IHS Transform for the Integration of Radar Imagery with other Remotely Sensed Data

Jeff R. Harris and *Richard Murray*
Intera Kenting/Canada Centre for Remote Sensing, 1547 Merivale Road, 5th Floor, Ottawa, Ontario K1A OY7, Canada
Tom Hirose
Neotix Research Inc., 902 - 280 Albert Street, Ottawa, Ontario K1P 5G8, Canada

ABSTRACT: The IHS color display transform is a technique for combining diverse data with radar data to provide color imagery suitable for qualitative and quantitative analysis. The integration of radar with other data types is discussed under four major themes: integration of radar with other remotely sensed data, airborne geophysical data, thematic data, and data extracted from multiple radar images. Examples of IHS transformed images for each theme listed above are presented and discussed with a view to their application to various Earth science disciplines, particularly geology and sea ice.

INTRODUCTION

GREATER EMPHASIS TODAY is being placed on the digital integration of diverse data types as a result of new developments in computer image analysis and geographic information system (GIS) technology (Aarnisalo *et al.*, 1982; Conradson and Nilsson, 1984; Freeman *et al.*, 1983; Harris *et al.*, 1986; Slaney, 1985; Haydn *et al.*, 1982). Data integration is obviously not a new concept and has been pursued for many years on an analog basis in many Earth science disciplines. However, rapid advances in image analysis hardware and software have allowed for greater flexibility and innovative techniques for combining and integrating digital data.

Many techniques exist for combining digital data but most fall into two categories: statistical/arithmetic transforms and visual display transforms. Statistical/arithmetic transforms such as principal components, canonical, factor, and arithmetic operators are effective techniques for combining multivariate data. However, the end products (i.e., color composite images) are often difficult to interpret quantitatively and qualitatively as the statistical properties of the data have been manipulated and, thus, the original integrity of the data is not left intact. This is commonly the case with color composite imagery of principal components as the resulting imagery is often characterized by vivid colors that are, in many instances, difficult to relate consistently to surface features as each component is a linear mix of the original input variables. Conversely, color display transforms such as intensity-hue-saturation (IHS) can be used to produce more effective and controlled visual presentations of the data for both qualitative and quantitative interpretation procedures. The IHS color transform (Pratt, 1978; King *et al.*, 1984; Gillespie, 1980; Buchanan and Pendergrass, 1980; Buchanan, 1979) has seen many applications for the display of remotely sensed data (Haydn *et al.*, 1982; Daily, 1983; Raines, 1977; Kruse and Raines, 1984; Gillespie *et al.*, 1986; Sabins, 1986; Robertson and O'Callaghan, 1988).

This paper describes how the IHS transform can be used for integrating radar with diverse types of data such as Landsat TM, airborne geophysical (magnetics and gamma ray spectrometer), and thematic (maps, classifications) data. The objective is to provide imagery in which image color (hue) can be interpreted in both a relative and an absolute sense. In addition, the use of the IHS transform is demonstrated for displaying the results of quantitative type analyses such as change detection studies and comparison between images characterized by different sensing parameters (i.e., frequency, polarization, etc.).

BACKGROUND

Radar imagery is used as a base product for integration for a number of reasons. Much emphasis is being placed on radar as an effective tool for Earth sensing and observation as many countries, including Canada (RADARSAT), the United States (SIR-C), Europe (ERS-1), and Japan (JERS-1), are now actively involved in the development of spaceborne radar systems. Radar, because of its side viewing geometry and longer wavelengths, which results in an all-weather sensing capability, has established itself as an extremely effective sensor for Earth observation. Furthermore, radar offers a unique view of the terrain, making it useful for a variety of geoscience studies where information regarding terrain geometry (topography), surface roughness, and moisture content are important variables.

IHS TRANSFORM

A plethora of color coordinate systems have been developed over the past 40 years, with most of the systems being developed to quantify color photographs and predict human perception (Gillespie, 1980). Although the red-green-blue (RGB) color system, commonly used to display three-channel remotely sensed imagery, is simple and often effective, a number of shortcomings exist (Robertson and O'Callaghan, 1988). The RGB system is not based on readily definable color attributes and, therefore, color variations as defined by the mix of red, green, and blue primaries are not always easy to perceive and/or to describe numerically, resulting in displays in which the numerical characteristics of the data are not represented by uniform color gradations.

An effective display coordinate system which can overcome many of these shortcomings is the IHS transform, which is defined by three separate, orthogonal, and easily perceived color attributes, those of intensity, hue, and saturation. Geometrically, the RGB system can be represented as a cube (Figure 1) with the red, green, and blue axes defining the x, y, and z vectors respectively. Vector A in Figure 1 represents the achromatic (grey) vector. The IHS coordinate system can be represented as a cylinder or a sphere, as shown in Figure 2 (modified from King *et al.*, 1984). Intensity, which represents the total energy or brightness of the image, defines the vertical axis of the cylinder, or the radius of the sphere. Hue represents the average wavelength of color and defines the circumferential angle of the cylinder or sphere, and ranges from blue (0 degrees) through green, yellow, red, and purple (360 degrees). Saturation can be thought of as the purity of the color (i.e., percentage of white light in the image) and defines the colatitude of the sphere, or the radius of the cylinder. The mathematics involved in the

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING,
Vol. 56, No. 12, December 1990, pp. 1631-1641.

0099-1112/90/5612–1631$03.00/0

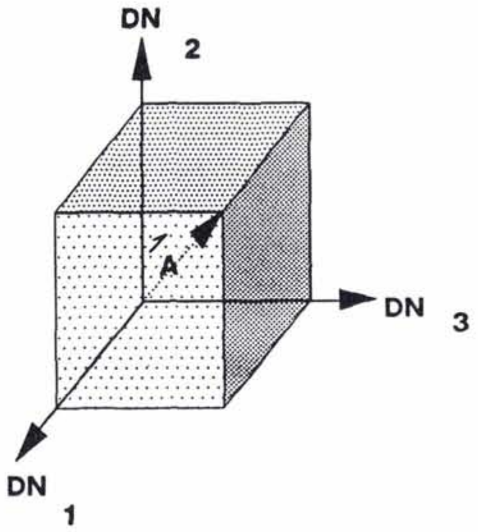
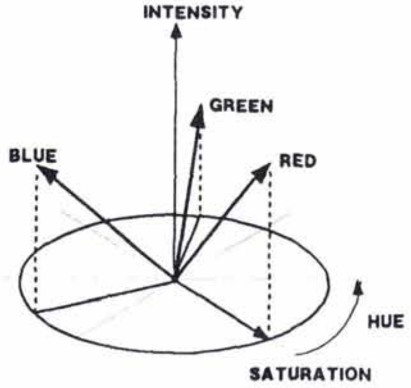
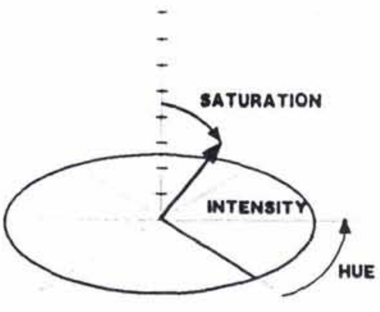


FIG. 1. Initial cartesian RGB space. A is the achromatic (grey) vector.



