First Quarterly Progress Report on CESDIS Contract S.C. 550-80

A Planetary Version of PC-McIDAS

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15 October 1992

This is the first quarterly progress report on CESDIS (S.C. 550-80). Previous work performed in the first year of the three year program was performed under NASA contract Contract NAS5-31347.

The primary accomplishement in this quarter was the completion of the multispectral classification capability within the McIDAS-X environment that was begun in the previous year. This work also resulted in the completion of Master of Science Degree requirements for Mr. Gerald R. Peltzer in the Department of Civil and Environmental Engineering, University of Wisconsin-Madison.

A user manual to run the suite of classification programs and a copy of the M.S. thesis submitted by Mr. Gerald R. Peltzer describing the classification scheme and the source code form the core of this quarterly progress report, and are attached herewith.

Work is continuing on creating new or adapting existing applications programs for planetary use under the McIDAS-X environment. It is anticipated that the planetary software will soon be tested in the McIDAS-OS/2 environment while contiuing work on the incorporation of the NAIF library routines in the McIDAS applications. These activities which have been initiated in this reporting period will be described in the next progress report.

ATTACHMENTS

1. **THE McIDAS UNSUPERVISED CLASSIFICATION SYSTEM OPERATIONS MANUAL.** Also contains the source (which forms APpendix B of the MS Thesis by Mr. G.R. Peltzer, below).

2. **A COMPREHENSIVE UNSUPERVISED CLUSTERING TECHNIQUE FOR THE CLASSIFICATION OF REMOTELY SENSED DATA.** Copy of the M.S. Thesis by Mr. G.R. Peltzer submitted to the Civil and Environmental Engineering Department, University of Wisconsin-Madison, 51 pp with two appendices, 1992. (Appendix B contains source code which is also incorporated into the Operations Manual (above), and is not reproduced here so as to avoid duplication in the report as it is also included in the Operations Manual included above.

1. THE McIDAS UNSUPERVISED CLASSIFICATION SYSTEM OPERATIONS MANUAL.

The McIDAS Unsupervised Classification System

Operations Manual

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1.0 INTRODUCTION

An original procedure to classify multispectral images into spectrally similar categories in an automatic, or unsupervised, manner has been developed at the Space Science and Engineering Center of the University of Wisconsin - Madison. This procedure has been integrated into the Man-Computer Image Data Acces System (McIDAS) package and provides an accurate, adjustable, and easy to use process for the extraction of thematic information from multispectral data. The package presented consists of routines for image classification and analysis of classification output. It also includes routines which aid in comparing output with that of other classification methods.

A full description of multispectral classification and details on the development and testing of the algorithms used in the McIDAS classification system can be found in:

Peltzer, G. R., 1992. A Comprehensive Unsupervised Clustering Technique for the Classification of Remotely Sensed Data. M.S. Thesis, University of Wisconsin-Madison.

Contents of the system

The McIDAS classification system developed by the author consists of a set of original routines and existing functions that allow the user to classify and analyze multispectral images within the McIDAS system. In this new system, there are essentially three classification routines (USCLAS, MDCLAS, and ISO.FOR) and a routine for visualizing the output classes of a classification (ELLIPS). In addition, the McIDAS system has been enhanced by adding a utility function (COMBIN) and provides routines for displaying classifications and changing the output enhancement table in order to highlight or merge classes.

USCLAS is the unsupervised classification routine which classifies a multi-band McIDAS area automatically. MDCLAS is a Minimum Distance to

Mean classification routine which uses cluster statistics developed from a previous classification to classify an area. A good application for MDCLAS is in classifying a time series of images using a set of class statistics derived by USCLAS. ISO.FOR contains standard ISODATA subroutines for cluster merging and splitting which can be inserted into USCLAS to make a standard ISODATA routine. COMBIN is a utility function which combines several one-band McIDAS areas into a multi-band area to be used by USCLAS or MDCLAS. ELLIPS is a cluster visualization utility which displays plots of class statistics graphically.

2.0 USCLAS

The USCLAS routine performs an unsupervised classification in a recursive process based on the ISODATA method which classifies an image repeatedly, using a changing set of spectral clusters which evolve to represent the statistical classes present in the data. Throughout the classification, oversized clusters are split using a method analogous to analyzing mass moments of inertia, while poorly separated clusters are merged using Transformed Divergence as a decision function for class separability. The advantage of these methods is that they give the user an absolute index for cluster separation. The final number of classes produced is a function of the degree of class separation and the class shape desired by the user.

