The Use of Intensity-Hue-Saturation Transformations for Merging SPOT Panchromatic and Multispectral Image Data

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ABSTRACT: Several techniques have been developed to merge SPOT 10-m resolution panchromatic data with simultaneously-acquired 20-m resolution multispectral data. Normally, the objective of these procedures is to create a composite image of enhanced interpretability. That is, the effectively 10-m resolution multispectral images produced through the various merging methods contain the high resolution information of the respective panchromatic images while maintaining the basic color content of the original multispectral data. The utility of intensity-hue-saturation (IHS) transformation procedures for creating such composites under varying land cover conditions is illustrated. Correlation analysis of original multispectral image data and their counterparts in IHS composites indicates the need to consider carefully the potential influence alternative implementations of IHS procedures might have on the spectral characteristics of the resulting multiresolution products. The use of a weighted average of panchromatic and near-infrared data as a substitute for intensity in merged images was found to be particularly effective in this study. This approach has been used in the production of an experimental SPOT image map of Madison, Wisconsin, and vicinity.

INTRODUCTION

THE VISUAL INFORMATION CONTENT of remotely sensed images is a function of the combined influence of the radiometric, spatial, and spectral resolution of the sensor. The apparent spatial resolution of multispectral digital images, and their interpretability, has been shown to be enhanced by merging these data with higher resolution digital data (Chavez, 1984; Cliche *et al.*, 1985; Welch, 1985; Welch and Ehlers, 1987; Chavez and Bowell, 1988). When such a merger is performed to aid in visual interpretation, it is important that the operation maintain as much of the original spectral information as possible, while maximizing the amount of spatial information from the high resolution data.

Several different methods exist for the specification of color on electronic display devices. One is the well-known RGB (red-green-blue) color model which is traditionally used for generating three-band color composite images. Another model receiving increased application is the Intensity, Hue, and Saturation (IHS) system. Fundamentally, IHS transformations permit the separation of spatial information as an intensity component from the spectral information in the hue and saturation components of a three-color composite image. The analyst is then able to manipulate independently the spatial information while maintaining the overall color balance of the original scene. However, care must be taken to ensure that the intensity component of the enhanced composite maintains a strong correlation with the intensity of the original image data. Otherwise, subtle intensity differences, such as those between various coniferous and deciduous trees on a color infrared composite, may be obscured.

IHS TRANSFORMATIONS

Intensity, hue, and saturation refer to the parameters of human color perception (Judd and Wyszecki, 1975; Lillesand and Kiefer, 1987). "Intensity" (Munsell's 'value'; see Munsell (1971)) refers to the total brightness of a color. "Hue" generally refers to the dominant or average wavelength of light contributing to a color. When applied to data displayed on an RGB monitor, hue can be described on a circular scale progressing from red to green to blue and back to red (Figure 1a). A pixel's hue is

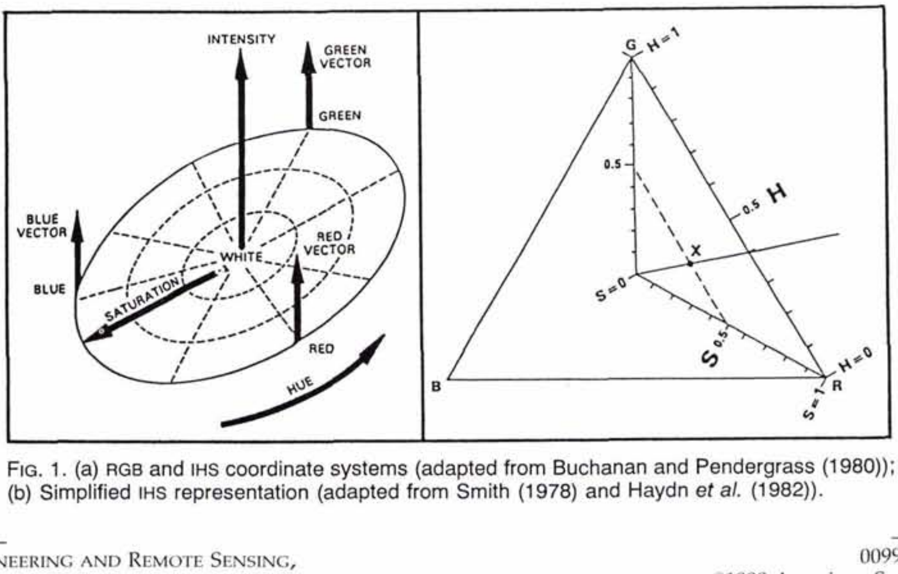

FIG. 1. (a) RGB and IHS coordinate systems (adapted from Buchanan and Pendergrass (1980)); (b) Simplified IHS representation (adapted from Smith (1978) and Haydn *et al.* (1982)).

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determined by the relative proportion of its red, green, and blue inputs. "Saturation" specifies the purity of a color relative to gray. Vivid colors are highly saturated while pale, pastel colors have low saturation.

Many IHS transformation algorithms have been developed for converting RGB tristimulus values into the parameters of human color perception and vice versa (e.g., Smith, 1978; ACM, 1979; Siegal and Gillespie, 1980; Haydn *et al.*, 1982). Beyond their computational speeds, these algorithms differ mainly in the method used in calculating the intensity component of the transformations. In general, while the speed and complexity of these models vary, they tend to produce similar values for hue and saturation.

The intensity of an RGB color is a function of the magnitude of the input primaries. Some algorithms define an RGB color's intensity as the magnitude of the largest input. Using this definition, Smith's "Hexcone" model and Siegal and Gillespie's model will produce equal intensity values for a red pixel with RGB tristimulus values [255 0 0] and a white pixel with values [255 255 255] (throughout this paper we assume that all RGB inputs are scaled over the range of 0 to 255). Smith's "Triangle" model and a model documented by Haydn *et al.* calculate intensity as the average of the three RGB values. Using this system, the white pixel in our example would be three times more intense than the red pixel. The Association for Computing Machinery (ACM, 1979) algorithm calculates intensity based on the average of the highest and lowest of the RGB primary inputs.

Calculation of a pixel's intensity, hue, and saturation necessitates definition of a color space in which the relationships between the RGB and IHS coordinates of a color are known. Smith's "Triangle" model (Figure 1b) was used for the SPOT data mergers performed in this study (Smith, 1978).