CYLINDRICAL



SPHERICAL

FIG. 2. IHS display space.

transform from cartesian (RGB) to spherical or cylindrical (IHS) coordinates are reviewed by Gillespie (1980), King *et al.* (1984), and Robertson and O'Callaghan (1988), while Haydn *et al.* (1982) and Sabins (1986) provide a general descriptive review of the IHS system.

The advantages of the IHS coordinate system over the RGB system are first, that the informative aspects of an image are presented using readily identifiable and quantifiable color attributes that can be distinctly perceived. Second, numerical variations in the image data can be uniformly represented in an easily perceived range of colors and, third, individual control over the chromatic (hue) and achromatic (saturation) components of the image is possible. Furthermore, mapping different data types into the IHS color space can produce more complex images in which variables with diverse information content can be represented by different color attributes. It is also possible to produce images which are a combination of more than three channels, thus providing more information in the resultant color composite image after transformation back to RGB space for display on a video monitor.

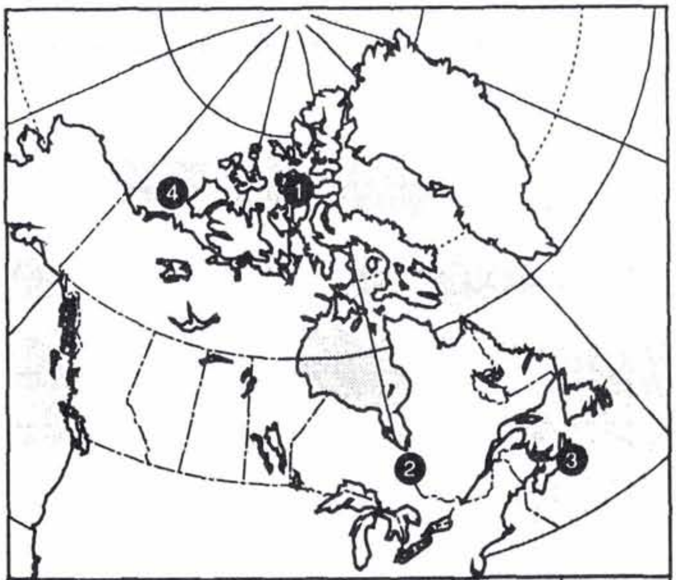
METHODOLOGY

The following section describes how the radar based IHS transformed images discussed in this paper were generated. The discussion has been organized into four major themes consisting of the integration of radar data with

- Landsat Thematic Mapper data,
- airborne geophysical data,
- thematic data, and
- radar data (for change detection analysis).

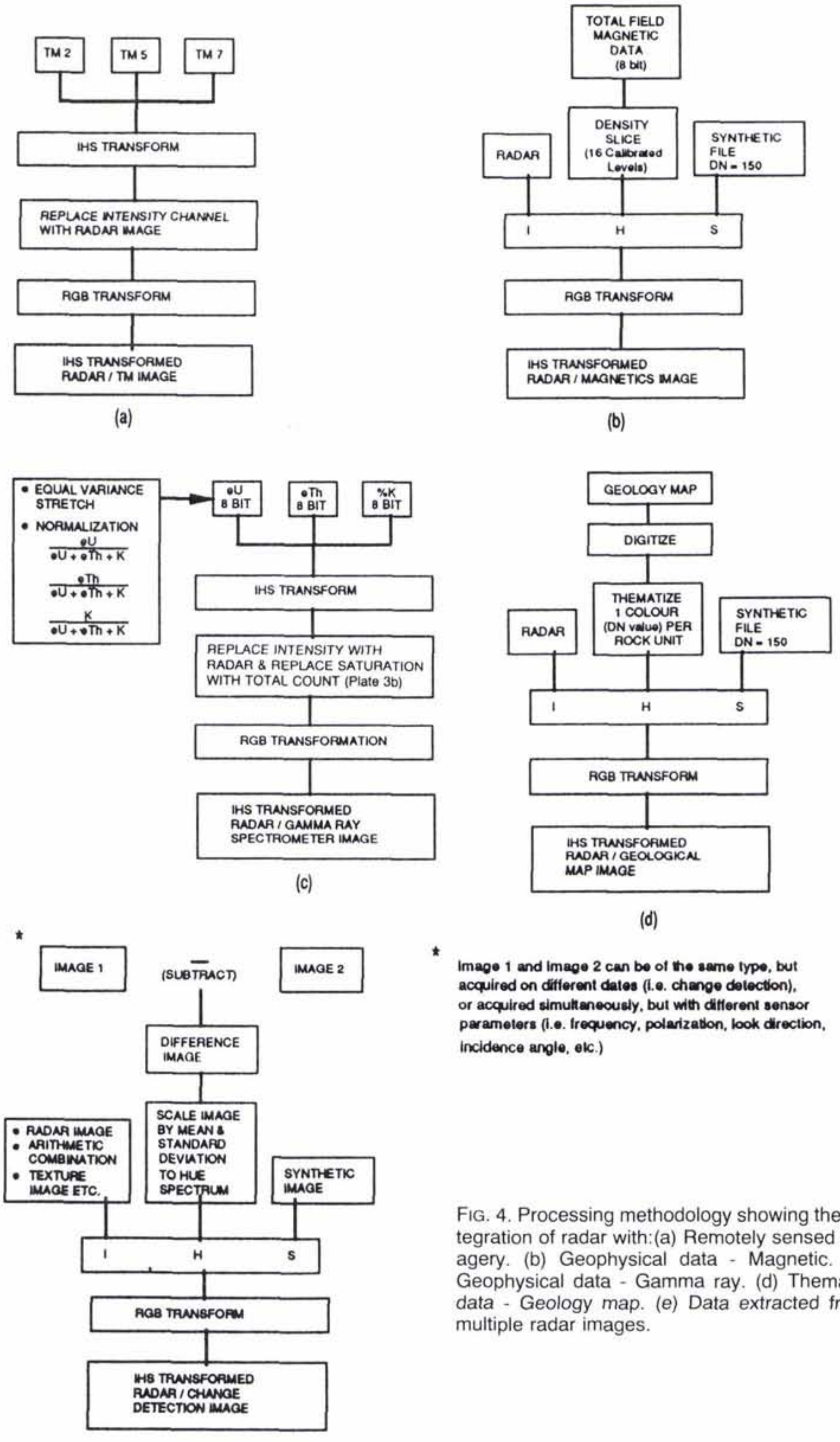
Figure 3 is a generalized map of Canada showing the geographic locations of the imagery discussed while Figure 4 is a diagram summarizing the various steps required to produce the IHS transformed color images presented in this paper.

Several hardware and software components were employed to create the images described below. They include computer image analysis system and associated software, available from Dipix Technologies Ltd. (ARIES-III) and PCI Ltd., the Film Image REcorder (FIRE) from MacDonald Detwiler and Associates, and software written by Intera Kenting under contract to the Canada Centre for Remote Sensing (CCRS). The software used three related IHS type transformations, one based on a spherical mathematical model, and the other two based on cylindrical transformations.



LOCATION #	1	2	3	4
PLATE #	1	2	3,4	6

FIG. 3. Image location map.