Running USCLAS

To begin an image classification, a one-byte multi-band McIDAS area must be first obtained. (USCLAS will classify a single-band image, but this amounts to performing a level slicing operation.) If the image is in the form of several single-band areas, then the user must first run the McIDAS COMBIN routine, which was developed by the author to make a multi-band image from

single-band components.

The next step is to run USCLAS. A help menu for the program can be obtained through the *HELP USCLAS* command. When running this or any other classification routine, the best approach is to switch to a separate output window, start the classifier, then switch back to the first output window. The USCLAS output, which includes progress updates every iteration, can then be monitored separately while other McIDAS routines are run.

USCLAS is run as a command in the McIDAS system, with parameters entered through the command line. The only required parameters are for the input and output areas, though a number of adjustable parameters may be entered. When first viewing the USCLAS help menu, the assortment of parameters might seem confusing. This should not be disconcerting, as the program is designed for ease of use and should produce good classification results using defaults. The additional parameters, however, can be very useful in gaining added control over the output of the classifier. The following is a list of the command line parameters of USCLAS as seen through the help menu:

```
C=====================================================================
C ?   USCLAS -- SPECTRALLY CLASSIFY A MULTI-BAND IMAGE
C ?     --- UNSUPERVISED MULTISPECTRAL IMAGE CLASSIFICATION ---
C ?
C ?            USCLAS INAREA OUTAREA
C ?   PARAMETERS:
C ?          INAREA  - AREA TO BE CLASSIFIED
C ?          OUTAREA - FINAL CLASSIFIED AREA WITH ~M CLASSES.
C ?
C ?   KEYWORDS:
C ?          BANDS:  NUMBER OF AREA BANDS TO CLASSIFY,
C ?               DEFAULT IS ALL BANDS IN AREA.
C ?               USER DEFINES THE BANDS TO USE:
C ?                  BANDS= BAND1 BAND2 ... BANDN
C ?          CLASES:  INITIAL # OF CLASSES PRESENTED.
C ?                  CLASES= M            DEFAULT IS 100
C ?           SKIP:  SKIP FACTOR FOR ITERATIVE
C ?               CLASSIFICATION.  NUMBER OF ROWS
C ?               AND COLUMNS SKIPPED. MUST BE < 8.
C ?                  SKIP= N              DEFAULT IS 4
C ?           ITER:  MAXIMUM ALLOWED ITERATIONS
```

```
C ?                ITER= P              DEFAULT IS 35
C ?          MERGE:  CLUSTER MERGING FACTOR, 0 TO 2000,
C ?               IF A DIVERGENCE < MERGE THEN MERGE.
C ?               0 = NO MERGING
C ?                  MERGE= Q             DEFAULT IS 1400
C ?          SPLIT:  SPLITTING FACTOR, 1 TO 10,
C ?               IF BIG/SMALL DIMS. > SPLIT == SPLITTING
C ?               0 = NO SPLITTING
C ?                  SPLIT= R             DEFAULT IS 3.0
C ?           NULL:  DATA DROP-OUT DECISION.
C ?               ANY: CLASSIFY AS ZERO IF ANY BAND HAS 0.
C ?               ALL: CLASSIFY AS ZERO IF ALL BANDS = 0.
C ?                                 DEFAULT IS ALL
C ?         MINPIX:  SMALLEST PIXEL COUNT ALLOWABLE IN A CLASS
C ?                               DEFAULT = 0.01% OF DATA
C ?        STRETCH:  OUTPUT COLOR STRETCH TYPE.
C ?               LINE: LINEAR STRETCH FOR CLASS COLORS
C ?               HIST: HISTOGRAM EQUALIZATION STRETCH
C ?                               DEFAULT = HIST
C-----------------------------------------------------------------------
```

The first optional parameter is *nbands*, the number of bands. This parameter allows the user to run a classification using either all of the bands of an image, or only selected bands. The maximum number of bands is currently set at seven. The selection of the first three bands used is important in that it will determine the output color scheme of the classification.