BACKGROUND

The launch of the French SPOT (Systeme Pour l'Observation de la Terre) satellite system in February of 1986 has given the civilian remote sensing sector the capability of applying high resolution multispectral imagery to a range of land use and land cover analyses. The SPOT-1 satellite is equipped with two HRV (High Resolution Visible) linear array (pushbroom) sensors capable of operating in either a panchromatic (PAN) mode with 10-m resolution, or a three-band multispectral (XS) mode with 20-m resolution (Table 1).

Welch and Ehlers (1987) have proposed using an IHS transformation to accomplish the merger of SPOT PAN and XS data, as well as the merger of the PAN data with Landsat Thematic Mapper multispectral data, for visual interpretation of urban areas. In this transformation IHS components are derived from the XS data and panchromatic data are then substituted directly for the computed intensity. After the reverse transformation is performed, the resulting RGB composite images are "of similar spatial resolution to the PAN reference image, yet provide excellent spectral discrimination of natural and cultural features in the urban environment."

Cliche *et al.* (1985), working with SPOT simulation data prior to the satellite's launch, showed that simulated 10-m resolution color images can be produced by modulating each XS band with PAN data individually. Various methods of integrating the data sets were tested, none of which used an IHS transformation. The most suitable merger, for visual interpretation of one test area, was produced using the following formulas:

$$C1 = A1 + B1 * (PAN * XS1)^{1/2}$$
$$C2 = A2 + B2 * (PAN * XS2)^{1/2}$$
$$C3 = A3 + B3 * (PAN + 3 * XS3) / 4$$

where C1, C2, and C3 are BGR ouput values, and AX and BX are constants.

They reported that "however arbitrary, the weights used for the panchromatic and infrared channels increase the spatial resolution from 20 to 10 m and preserve much of the infrared information."

Chavez and Bowell (1988) used SPOT panchromatic data to "sharpen" TM images for agricultural, urban, and geologic test sites in the Phoenix, Arizona, region. The method used to combine the various data sets employed pixel-by-pixel addition, rather than IHS transformation. This involved applying a high pass filter to the SPOT panchromatic data before merging them with the TM data. This was done in order to "enhance the high frequency/spatial information but, more important, it will suppress the low frequency/spectral information in the higher resolution image." This is necessary so that simple addition of the images does not distort the spectral balance of the combined product.

In short, these authors stress the basic point that "the method used to combine the digital data can influence the type of information seen in the resultant product." In the present study, we evaluated alternative means of addressing this problem through the comparison of different methods for developing the intensity component of an IHS transformation.

DATA ACQUISITION AND STUDY AREAS

Under the aegis of the SPOT PEPS program, the Environmental Remote Sensing Center at the University of Wisconsin-Madison received SPOT data acquired near Madison and Spooner, Wisconsin. The Madison scene was acquired on 3 June 1986, and the Spooner scene was acquired on 9 August 1986. Both images were processed to Level 1B of the SPOT processing system.

Three test areas were extracted from the above SPOT scenes for detailed analysis. The "Minong" and "Spooner" test sites are 512 row by 512 column subsets of the PAN data (Figures 2a and 3a, respectively) from the Spooner scene and the corresponding XS intensity data (Figures 2b and 3b). The Minong site is typical of "Lake States" vegetational diversity, containing both upland and lowland forest types and non-forested wetlands. The Spooner test area includes the city of Spooner, Wisconsin, and surrounding agricultural and forested areas. The "Mt. Horeb" test site is a 512 row by 512 column subset of the PAN image (Figure 4a) of the Madison scene and the corresponding XS intensity data (Figure 4b). This is an agricultural area interspersed with woodlots. The scene contains many bare fields, reflecting the phenological condition of the crops in early June. Many of these "bare" fields actually contain young corn crops.

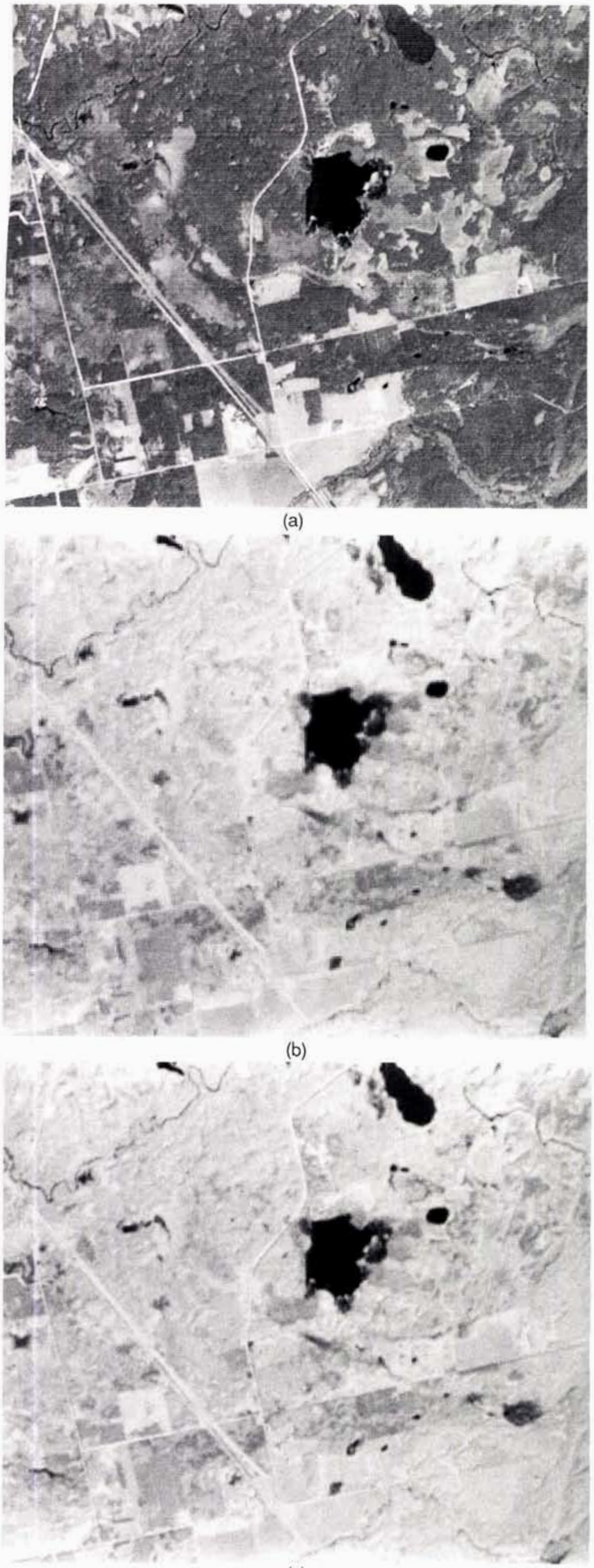
In order to register the XS images to the PAN images, control points were located on the PAN and XS1 images and an affine coordinate transformation was used. The three XS images were then resampled into the 10-m PAN coordinate system using a cubic convolution algorithm prior to the further processing. These resampled XS images are hereafter referred to as RSM1, RSM2, and RSM3 for the XS1, XS2, and XS3 bands, respectively.