* **Image 1 and Image 2 can be of the same type, but acquired on different dates (i.e. change detection), or acquired simultaneously, but with different sensor parameters (i.e. frequency, polarization, look direction, incidence angle, etc.)**

FIG. 4. Processing methodology showing the integration of radar with: (a) Remotely sensed imagery. (b) Geophysical data - Magnetic. (c) Geophysical data - Gamma ray. (d) Thematic *data - Geology map. (e) Data extracted from* multiple radar images.

INTEGRATION WITH THEMATIC MAPPER DATA

Plates 1a and 1b show IHS color composite integrations of radar and TM imagery of the central portion of Cornwallis Island in the remote Canadian Arctic (see Figure 3 for location). The X-band radar image was acquired by Intera Kenting during October, 1987 while the Landsat TM data were acquired in July, 1987 (CCRS scene number 51221-180619). The radar data were resampled from 12.5 metre to 30 metre pixels to match

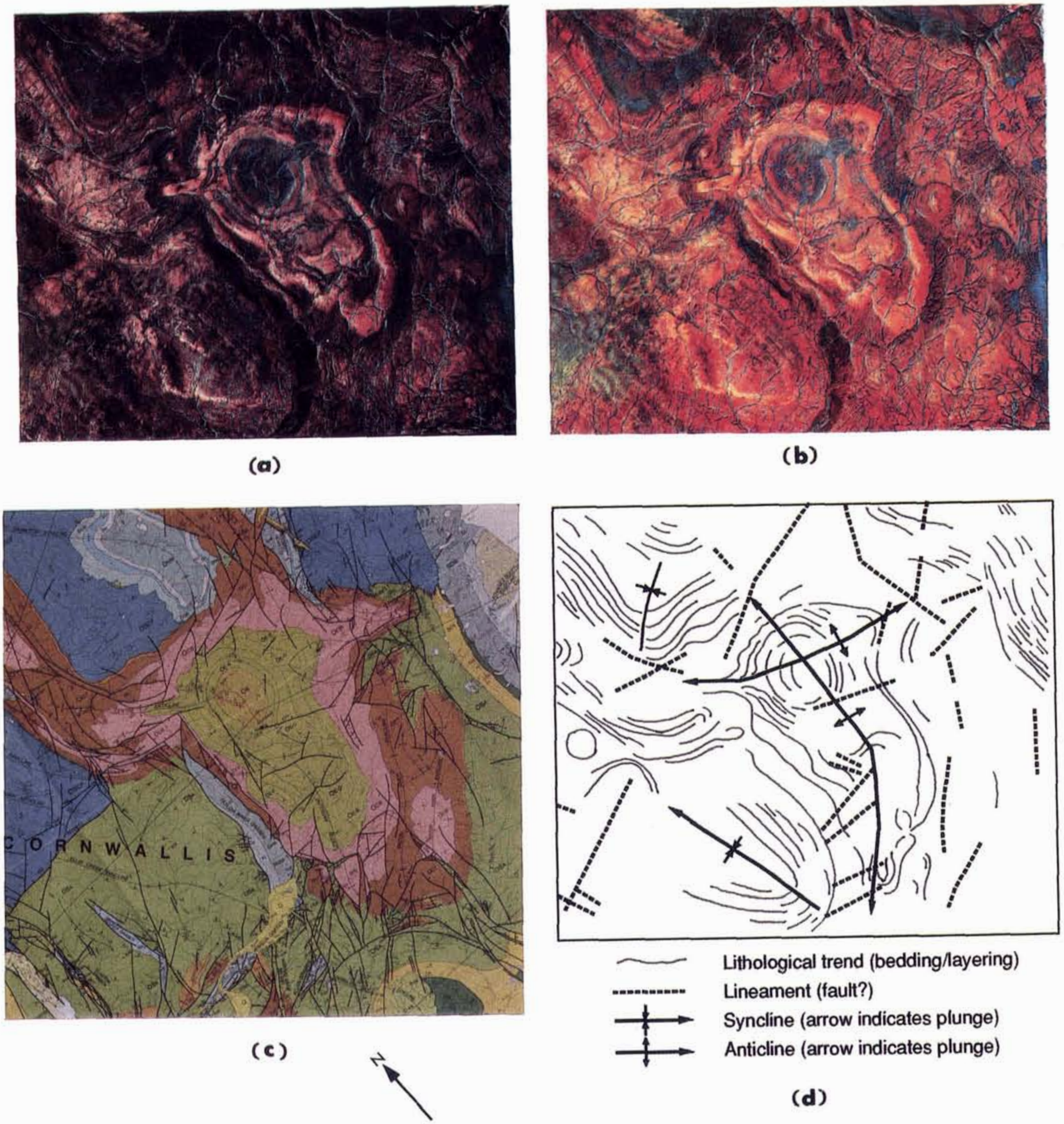


PLATE 1. (a) IHS transformed radar/TM image, I = radar, H = TM bands 2,4,7, S = DN 150. b) IHS transformed radar/TM image, I = radar, H = TM bands 2,5,7, S = DN 150. (c) Geological map (Thorsteinsson, 1986). (d) Interpretation map.

the TM data and then registered to the TM. TM bands 2, 4, and 7 (Plate 1a) and 2, 5, and 7 (Plate 1b) were chosen as input to the IHS transform as these particular combinations provided the best visual separation of lithologic units. After the TM data were transformed to IHS coordinates, the intensity channel was replaced by the contrast enhanced radar image and these modified tiplets were used as input to the reverse IHS to RGB transform for display on a video monitor and subsequent recording on a three-channel color image recorder. Figure 4a is a flowchart summarizing the steps required to produce these images.

INTEGRATION WITH AIRBORNE GEOPHYSICAL DATA

In the examples discussed below the high resolution radar data have been used to modulate intensity while the lower resolution geophysical data have been used to provide image hue.

Plate 2a is an IHS transformed image which combines radar and a single-channel total-field magnetics image over part of the Superior geologic province which comprises much of the Precambrian Canadian Shield of northern Ontario and Quebec. Plate 2b is a generalized geological interpretation of this image. The airborne magnetic data, acquired digitally, compiled, and gridded by the Geological Survey of Canada (Hood, 1979), were registered and geometrically corrected to a Universal Transverse Mercator (UTM) topographic map base. The X-band radar data acquired by Intera Kenting were also registered to the UTM base and formatted with 25-m pixels. Once the data were registered, the IHS transformed image was generated using the methodology outlined in Figure 4b. The 8-bit magnetic data with values ranging from 0 to 255 DN (digital number) were sliced into 16 discrete levels representing absolute measurements of the magnetic total field in units of gamma. These 16 levels were mapped into the hue spectrum so that low levels of gamma are represented in blue and green while higher levels range from orange through to red and purple (see legend on Plate 2a). Because the minimum and maximum gamma values were mapped to 0 and 255 DN, respectively, the slices and subsequent image hues could be calibrated to units of gamma. The radar data were used to modulate image intensity while a saturation file was synthetically generated and assigned a DN level of 150 to ensure a proportionate mix of the radar and magnetic data and to provide hues that were less vibrant. These three IHS channels were then reverse transformed to RGB space to produce the viewable image product.