The next parameter, *clases*, allows the user to choose the initial number of classes for the classifier to work with. The initial number of classes has an important and predictable effect on the classification output. Increasing the number of initial classes in USCLAS generally produces a larger number of output classes that meet all the other requirements of the classification. This effect is one of diminishing returns, however, and increasing the initial number of classes beyond a certain threshold ceases to change the output classification. A high value of around 200 initial classes has been found to be most effective for finding as many distinct classes as possible in the data; however, values greater than 100 generally work well.

The *skip* parameter sets the classifier to analyze data only at every nth row and column. This speeds up the clustering by a factor of n^2, but at a cost of

a poorer classification. Unlike the ERDAS approach, the skip factor in USCLAS is used until convergence is reached, at which point the whole image (*skip* set at 1) is classified. A good approach to getting to a desired type of output quickly is to run USCLAS classifications with a large skip factor until the most useful program settings are found, then run USCLAS on the whole image to produce the final output. Increasing the skip factor generally reduces the output number of classes slightly as there is less information used in the analysis.

The parameter *iter*, the maximum number of iterations allowed, has a default of 35. This should be enough in most cases, except for data where the image bands are not registered well to each other. In general, changing the other parameters in USCLAS makes the classifier either more or less demanding, which is reflected in an increase or decrease in the required iterations. If USCLAS goes to the maximum number of iterations, it terminates and classifies the image using the last set of classes.

The *merge* and *split* parameters work as described earlier, and are developed in detail in the thesis. For merging, a transformed divergence value is entered. This value is the minimum transformed divergence allowed between cluster pairs. Although values of 1700 or greater are considered good theoretically, practical values of around 1400 seem to show better results. Increasing the the *merge* parameter in USCLAS makes for a more demanding classifier which reduces the output number of classes and increases the iterations required. Because of the predictable nature of this criterion, adjusting the merging parameter is the best way to fine-tune the number and characteristics of the output classes desired.

For cluster splitting, a value for the ratio of the largest to smallest cluster dimensions is entered. The default ratio of three allows clusters to be essentially up to three times as long as they are wide. In general, entering a

large *split* parameter produces fewer output classes. Due to the nature of the criterion however, the splitting factor is not recommended as a means to adjust the number of output classes, but rather as a check to ensure that class sizes are well behaved. For cluster splitting as well as merging, an input of zero disables the routine.

The *null* parameter tells the MDM classifier how to handle data in which there are areas of no data for some or all of the bands. In the case where some bands are zero, USCLAS is generally forced to develop an entirely new set of classes for that area which have a zero mean in the empty bands. As this can be good or bad depending on the application, the null parameter can be set to classify pixels as zero if any one of the bands contains drop-outs, or only if all bands are empty. The classifier reserves the special class of zero for data drop out.

The *minpix* parameter is the key in defining the minimum number of pixels allowed in each cluster. In USCLAS, a cluster is defined as empty and is removed if there are fewer than the minimum number of pixels in that cluster. As many images contain noise pixels, setting the minimum number of pixels to a value greater than zero reduces the presence of small noise classes. Setting this parameter to a value too high can eliminate small classes of useful information, however.

The *stretch* parameter in USCLAS allows the user to change the output appearance of the classification. In USCLAS, the output classes are given colors (described in the classification's enhancement table file) which try to match the 'colors' of the class mean vectors in the first three bands of the data. To make a more pleasing display, the colors are obtained from a histogram stretch of the mean vectors. The *stretch* parameter defines the type of stretch used: either linear or histogram equalization may be used.

The speed of USCLAS on an IBM RISC workstation is very fast relative to an ISODATA routine running on a PC-compatible computer, but still requires a significant amount of time. As an example of the time required, a full USCLAS classification of a 512 by 512 image containing six bands takes from twenty to forty minutes to classify, depending on the number of iterations required. The same scene processed through the ERDAS ISODATA on a 33MHz 80486 based PC-compatible computer can require over five hours to complete. The large difference in speed is due mainly to the differences in processing power and disk access time between the two computers, but there are also some speed enhancements incorporated into USCLAS. The standard ISODATA routine is slowed considerably by its need to access the disk repeatedly. For every iteration, it must read in the image, read in the old classification for comparison, then write out the new classification. This heavy disk access creates a scenario where the classifier works at the speed of the disk drive, no matter how fast the processor. In USCLAS, the output classification is kept entirely in memory until the final write, thus reducing the three disk operations to only one disk read each iteration.