TABLE 1. SPECTRAL SENSITIVITY OF SPOT-1 SATELLITE IMAGING SENSORS.

Band	Spectral Sensitivity (μm)	Resolution (m)
XS1	0.50 - 0.59	20
XS2	0.61 - 0.68	20
XS3	0.79 - 0.89	20
PAN	0.51 - 0.73	10

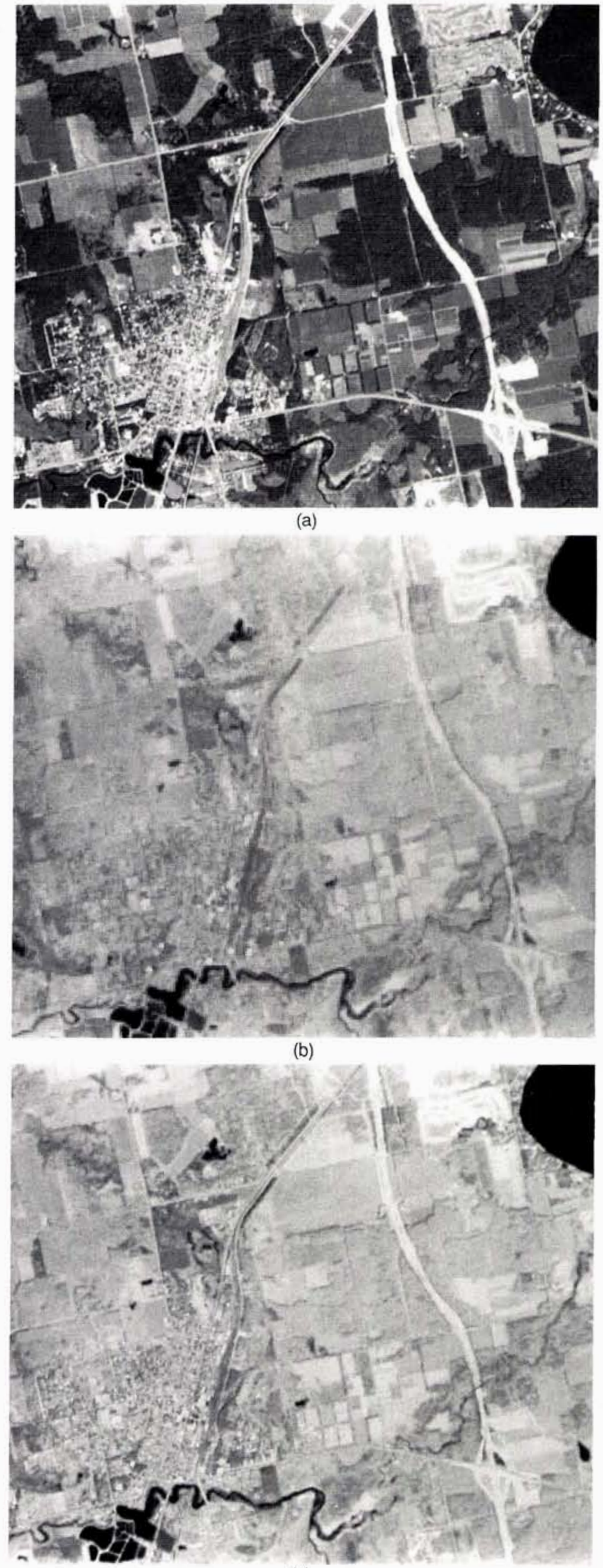
METHODS

The typical low or negative correlation between the PAN and RSM3 (near-infrared band) data (Table 2) in these test sites necessitates treatment of RSM3 such that the amount of spectral



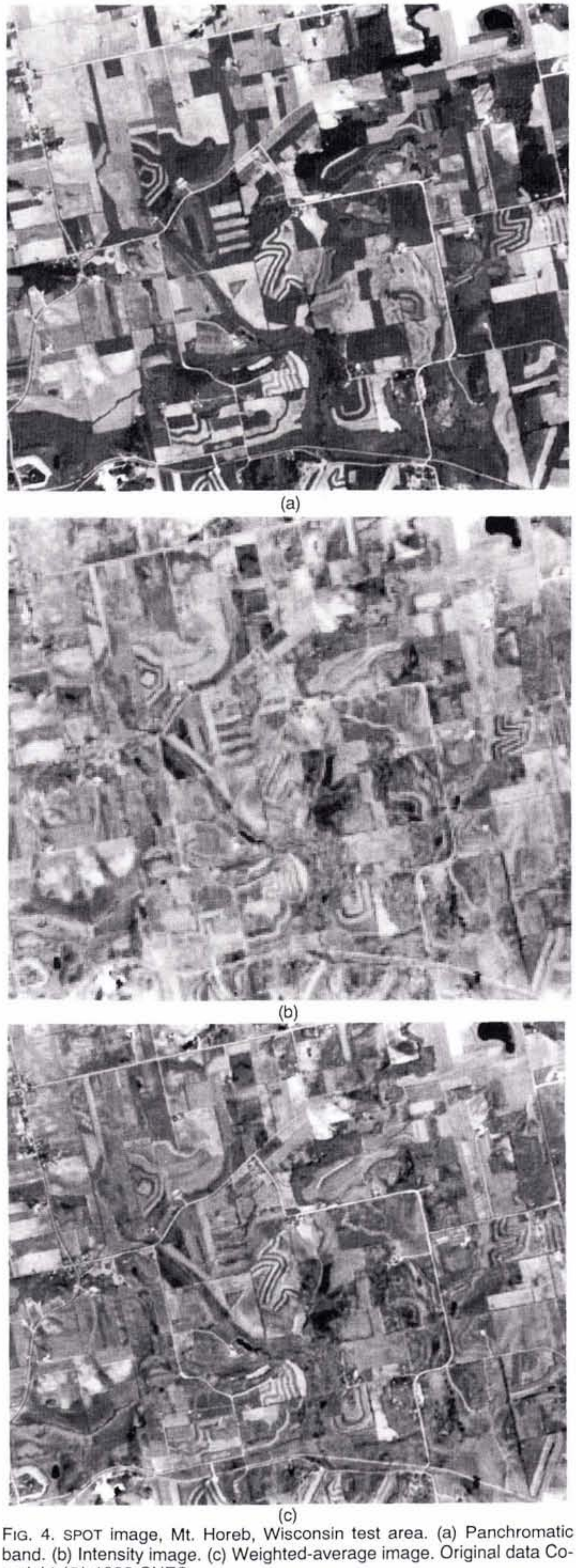
(a) (b) (c)