A single channel (magnetics) has been used to provide color information in Plate 2a. However, multiple channels may be used in the IHS transform to provide hue information as suggested by Buchanan (1979). Plate 3a is an example of a radar/gamma ray spectrometer IHS image covering an area in eastern Nova Scotia, Canada (see Figure 3 for location) in which the hue information has been supplied by three gamma ray spectrometer channels, equivalent uranium (eU), equivalent thorium (eTh), and percent potassium (%K). A C-band wide swath radar image is used to modulate image intensity. The airborne gamma ray spectrometer data were acquired digitally, compiled, and gridded to 200-metre pixels by the Geological Survey of Canada (Grasty, 1972). The data were then resampled to 50-metre pixels and

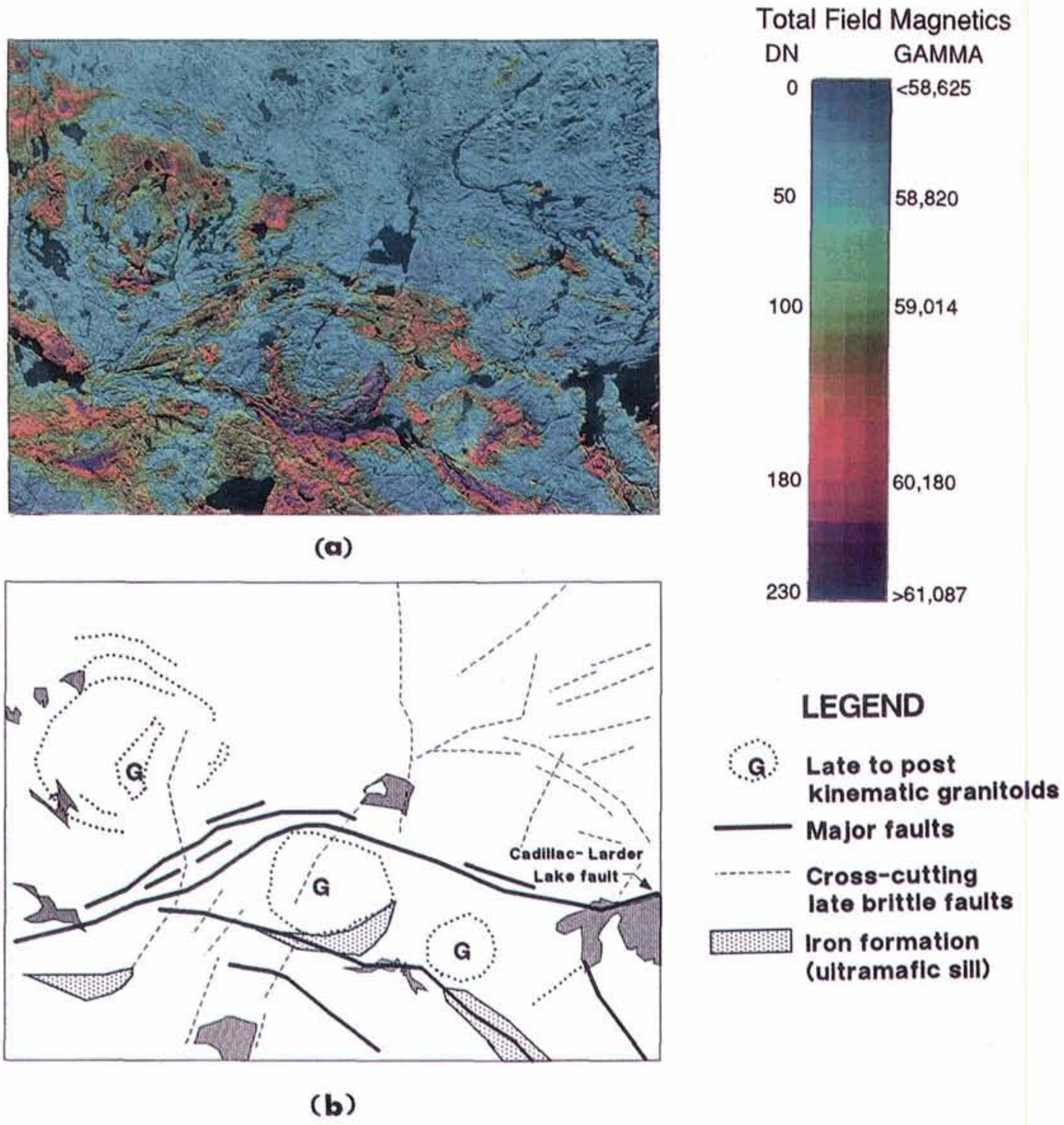


PLATE 2. (a) IHS transformed radar/magnetic image. (b) Geological interpretation map.

