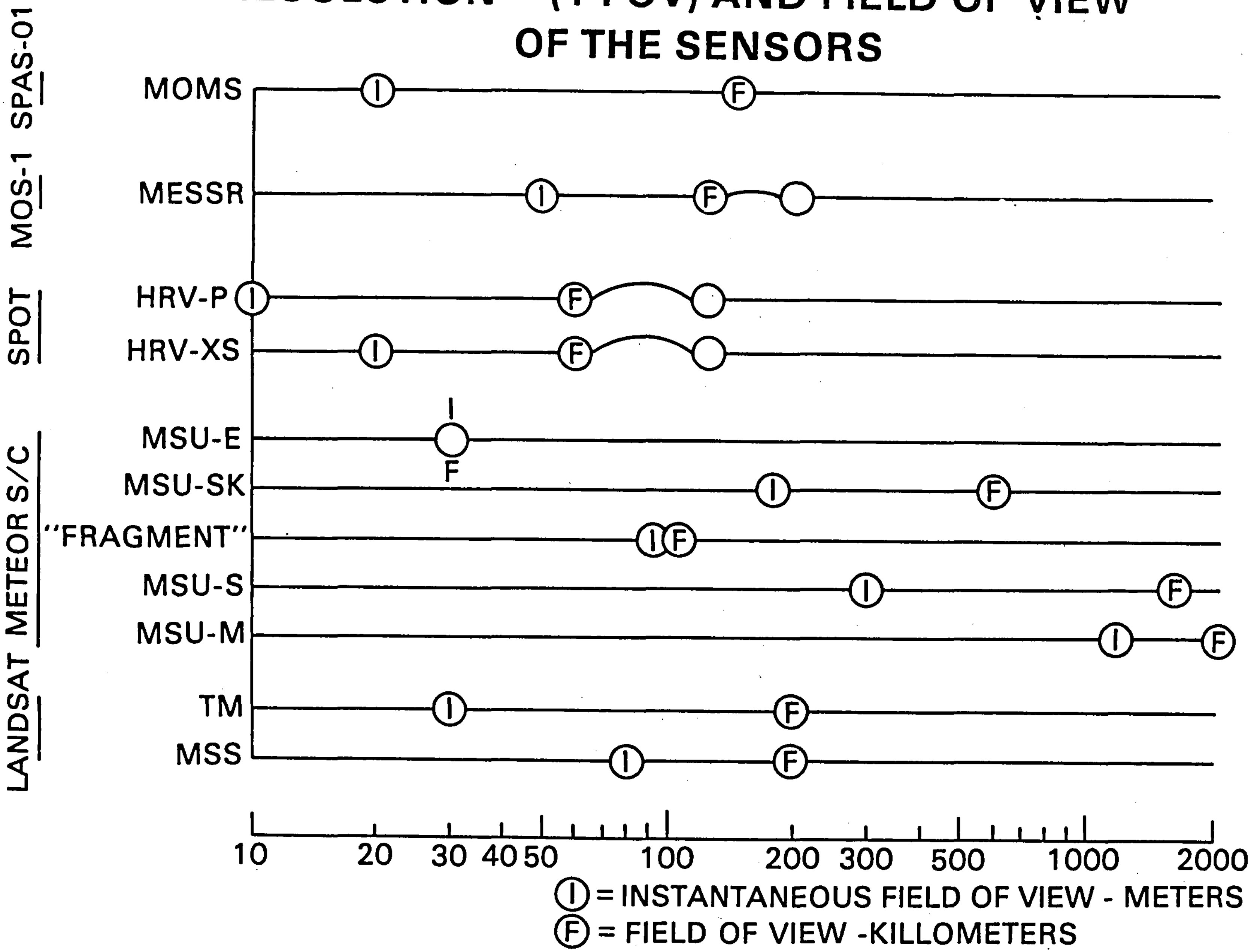
ON TWO 2048 CCD DETECTOR ARRAYS

EACH TELESCOPE HAS A FIELD OF VIEW OF 100 KM

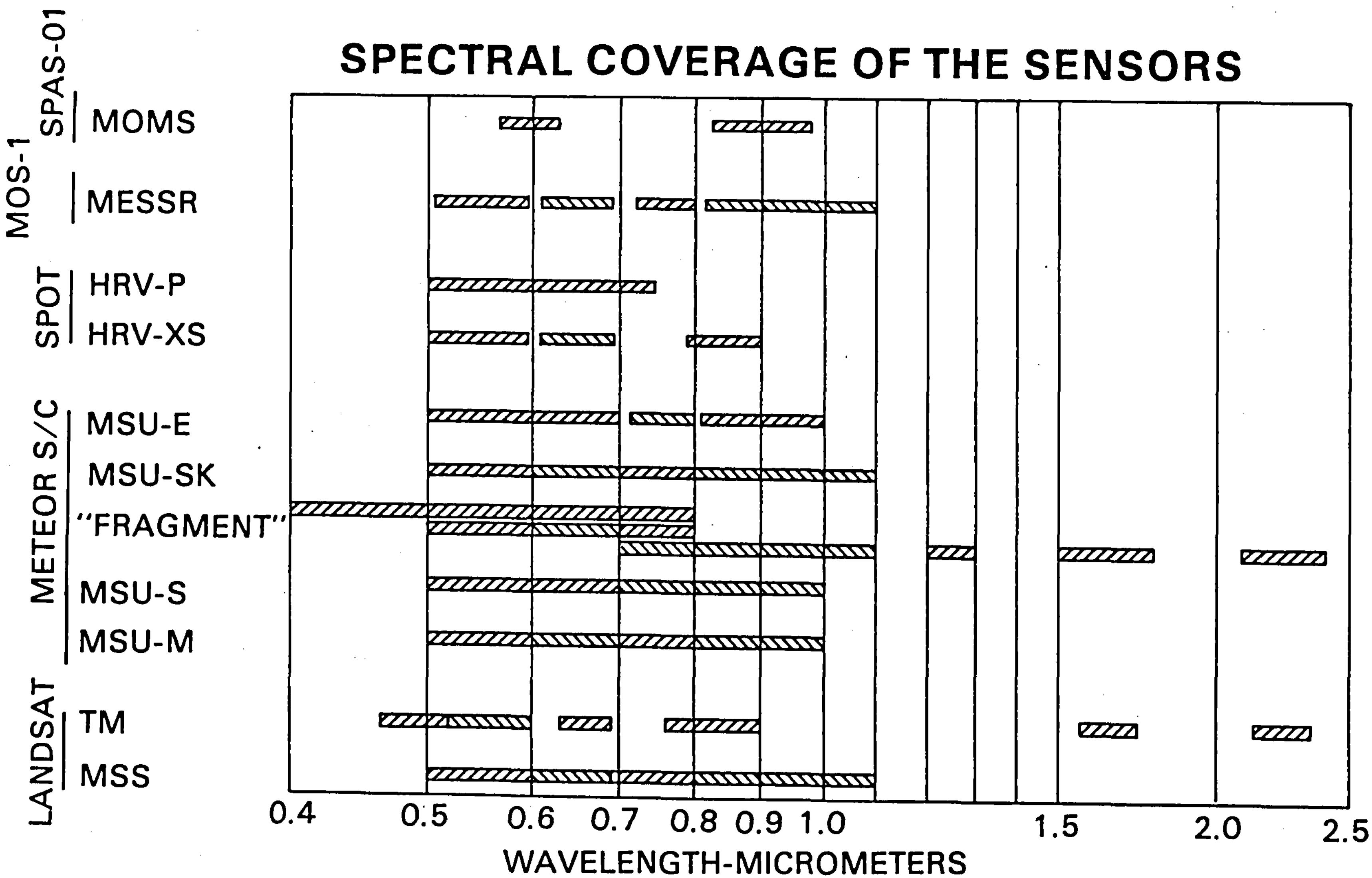
TWO PAIRS OF TELESCOPES ARE CANTED TO PROVIDE A 200 KM FOV, 50 M IFOV, 4 BAND SENSOR

SPECTRAL BANDS (NM)	0.51-0.59
	0.61-0.69
	0.72-0.80
	0.80-1.10
RADIOMETRIC RESOLUTION	39 DB (90 TO 1)
IFOV (M)	50

"RESOLUTION"- (I FOV) AND FIELD OF VIEW OF THE SENSORS



SPECTRAL COVERAGE OF THE SENSORS



Jackson, T. J., and Ragan, R. M., 1977, Value of Landsat in Urban Water Resources Planning, Journal of the Water Resources Planning and Management Division, ASCE, Vol. 103, No. WR1, pp. 33-46.

Jackson, T. J., and Ragan, R. M., and Fitch, W. N., 1977, Test of Landsat-Based Urban Hydrologic Modeling, Journal of the Water Resources Planning and Management Division, ASCE, Vol. 103, No. WR1, pp. 141-158.

McKeon, J. B., Reed, L. E., Rogers, R. H., Ragan, R. M., and Wiegand, O. C., 1978, Landsat Derived Land Cover and Imperviousness Categories for Metropolitan Washington: An Urban/Non-Urban Computer Approach, Proceedings of the ASCM-ASP Annual Meeting, Washington, D.C.

Price, J. C., 1982, Estimation of Regional Scale Evapotranspiration through Analysis of Satellite Thermal Infrared Data, to be published in Transactions of the IEEE.

Ragan, R. M., and Jackson, T. J., 1980, Runoff Synthesis Using Landsat and the SCS Model, Journal of the Hydraulics Division of the ASCE, Vol. 106, No. HY5, pp. 667-678.

Slack, R. B., and Welch, R., 1980, Soil Conservation Service Runoff Curve Number Estimates from Landsat Data, Water Resources Bulletin, Vol. 16, No. 5, pp. 887-893.

SCHEDULE OF PAST AND PROPOSED FLIGHTS