FIG. 2. SPOT image, Minong, Wisconsin test area. (a) Panchromatic band. (b) Intensity image. (c) Weighted-average image. Original data Copyright (©) 1986 CNES.



(a) (b) (c)

FIG. 3. SPOT image, Spooner, Wisconsin test area. (a) Panchomatic band. (b) Intensity image. (c) Weighted-average image. Original data Copyright (©) 1986 CNES.



(a)

(b)

(c)

FIG. 4. SPOT image, Mt. Horeb, Wisconsin test area. (a) Panchromatic band. (b) Intensity image. (c) Weighted-average image. Original data Copyright (©) 1986 CNES.

TABLE 2. CORRELATION AMONG MULTISPECTRAL, PANCHROMATIC, AND DERIVED INTENSITY DATA FOR THREE TEST AREAS.

Minong Test Area	RSM1	RSM2	RSM3	PAN	INT
RSM1	1.0				
RSM2	0.838	1.0			
RSM3	−0.023	−0.164	1.0		
PAN	0.824	0.807	−0.048	1.0	
INT	0.282	0.145	0.945	0.224	1.0

Spooner Test Area	RSM1	RSM2	RSM3	PAN	INT
RSM1	1.0				
RSM2	0.925	1.0			
RSM3	−0.065	−0.195	1.0		
PAN	0.933	0.909	−0.112	1.0	
INT	0.539	0.428	0.751	0.473	1.0

Mt. Horeb Test Area	RSM1	RSM2	RSM3	PAN	INT
RSM1	1.0				
RSM2	0.975	1.0			
RSM3	−0.572	−0.656	1.0		
PAN	0.969	0.962	−0.597	1.0	
INT	0.484	0.391	0.433	0.431	1.0

contamination introduced by the PAN data is minimized when these data sets are merged (Cliche *et al.*, 1985; Chavez and Bowell, 1988). This becomes a problem when the goal is the integration of the high resolution spatial information of the PAN data into the spectral information of the RSM data. On the other hand, RSM1 and RSM2 are quite highly correlated with the PAN data over the test areas. Examination of the correlation between the intensity data derived from the multispectral images and the PAN data underscores the need for additional processing before directly substituting the PAN data for the intensity component of the merged product.

One method of quantifying the spectral changes resulting from data merging is to determine the change in correlation among the PAN image data and the pre- and post-merger IR bands. A good integration technique should alter this correlation less than a poor one (assuming the objective is to preserve the appearance of the original multispectral composite as closely as possible). Another method is to examine the correlation between the intensity derived from the original multispectral data and the intensity of the merged product. This correlation should be high, so that objects that were bright on the original multispectral composite are also bright on the merged image.

The spatial resolution enhancements suggested by Cliche *et al.* and by Welch and Ehlers (described above) were each performed on the three test areas. Correlation matrices were generated for selected sets of these data. All correlations were performed on images subsampled to every tenth row and column in an attempt to reduce spatial auto-correlation effects in the analysis. Table 3 summarizes the correlations among the resampled multispectral data and their derived intensity values (RSM1, RSM2, RSM3, and INT, respectively), the data generated using the Welch and Ehlers method of substituting PAN for intensity (W1, W2, W3), and those created using the method developed by Cliche *et al.* (C1, C2, and C3).

Images resulting from the direct PAN substitution procedure (W1, W2, W3), while providing simulated 10-m resolution, have modified spectral character. For example, vegetated areas take on a dark red appearance as a result of their low reflectance in the visible region of the spectrum (note the low correlation between the derived intensity and the panchromatic data for the test areas shown in Table 2). Hence, differentiability of plant species present in the multispectral data is diminished. In general, direct substitution of the panchromatic data for intensity derived from the multispectral data is not recommended for

TABLE 3. CORRELATION BETWEEN ORIGINAL RESAMPLED SPOT DATA AND DATA GENERATED USING THE ABOVE INTEGRATION METHODS FOR THREE TEST AREAS. (CINT = [C1 + C2 + C3] / 3)

Minong Test Area	W1	W2	W3	PAN	C1	C2	C3	CINT
RSM1	0.71	0.70	0.52	0.85	0.94	0.86	0.04	0.45
RSM2	0.73	0.85	0.41	0.85	0.85	0.96	−0.11	0.36
RSM3	−0.62	−0.56	0.63	0.03	−0.04	−0.13	0.99	0.89
INT	−0.36	−0.28	0.76	0.31	0.26	0.17	0.96	0.96
PAN	0.79	0.79	0.72	1.00	0.95	0.91	0.02	0.43
Spooner Test Area	W1	W2	W3	PAN	C1	C2	C3	CINT
RSM1	0.87	0.87	0.62	0.93	0.98	0.95	0.08	0.75
RSM2	0.86	0.94	0.51	0.91	0.93	0.98	−0.06	0.65
RSM3	−0.46	−0.41	0.58	−0.11	0.09	−0.16	0.99	0.58
INT	0.13	0.21	0.86	0.47	0.51	0.46	0.87	0.94
PAN	0.92	0.93	0.69	1.00	0.99	0.97	0.04	0.73
Mt. Horeb Test Area	W1	W2	W3	PAN	C1	C2	C3	CINT
RSM1	0.96	0.96	0.65	0.97	0.99	0.98	−0.41	0.83
RSM2	0.97	0.98	0.56	0.96	0.97	0.99	−0.51	0.76
RSM3	−0.73	−0.72	0.07	−0.60	−0.59	−0.64	0.98	−0.04
INT	0.27	0.30	0.77	0.43	0.46	0.41	0.59	0.86
PAN	0.98	0.97	0.71	1.00	0.99	0.99	−0.432	0.82

visual interpretation of data from agricultural, forested, or other heavily vegetated areas.