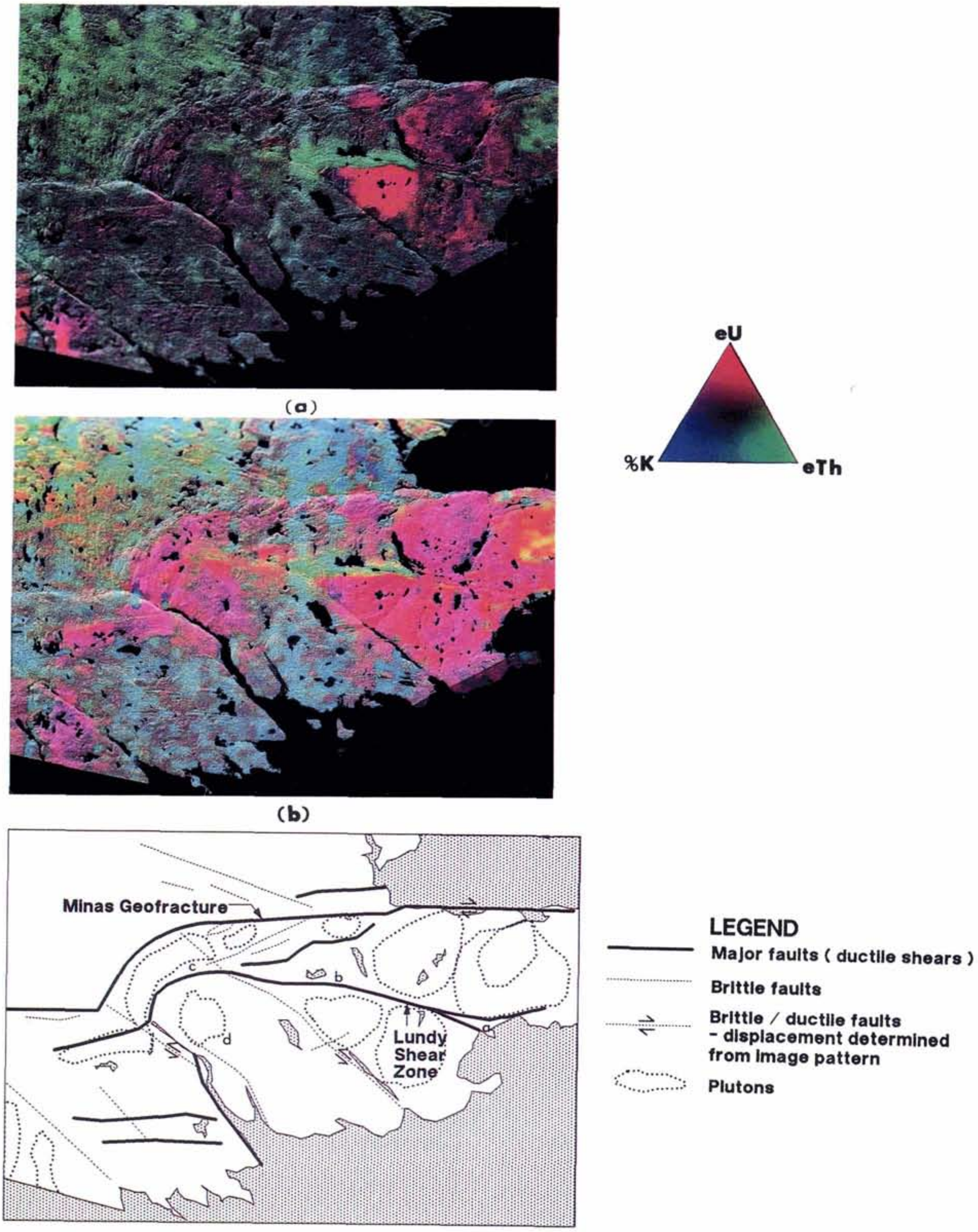


PLATE 3. (a) IHS transformed radar/gamma ray spectrometer image, I = radar, H = eU, eTH, %K, S = original saturation value from transform (b) IHS transformed radar/gamma ray spectrometer image, I = radar, H = eU, eTH, %K, S = total count. (c) Geological interpretation map.

registered to a UTM topographic base. The radar image was acquired by the Canada Centre for Remote Sensing at a pixel size of 12.5 metres. The image was subsequently resampled to 50-metre pixels and registered to the UTM topographic map base.

The image production process, outlined in Figure 4c, consisted of equalizing the means and standard deviations of each of the three spectrometer channels and stretching the minimum and maximum values to cover the full range of the 8-bit data (i.e., 0 to 255 DN). The three spectrometer channels were then used as input to the IHS transform and the radar image was used to replace the intensity channel before converting back to RGB space. The color triangle associated with Plate 3a provides a color guide with which to interpret the relative mix of the eU, eTh, and %K channels. Areas high in eU are red, high in eTh are green, and high in %K are blue. Proportionate mixes of the primary colors result in magenta, cyan, and yellow colors that can be interpreted on a relative basis as mixtures of the three spectrometer channels. Thus, yellow areas have roughly equal proportions of eU (red) and eTh (green) while cyan areas have comparable proportions of eTh (green) and %K (blue).

Saturation in Plate 3a was derived from the original RGB to IHS transformation. However, the original saturation channel could be replaced, for example, with a measure of the total radiation referred to as the total count, thus providing additional information on the radiometric characteristics of the surface. Plate 3b shows a radar/gamma ray spectrometer IHS transformed image in which the saturation channel has been replaced by the total count channel before conversion back to RGB space. The effect of modulating the saturation with total count can be seen clearly as the colors tend to be more vibrant, due to high total count values, than the colors on Plate 3a, where total count was not used to modulate saturation. However, the intensity information provided by the radar is suppressed in this image.

INTEGRATION WITH THEMATIC DATA

Thematic data, including maps or thematic classifications derived from remotely sensed or geophysical data, can also be effectively integrated with radar using the IHS transform. Plate 4 is an IHS image of eastern Nova Scotia, Canada which combines a geological map and a C-band radar image. The radar data were acquired and processed by the Canada Centre For Remote Sensing (CCRS) and the geological map was produced by the Nova Scotia Department of Mines (Keppie, 1979). The map was digitized and registered to a standard UTM topographic base and reformatted to a 50-metre pixel size. The radar data, after registration to the UTM map base, were used to modulate the intensity of the image, while the geological map provides the color information with each lithological unit displayed in a different hue. Saturation has been set to a DN of 150 to ensure an equal mix of the radar and thematic map data (see Figure 4d).

INTEGRATION WITH RADAR DATA FOR CHANGE DETECTION

The IHS transform can be used to produce images in which color variations can be calibrated to reflect differences between two different images. The images can be acquired on different dates; thus, the difference between the two images will relate to temporal variations in ground cover. Conversely, the images may be acquired simultaneously but with different sensing parameters (i.e., frequency, polarization, look direction, etc.). This concept is demonstrated in Figure 4e and Plate 5. Plate 5 shows a theoretical histogram of a difference image, annotated in units of standard deviation and formed by subtracting one image from the other. The difference image is mapped to the hue spectrum so that areas of greatest change between the two images (i.e., > ± 2 standard deviations) are displayed in red/purple hues and blue hues. Areas of minimal change (< ± 2 standard deviations) are displayed in cyan, green, yellow, and orange hues.

Plates 6a and 6b are L- and X-band HH polarized radar images of sea ice in the Beaufort Sea (see Figure 3 for location) acquired simultaneously with the CCRS airborne SAR system. Plates 6c and 6d are IHS transformed radar images constructed using a method similar to that discussed above and outlined in Figure 4e. Plate 6c was constructed by modulating image hue with a diference image between the X- and L-band data and image intensity with an average of the two frequencies produced by summing the X- and L-band data and dividing the sum by two. Hue information in Plate 6d was provided by a difference image between the L- and X-band imagery while image intensity was modulated by the L-band image. The histograms of the normalized difference images are similar to that shown in Plate 5.

RESULTS AND DISCUSSION

Although the IHS color transform can be used for a variety of applications, the examples in this paper are drawn from the discipline of geology/geomorphology and also from sea ice applications. However, many of the ideas developed in this paper may be applied to other disciplines such as agriculture, forestry, and hydrology.

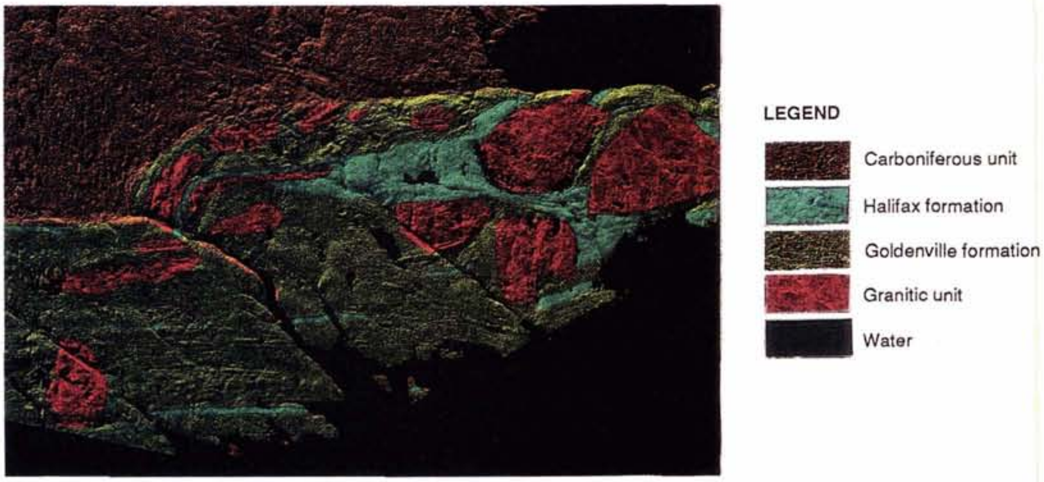
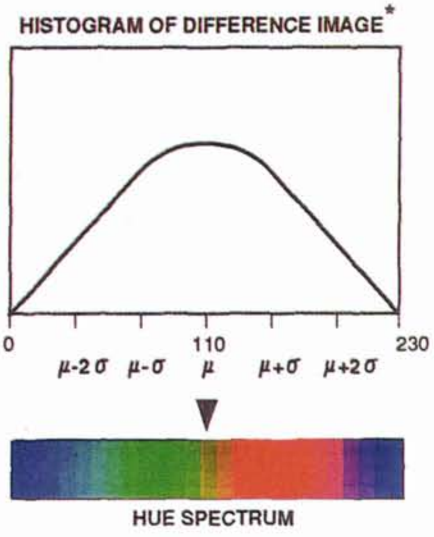


PLATE 4. IHS transformed radar/geology map.



* 2 IMAGES OF DIFFERENT DATES OF ACQUISITION OR DIFFERENT SENSING PARAMETERS (i.e. FREQUENCY, POLARIZATION, LOOK DIRECTION, etc.)

PLATE 5. Histogram of difference image and associate hue spectrum.

The advantages of each IHS image and how it has been used for a particular application and the appropriate references to that application project are discussed below.

The IHS transformed images shown in Plates 1a and 1b have been successfully used to help define lithologic and structural features, many of which are absent on the geological map of the area shown in Plate 1c. The radar image provides additional information regarding surface textures and topographic patterns not evident on the TM data and, when combined with the spectral information offered by the TM using the IHS transform, many unmapped surficial and lithologic patterns can be discriminated. This is especially evident in the central portion of the IHS transformed images in which a large domal structure is clearly visible (see interpretation map, Plate 1d). This feature is marked by individual sedimentary layers comprising the dome, which are displayed in shades of red and yellow. Many of these layers appear to represent separate lithologic units that have not been mapped (compare Plates 1a and 1b with Plate 1c). Separate and distinct lithological layers, displayed as alternating red and yellow bands southwest of the domal structure (see Plate 1b), define a large northwest plunging syncline. A more detailed description of the geological interpretations of the IHS transformed imagery and associated enhancements can be found in Misra *et al.* (1990).

Plate 2a (radar/magnetics IHS image) provides a useful product for geologic exploration as the cartographic information such as lakes, roads, and urban areas, provided by the radar, helps to locate and evaluate the patterns present on the magnetic data more accurately. This can be especially important when undertaking field programs. Furthermore, the detailed terrain information provided by the radar can be compared easily to the magnetic patterns which reflect the subsurface magnetic properties of various rock units. Thus, the IHS transformed image can provide a useful product for evaluating the spatial relationship between surface and subsurface geologic patterns.

In this particular area of Canada the recognition of east-west trending geologic structures (faults) is important as these structures are potential targets for gold exploration (Roberts, 1987). A number of east-west trending lineaments can be delineated based on the terrain information provided by the radar (see Plate 2b). Many of these lineaments and lineament zones coincide with linear magnetic anomalies, thus assisting in their recognition, verification, and subsequent mapping as real geologic features. Furthermore, younger geologic structures which crosscut these major east-west trending structural belts may also provide targets for exploration where they intersect east-west structures (Bowen, 1986). Many of these features can be recognized on the IHS transformed image and in some instances they appear to truncate magnetic linear anomalies (area "a", Plate 2b). The areas of purple and red represent lithologic units or horizons with a high proportion of a magnetic mineral such as magnetite. The purple elliptical shaped area in the central portion of Plate 2a, for example, represents an ironstone formation which has a very strong magnetic signature. The blue and green areas reflect primarily volcanic and granitic lithologies. The granitic bodies can be delineated by their circular shapes present in both the magnetic and topographic patterns displayed together on the IHS transformed image.

The IHS transformed images combining radar and gamma ray spectrometer data (Plates 3a and 3b) represent multi-channel color composite images as Plate 3a is a combination of four data channels (radar + eU, eTh, %K) while Plate 3b is a five-channel combination (radar + eU, eTh, %K, total count). These experimental IHS images have been used to aid in the mapping of lithology, particularly granites, and regional structural patterns in eastern Nova Scotia (Harris, 1989). A generalized geological interpretation derived from the IHS transformed images is shown in Plate 3c. The two data types comprising the imagery act as complements, with the radar providing a map of the terrain surface in which topographic patterns are enhanced and the spectrometer data providing a picture of the "radiometric landscape." The two different views of the terrain contained in one image facilitate photogeologic interpretations as interpreted features can be compared and more easily verified from a geological perspective. For example, a dramatic east-west topographic break, known as the Minas Geofracture (Keppie, 1982), can be seen clearly on the IHS imagery. The areas to the north and south of this tectonic break are characterized by different topographic and radiometric patterns reflecting different geological terranes. The area south of this major fault also appears to be tectonically disrupted (sheared) as evidenced on the IHS imagery based on the sinuous topographic patterns and the elongate shape of many of the granitic bodies displayed in red and magenta colors. Field work by Keppie *et al.*, (1983), Hill (1987), O'Reilly (1988), and by the principal author have verified the tectonic disruption in this zone as a pervasive ductile dextral shearing event. Another major shear zone (Lundy Shear Zone, Keppie *et al.* (1983)) can also be identified on the IHS imagery (see Plate 3c). Between locations "a" and "b" on Plate 3c the shear zone is expressed topographically as a number of east-west trending ridges, but between "b" and "c" it is subtle. However, between these points it is expressed as a linear zone of relatively high eTh. Thus, the diverse information content present in the IHS imagery has facilitated a more accurate identification and mapping of this major shear zone. Identification of shear zones in this area is particularly important as they are targets for regional gold exploration.

These IHS transformed images have also been especially useful for the mapping of granitic plutons and areas of hydrothermal alteration within plutons as they are expressed in various shades of red, magenta, and green reflecting differing radioelement concentrations (see Plates 3a and 3b). In many cases the lithologic contacts between the metasediments and plutons can be delineated and verified by study of topographic patterns supplied by the radar (area "d" on Plate 3c).