Note the high correlation of C1, C2, and C3 with RSM1, RSM2, and RSM3, respectively, for all scenes. This is an indication of how the weighted averaging employed in computing the output value for the C3 data ((PAN + 3∗RSM3)/4) serves to maintain the overall spectral quality of the image. Also note that the correlation between the intensity derived from the resampled images (INT) and that derived from C1, C2, and C3 (CINT) is high.

The high correlation among RSM1, RSM2, and PAN for all test areas suggests an alternative integration method. Intensity, calculated as the average of the three multispectral images, can be thought of as consisting of two visible multispectral bands plus the near IR band. A weighted average (WTA) of twice the PAN plus RSM3 was found to be highly correlated with the intensity derived from the multispectral data. Table 4 shows the relative performance of other means of computing the intensity component for the Mt. Horeb test area. Figure 5, showing frequency histograms of data from the Mt. Horeb test area, illustrates the relationships among the PAN, RSM3, INT, and WTA data sets.

Table 5 indicates the correlations resulting when the IHS algorithm is applied to the multispectral data with WTA substituted for the intensity. Figures 6, 7, and 8 show the individual blue, green, and red RSM and WTA data sets for the Mt. Horeb test site. Note the high correlation between the respective RSM and WTA bands, inferring the maintenance of the spectral quality of the original multispectral data. Note also that the correlation of WTA with the PAN data is higher than that between INT and PAN and that this correlation is greater than that of PAN with CINT.

CONCLUSIONS

The use of image correlation data, although not an absolute measure of the quality of the output images, provides at least some indication of the amount of visual change in merged data after processing. Inspection of the correlation of the intensity derived from the original data with the intensity of the simulated 10-m data, as well as correlations between the original multispectral images and those generated by the data merger, can be used to assess how accurately the spectral content of the original multispectral imagery is simulated.

TABLE 4. CORRELATION AMONG VARIOUS METHODS USED TO COMPUTE THE INTENSITY COMPONENT OF THE MERGED DATA SET, MT. HOREB TEST AREA.

	AVE	CRT	WTA	SRT	INT
AVE	1.000	0.410	0.795	0.791	0.880
CRT		1.000	0.874	0.874	0.712
WTA			1.000	0.985	0.936
SRT				1.000	0.992
INT					1.000

AVE = (Pan + XS3) / 2
CRT = $(\text{Pan} \cdot \text{Pan} \cdot \text{XS3})^{1/3}$
WTA = ((2 • Pan) + XS3) / 3
SRT = $(\text{Pan} \cdot \text{XS3})^{1/2}$
INT = (XS1 + XS2 + XS3) / 3

TABLE 5. CORRELATION BETWEEN ORIGINAL RESAMPLED SPOT DATA AND DATA GENERATED USING THE WEIGHTED AVERAGE OF PAN AND XS3 AS INTENSITY.

Minong Test Area	RSM1	RSM2	RSM3	INT	WTA1	WTA2	WTA3	WTA
RSM1	1.00	0.84	−0.02	0.28	0.94	0.81	−0.01	0.30
RSM2	0.84	1.00	−0.16	0.14	0.79	0.96	−0.15	0.16
RSM3	−0.02	−0.16	1.00	0.94	−0.05	−0.17	0.99	0.92
PAN	0.82	0.80	−0.05	0.22	0.92	0.88	0.03	0.35
Spooner Test Area	RSM1	RSM2	RSM3	INT	WTA1	WTA2	WTA3	WTA
RSM1	1.00	0.92	−0.07	0.54	0.97	0.92	0.00	0.62
RSM2	0.92	1.00	−0.19	0.43	0.89	0.98	0.14	0.50
RSM3	−0.07	−0.19	1.00	0.80	−0.08	−0.20	0.99	0.70
PAN	0.93	0.91	−0.11	0.47	0.98	0.96	−0.01	0.63
Mt. Horeb Test Area	RSM1	RMS2	RMS3	INT	WTA1	WTA2	WTA3	WTA
RSM1	1.00	0.98	−0.57	0.48	0.99	0.97	−0.51	0.83
RSM2	0.98	1.00	−0.65	0.39	0.96	0.99	−0.60	0.76
RSM3	−0.57	−0.65	1.00	−0.43	−0.57	−0.65	0.98	−0.04
PAN	0.97	0.96	−0.60	0.43	0.99	0.98	−0.50	0.64

The weighted average intensity images for the three study areas are shown as Figures 2c, 3c, and 4c. Based on the correlations shown in Tables 3 and 5, we feel that the substitution of the weighted average (WTA) for the original intensity component consistently produces results as good as, or better than, any other method tested. The correlation of the RSM with WTA data is high for all study sites, and correlations between the individual merged bands and the PAN data are consistent with the original multispectral images.

Visual evaluation of the images produced by the above integration techniques (Plates 1 and 2) indicates that the merged multispectral images represent a substantial improvement in interpretability over the original multispectral data. Direct substitution of panchromatic data for the multispectral intensity, while not optimal for vegetation type mapping, is quite useful for urban resource inventories. While the technique developed by Cliche *et al.*, produces high quality images, similar results were consistently obtained by substituting a weighted average of the panchromatic and near infrared bands for the intensity component derived from the multispectral data.

Application of an IHS transformation to accomplish high resolution data integration simplifies the process; no spatial filtering or special weighting factors need be applied to the individual multispectral data in order to insure that the color balance of

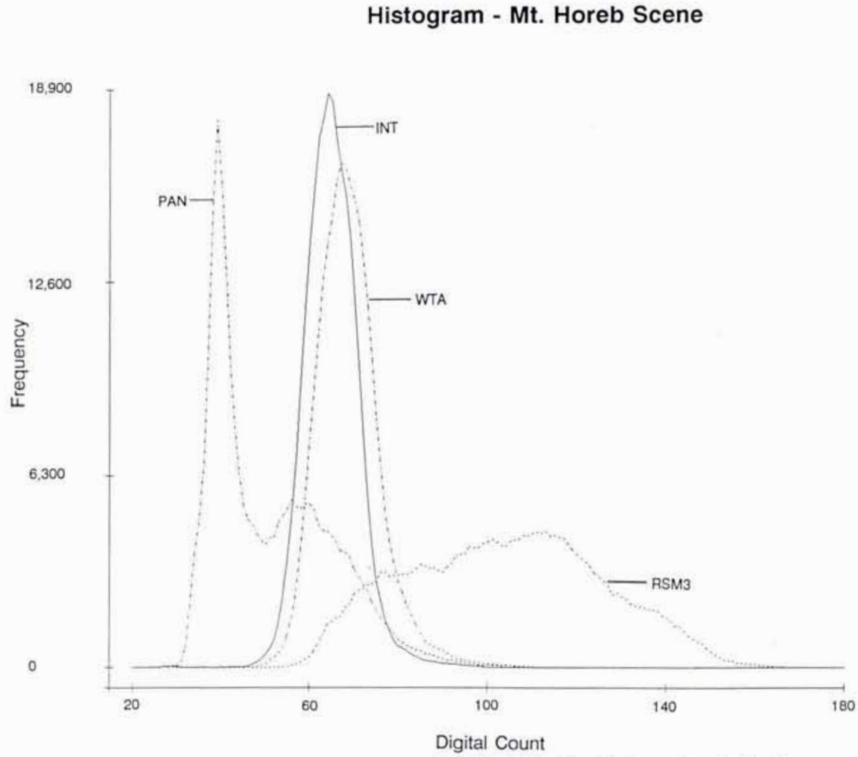


FIG. 5. Frequency histograms for SPOT RSM3, PAN, intensity (INT), and weighted-average (WTA) data, Mt. Horeb test site.

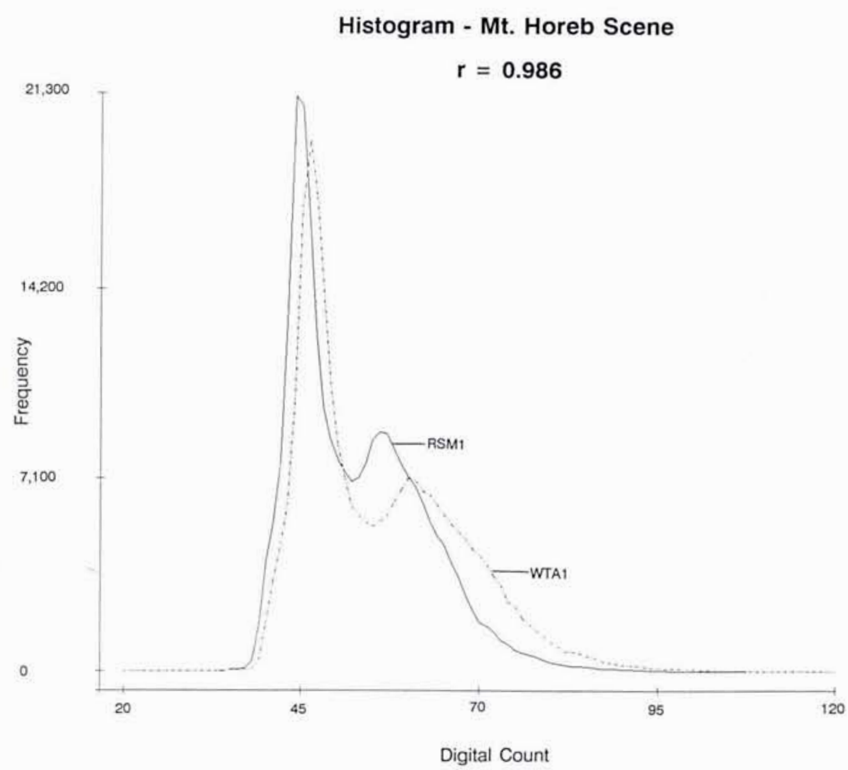


FIG. 6. Frequency histograms for RSM1 and WTA1 data, Mt. Horeb test site.

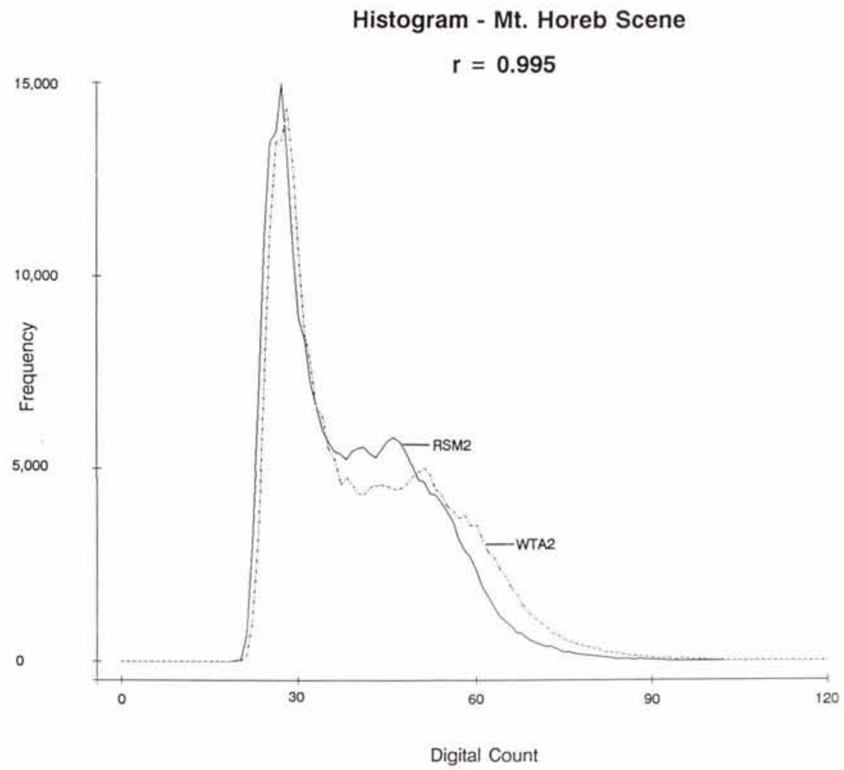


FIG. 7. Frequency histograms for RSM2 and WTA2 data, Mt. Horeb test site.