Plate 4 represents an enhanced geological map as carto-

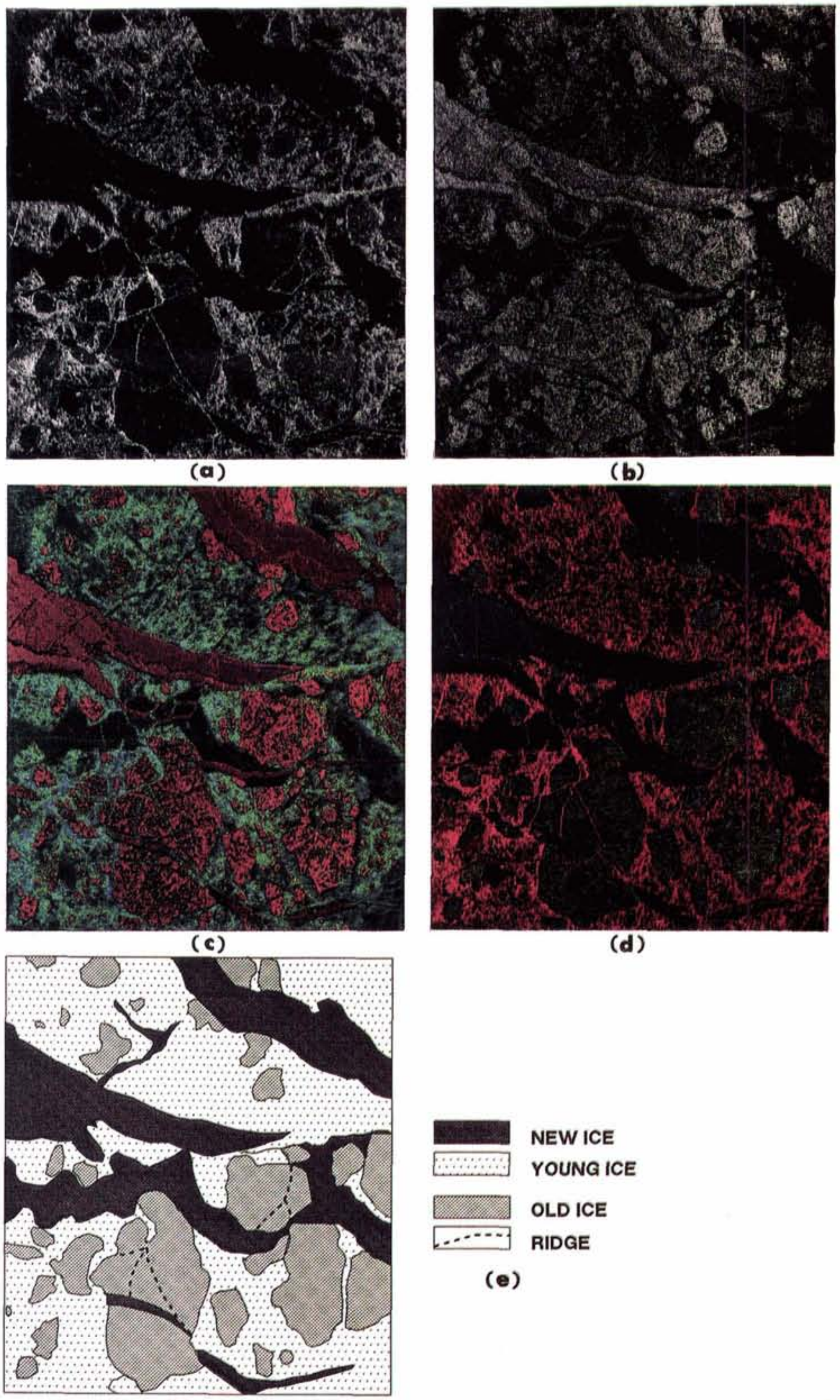


PLATE 6. (a) L-band radar image (CCRS) of Beaufort Sea Ice. (b) X-band radar image (CCRS) of Beaufort Sea Ice. (c) IHS transformed difference image of Beaufort Sea Ice, I = (X-band + L-band)/ 2.0, H = difference image (X-L), S = 150. (d) IHS transformed image of Beaufort Sea Ice, I = L-band, H = difference image (L-X), S = 150.

graphic, topographic, morphological, structural, and textural features provided by the radar have been combined with mapped lithological units. Many structural and surficial geologic features can be mapped on this image and their spatial extent and character can be directly assessed with respect to the known rock units. Furthermore, the position of lithological contacts can be evaluated and re-mapped based on terrain patterns provided by the radar. This image has been used successfully by geologists in the field as a source of both cartographic and geologic information (Harris, 1989).

An example demonstrating the use of the IHS transform not only for displaying backscatter differences between multi-frequency SAR data but also for the enhancement of various image features is shown in Plate 6. Three types of sea ice can be interpreted on the IHS imagery and are shown on the associated interpretation map (Plate 6e). They include old (survived through at least one summer), young, and new ice. In the L-band image (Plate 6a), the darkest tone represents new ice and the brighter features within the large areas of new ice are rafting. Old ice, shown as medium returns and rough texture, is in most cases discernible from the new ice. Ridges over the old ice are clearly visible and appear as bright linear features. The young ice regions also have a high return and are probably associated with brash ice, which appears rough at this frequency. The X-band image (Plate 6b) shows differences within the new ice not found in the L-band data, but does not show the rafting which is clearly displayed in the L-band image. The brighter regions in the new ice may be due to the presence of frost flowers. Old ice, also with a bright return, can be discriminated by its rougher texture, particularly the larger floes shown in the bottom of the X-band image.

The integration of the data sets using the IHS transform highlights the differences in ice types by color and texture. Texture for a particular frequency is emphasized through the intensity component and differences in tone between ice types for the combined frequencies are emphasized by the hue.

Plate 6c provides a general enhancement of ice texture as the intensity component is a combination of the L- and X-band images as discussed in the methodology section. The hues are a function of the difference image between the X- and L-band images (i.e., X minus L); therefore, areas characterized by high X-band returns and low L-band returns are purple/red while areas of high L-band but low X-band returns are blue. Areas that are characterized by less of a difference between L- and X-band backscatter are shown in greenish/cyan hues.

In Plate 6d the textural differences between the new and old ice found in the L-band data are emphasized. The hues are formed by the difference between the L- and X-band images (i.e., L minus X); thus, the hues are reversed with respect to Plate 6c. Areas characterized by low L-band return and high X-band return are displayed in bluish tones, whereas areas characterized by the opposite of the above are displayed in purple/red hues. These reddish areas correlate with young ice and ridges. Differences within the new ice, present on the X-band image but not on the L-band image, are shown as an orange/brown hue on the IHS image.

Furthermore, the combination of frequencies in the hue space enhances features not readily apparent on either single frequency image alone. Old ice floes present in the top left and botom right, shown as magenta in Plate 6d and blue in Plate 6c, are clearly visible but are confused with young ice in the X-band scene and not clearly defined in the L-band image.

SUMMARY AND CONCLUSIONS

A methodology for creating experimental color image products, combining airborne radar with diverse data types using the IHS color display transform, has been demonstrated. Although this methodology is applicable to the integration of virtually any digital data set, radar has been used as the base product for integration as it provides a good high resolution cartographic base in which topographic, morphologic, and surface textural patterns are enhanced. Combining radar with TM data offers an image product in which distinct spectral patterns provided by the TM are displayed in various hues while the radar provides an enhanced "picture" of the terrain. The integration of radar and geophysical data using the IHS transform results in imagery which displays a unique and often very informative "picture" of the Earth's surface. The radar provides a recognizable image of the terrain surface that facilitates a comparison between topographic and geophysical patterns which ultimately results in more detailed and accurate geological interpretations. The radar/magnetics IHS image provides an excellent product with which to map geological structures whereas rock units (particularly granites) can be easily distinguished and mapped on the radar/gamma ray spectrometer IHS imagery. Radar/thematic IHS combinations offer a topographically enhanced thematic map in which surface textures and patterns provided by the radar are incorporated directly into the thematic classes. The IHS can also be used as an enhancement technique, as demonstrated by the ice imagery shown in this paper, as well as a method for effectively displaying differences between imagery collected on different dates or with different sensing parameters.

In conclusion, the IHS color display transform is useful for the integration and unambiguous and controlled portrayal of diverse data types. Greater control over the image construction process is possible as individual data channels can be assigned to the quantifiable and easily perceived color parameters of intensity, hue, and saturation. By controlling image hue, the association of a meaningful color scheme with well defined characteristics of the input data can be achieved. The image hues can be interpreted on a relative or absolute basis, depending on what and how the data were mapped to the hue parameter.