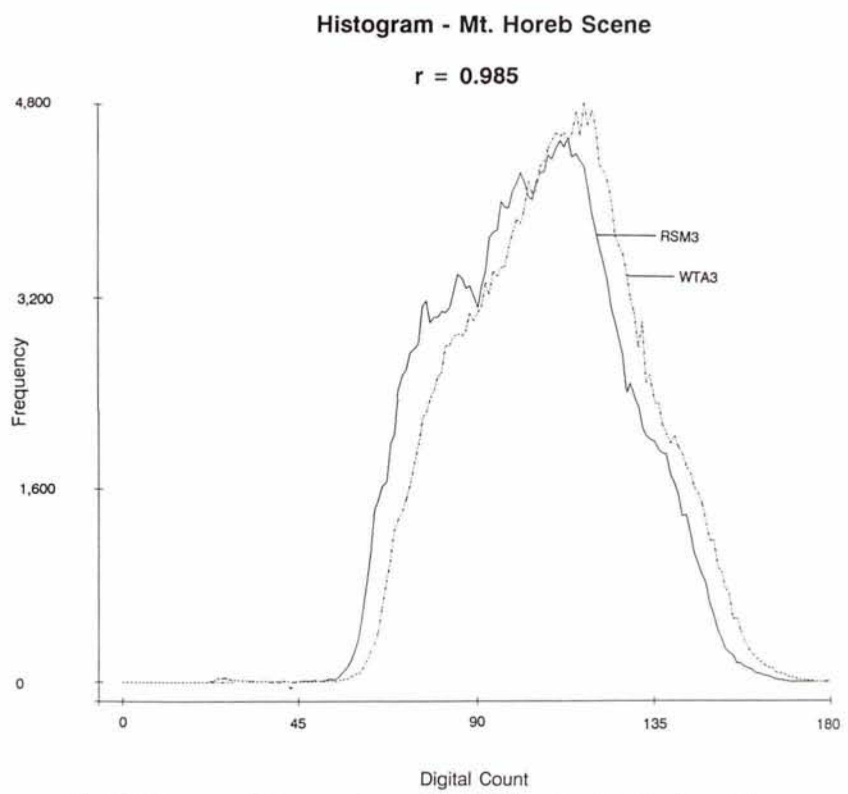
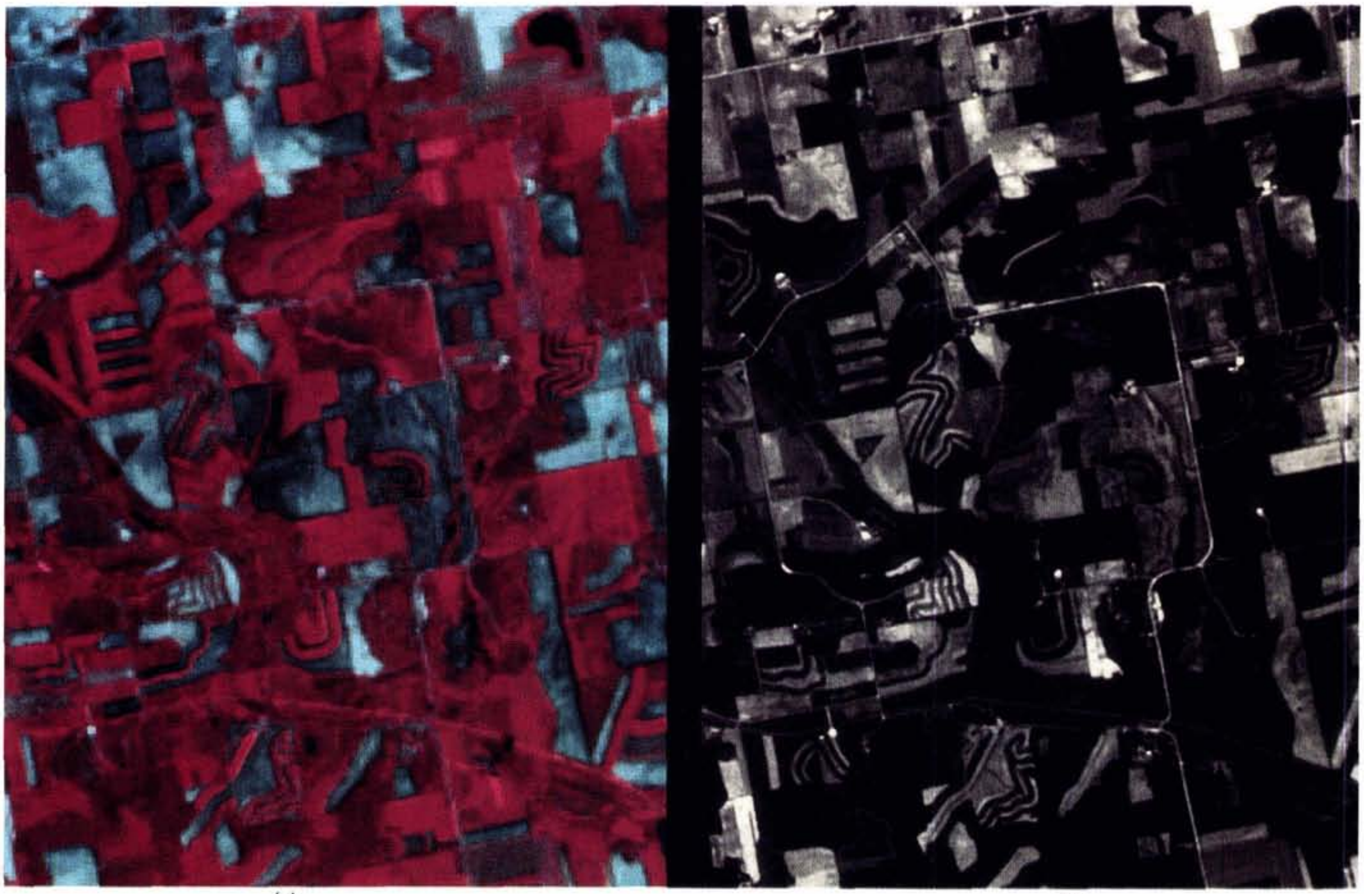


FIG. 8. Frequency histograms for RSM3 and WTA3 data, Mt. Horeb test site.



(a) (b)

PLATE 1. Mt. Horeb test site. (a) Multispectral data. (b) Panchromatic data. Original data Copyright (©) 1986 CNES.

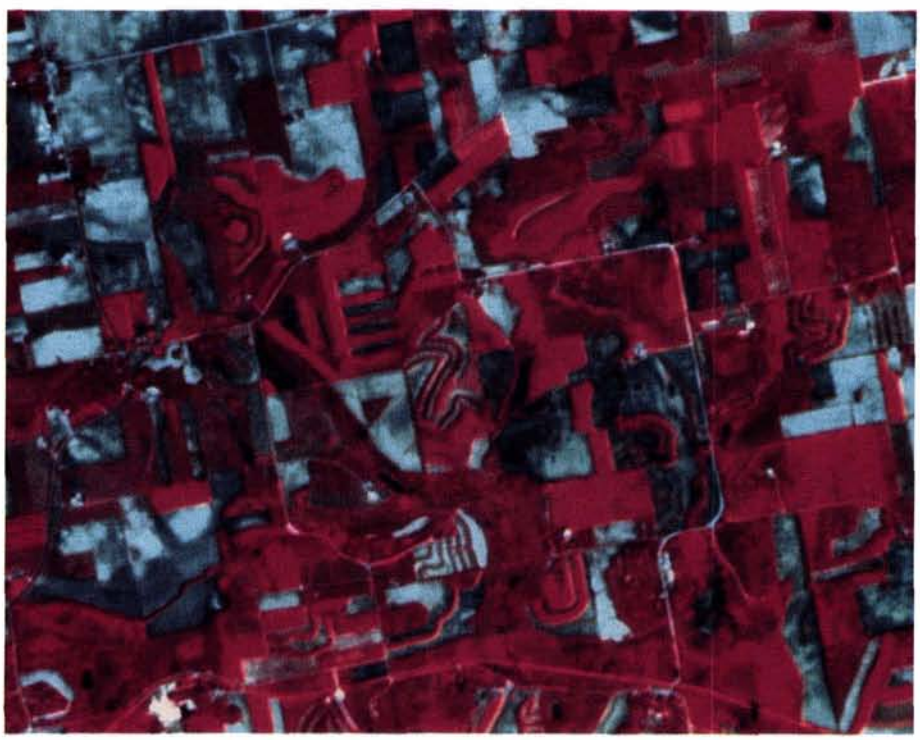


PLATE 2. Merged multispectral and panchromatic data using weighted-average (WTA) method, Mt. Horeb test site. Original data Copyright (©) 1986 CNES.

the original image is maintained. For our three study sites, the use of a weighted average of the panchromatic and near-infrared bands as a substitute for intensity duplicates the spectral content of the original data at least as well as any other method tested.

Based on the results of this study, we have used the weighted average approach to produce an experimental SPOT image map of Madison, Wisconsin, and vicinity using IHS merger of the PAN and XS data from the previously described "Madison" scene. This map has been published at a scale of 1:62,500 and depicts an area approximately 35 km by 37 km in size*. The overall detail and information content of the map is substantial, suggesting a very bright future for using multiresolution digital data to produce image maps on a broad-scale operational basis. Continuing research suggests a similarly bright future for multisensor, multiresolution data merging (e.g., data from SPOT, TM, and digitized aerial photographs).

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*The map is available for sale from the Wisconsin Geological and Natural History Survey, 3817 Mineral Point Road, Madison, WI 53705.

BOOK REVIEW

Fernerkundungs-Kartographie mit Satellitaufnahmen, Allgemeine Grundlagen und Anwendungen, Band IV/1 (*Remote Sensing Cartography Based on Satellite Pictures, General Principles and Applications,* Volume IV/1. by H.G.Gierloff-Emden. Publisher: Franz Deuticke, Vienna, XIV + 588 pages, 314 diagrams and drawings, 84 tables, 32 pages at the end of the text with color and black-and-white satellite pictures, diagrams and maps and a separate 24 page annex with black-and-white satellite pictures, 16.5 × 23.5 cm, hard cover.

THIS IMPRESSIVE BOOK is Volume IV/1 of an encyclopedic publication under the general heading: *Die Kartographie und ihre Randgebiete (Cartography and Associated Fields)*, initiated and published under the editorship of the now deceased Dr. Erik Arnberger, professor of geography and cartography at the University of Vienna. The author of the presently reviewed Volume IV/1 is also a professor of geography and remote sensing at the Ludwig Maximilian University of Munich. The publication of the present volume was supported by the Austrian Academy of Sciences.

This type of encyclopedic publication is popular in the German scientific literature and particularly so in the field of the geodetic disciplines, as illustrated by the famous Jordan, and then Jordan-Eggert, a several volume publication on geodesy, surveying, photogrammetry, and cartography. After the last war this work was completely rewritten, modernized, and very significantly enlarged (over ten large volumes). The presently reviewed publication seems to further illustrate the unprecedented development in the general area of our interest, and also points to the fact that the discipline of geography is assuming an increasing role as a mover not only in cartography, but also in the latest and future oriented technique of gathering physical information about the Earth, remote sensing. The depth and scope of this development can best be illustrated by listing the volumes of the encyclopedic edition of *Die Kartography und ihre Randgebiete* (titles translated into English):

Volume I, Erik Arnberger and Ingrid Kretschmer, *Essence and the Tasks of Cartography–The Topographical Maps*, 556 p. of text and 302 p. of illustrations and index.
Volume II, Leonhard Brandstätter, *Cartography of the Mountains*, 336 p. plus 2 map sheets.
Volume III, Hans F.Gorki and Heinz Pape, *Cartography in City Areas*. Volume III/1, 456 p. of text with 201 illustrations; Volume III/2, 236 p. of tables and 117 multicolor maps.
Volume B, Werner Witt, *Cartographic Lexicon* (Dictionary), 714 p.
Volume C, Ingrid Kretschmer, Johannes Dörflinger, and Franz Wawrik, *Lexicon of the History of Cartography*, 1040 p. with 172 illustrations plus 16 p. of color tables.
Volume IV/1, H.G. Gierloff-Emden, *Remote Sensing Cartography Based*

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