ACKNOWLEDGMENTS

The author would like to thank the internal CCRS reviewers of this paper, particularly V.R. Slaney, and two anonymous reviewers for constructive comments which vastly improved the original manuscript. Blair Moxon's help with the design and computer drafting of the figures was invaluable. Airborne radar data were provided by Intera Kenting and the Canada Centre for Remote Sensing (CCRS) while the airborne geophysical data was supplied by the Geological Survey of Canada (GSC). This work was carried out under CCRS contract OSIN:23413-7-9001, "Scientific and Technical Support for Radarsat."

REFERENCES

Aarnisalo, J., E. Franssila, J. Eeronheimo, E. Lakanen, and E. Pehkonen, 1982. On the Integrated Use of Landsat, Geophysical and Other Data in Exploration in the Baltic, Sheild, Finland, *Photogrammetric Journal of Finland*, 9(1):48–64.

Bowen, R.P., 1986. Geological Survey Maps p2968, 2969, 2970, 2971, 2972, Geological Series - Preliminary Maps, Ministry of Northern Development and Mines, Government of Ontario, Scale 1:15,840.

Buchanan, M.D., 1979. Effective utilization of colour in multidimensional data presentations, *Advances in Display Technology*, SPIE Vol. 199, pp. 9–18.

Buchanan, M.D., and R. Pendergrass, 1980. Digital Image Processing: Can Intensity, Hue and Saturation Replace Red, Green, and Blue?, *Electro-Optical Systems Design* (EOSD).

Conradson, K., and G. Nilsson, 1984. Application of Integrated Landsat, Geochemical and Geophysical Data in Mineral Exploration, *Proceedings of the International Symposium on Remote Sensing Environment, Third Thematic Conference, Remote Sensing for Exploration Geology*, Colorado Springs, Colorado, pp. 499–511.

Daily, M., 1983. Hue-Saturation-Intensity Split-Spectrum Processing of Seasat Radar Imagery, *Photogrammetric Engineering & Remote Sensing*, 49(3):349–355.

Freeman, S.B., S.L. Bolivar, and T.A. Weaver, 1983. Display Techniques for Integrated Data Sets, *Computers and Geoscience*, 9(1):59–64.

Gillespie, A.B., A.B. Kahle, and R.E. Walker, 1986. Colour Enhancement of Highly Correlated Images, I. Decorrelation and HSI Contrast Stretches, *Remote Sensing of Environment* 20:209–235.

Gillespie, A.R., 1980. *Digital Techniques of Image Enhancement in Remote Sensing in Geology* (B.S. Siegal and A.R. Gillespie, eds.), New York, Wiley, pp. 139–226.

Grasty, R.L., 1972. *Airborne Gamma Ray Spectrometry Data Processing Manual*, Geological Survey of Canada, G.S.C. Open File Report 109.

Harris, J.R., 1989. *Mapping of Regional Structure of Eastern Nova Scotia: Implications for Regional Tectonics and Gold Mineralization* (in press).

Harris, J.R., L. Neily, T. Pultz, and V.R. Slaney, 1986. Principal Component Analysis of Airborne Geophysical Data for Lithologic Discrimination using an Image Analysis System, *Proceedings of the Twentieth International Symposium on Remote Sensing of Environment*, Nairobi, Kenya, pp. 641–657.

Haydn, R., G.W. Dalke, J. Henkel, and J.E. Bare, 1982. Application of the IHS Colour Transform to the Processing of Multisensor Data and Image Enhancement, *Proceedings of the International Symposium on Remote Sensing of Arid and Semi-Arid Lands*, Cairo, Egypt, pp. 599–616.

Hill, J.D., 1987. Geology of the Guysborough - Country Harbour Area, Nova Scotia in Current Research, Part A, *Geological Survey of Canada, Paper 87-1A*, pp. 415–422.

Hood, P.J., 1979. Magnetic Methods Applied to Base Metal Exploration, Geophysics and Geochemistry in the Search for Metallic Ores, *Geological Survey of Canada, Economic Geology Report 31*, (P.J. Hood, ed.) pp. 77–104.

Keppie, J.D., 1979. *Geological Map of the Province of Nova Scotia*, Department of Mines and Energy, Nova Scotia.

———, 1982. *The Minas Geofracture*, Nova Scotia, Department of Mines and Energy, Special Paper 24.

Keppie, J.D., S.J. Haynes, J.R. Henderson, P.K. Smith, B.H. O'Brien, M. Zentilli, L.R. Jansen, I.J. MacEachren, R. Stea, and D. Rogers, 1983. *CIM Geology Division Excursion Guidebook Deposits in the Meguma Terrane of Nova Scotia*, Canadian Institute of Mining and Metallurgy.

King, R.W., V.H. Kaupp, W.P. Waite, and H.C. MacDonald, 1984. Digital Colour Space Transformations, *Proceedings of IGARSS'84 Symposium*, Strasbourg, August, pp. 649–654.

Kruse, F.A., 1984. Munsell Colour Analysis of Landsat Colour - Ratio - Composite, Images of Limonitic Areas in Southwest New Mexico, *International Symposium on Remote Sensing of Environment Third Thematic Conference, Remote Sensing for Exploration Geology*, Colorado Springs, Colorado, pp. 761–773.

Kruse, F.A., and G.L. Raines, 1984. A technique for Enhancing Digital Colour Images by Contrast Stretching in Munsell Colour Space, *Proceedings of the International Symposium on Remote Sensing of Environment, 3rd Thematic Conference*, Environmental Research Institute of Michigan, Colorado Springs, Colorado, pp. 755–773.

Misra, K.S., V.R. Slaney, D. Graham, J.R. Harris, and R. Sharp, 1990. *Radar and Landsat Images for Mapping Cornwallis Island, Northwest Territories* (in press).

O'Reilly, G.A., 1988. *Geology and Geochemistry of the Sangster Lake and Larry River Plutons, Guysborough County, Nova Scotia*, unpublished MSC thesis, Dalhouse University, Halifax, Nova Scotia.

Pratt, W.K., 1978. *Digital Image Processing*, A Wiley-Interscience Publication, John Wiley and Sons, New York, 749 p.

Raines, G.L., 1977. Digital Colour Analysis of Colour-Ratio Composite Landsat Scenes, *Proceedings of the International Symposium Remote Sensing Environment*, Vol. 11, pp. 1463–1477.

Roberts, G.R., 1987. Archean Lode Gold Deposits, *Geoscience Canada*, 14(1):194.

Robertson, P.K., and J.F. O'Callaghan, 1988. The Application of Perceptual Colour Spaces to the Display of Remotely Sensed Imagery, *IEEE Transactions on Geoscience and Remote Sensing*, 26(1):49–59.

Sabins, Jr., F., 1986. *Remote Sensing - Principles and Interpretation*, 2nd ed, W.H. Freeman and Co., New York, 449 p.

Slaney, V.R., 1985. Landsat MSS and Airborne Geophysical Data Combined for Mapping Granite in Southwest Nova Scotia, *Proceedings of the Eleventh International Symposium on Machine Processing of Remotely Sensed Data*, Purdue University, Indiana, pp. 198–206.

Thorsteinsson, R., 1986. *Geology of Cornwallis Island and Neighbouring Smaller Islands, District of Franklin, Northwest Territories*, Geological Survey of Canada, Map 1626A, scale 1:250,000.

(Received 1 September 1989; revised and accepted 1 March 1990)