USCLAS output

The USCLAS program produces four separate output files which contain the information from the classification. The display part of the output consists of a McIDAS area containing classified values for the image classified and an *.ET* enhancement table to provide colors for these classes. The other two files are *.SIG* and *.LOG* files which contain the statistics of the classification. The *.LOG* file is a log of the classification's operations through every iteration, including detailed descriptions of changing cluster means and statistics. All these files consist of the McIDAS area number of the classified image plus the relevant extension.

3.0 MDCLAS

After processing, the classification output may also be used as input for another McIDAS program. The MDCLAS program can use the class statistics to classify other multi-band McIDAS areas quickly, using a spectral minimum distance to mean algorithm. Its premier use is to classify a large number of images in a time series with the classes obtained from a control image of the series.

MDCLAS is run similarly to USCLAS, with parameters entered through the command line. The required parameters are for the input and output areas, plus the area number for the class statistics to be used.

4.0 ELLIPS

The *.SIG* file may be used to visualize the positions of the output classes in the pattern space of the classification through the use of the cluster visualization program named ELLIPS. ELLIPS is so named because it plots elliptical plots of the statistical distribution of the data in each cluster. This program also plots only the locations of the mean vectors of the data if requested, but the elliptical plots give a much better indication of the spread and overlap of classes.

ELLIPS draws a series of elliptical plots, going through all the possible combinations of axes two at a time. In the ELLIPS program, a plot connecting the four points along the principal axes of the ellipse is performed for every class in the output. ELLIPS uses two standard deviations as a default value, but will also accept any other value as an input parameter. The only input Ellipse requires is the area number of the classification. A standalone version of ELLIPS which does not run under McIDAS is available, and is called ELLIPSE.

5.0 VISUALIZING A CLASSIFICATION

Once USCLAS or MDCLAS has finished running, the user may display the output area in the image window, using the command *EU REST nnnn* to color the classification image. (*nnnn* is the output area number; all the USCLAS output files are written as this number plus an extension.) Class colors may be modified with the *EU* command. Classes may also be merged by making component clusters of an information class the same color. The output class numbers visible are doubled from their original values used in analysis. This is an unfortunate necessity because McIDAS-X has a seven bit color plane which limits the visualization of output colors. Output classes thus go as 0, 2, 4, ... and odd numbers are not used.

To aid in the analysis of output classes, the ELLIPS program may be called to create a window containing a plot of statistical ellipses or class means. Several ELLIPS plots may be run at once; the only limitation is with available screen area for viewing. ELLIPS plots do not present doubled classes, and the user must remember to multiply by two when comparing with screen classes.

Some trial McIDAS areas which may be classified by USCLAS:
Gerry Peltzer, 11/20/1992

area	ss	yyddd	hhmmss	lcor	ecor	lr	er	zr	lsiz	esiz	z	bands
Thesis AVHRR scene of Kuwait, smoke:												
2230	60	91054	43100	661	1178	1	1	4	640	552	1	1234.....
2231	60	91054	43100	661	1178	1	1	1	640	552	1	1.....
2232	60	91054	43100	661	1178	1	1	1	640	552	1	.2.....
2233	60	91054	43100	661	1178	1	1	1	640	552	1	..3.....
2234	60	91054	43100	661	1178	1	1	1	640	552	1	...4.....
Example classifications of 2230, see "2230classes" for details:												
3063	60	91054	43100	661	1178	1	1	1	640	552	1	1.....
3064	60	91054	43100	661	1178	1	1	1	640	552	1	1.....
3065	60	91054	43100	661	1178	1	1	1	640	552	1	1.....
3066	60	91054	43100	661	1178	1	1	1	640	552	1	1.....
Classifications produced by ERDAS ISODATA:												
3098	0	92000	0	0	0	1	1	1	640	552	1	1.....
3099	0	92000	0	0	0	1	1	1	640	552	1	1.....
AVHRR of Kuwait, smoke:												
2351	61	91235	104500	2401	1051	1	1	1	580	800	1	1.....
2352	61	91235	104500	2401	1051	1	1	1	580	800	1	.2.....
2353	61	91235	104500	2401	1051	1	1	1	580	800	1	..3.....
2354	61	91235	104500	2401	1051	1	1	1	580	800	1	...4.....
AVHRR of Kuwait, smoke:												
2501	62	91316	43600	501	751	1	1	1	480	640	1	1.....
2502	62	91316	43600	501	751	1	1	1	480	640	1	.2.....
2503	62	91316	43600	501	751	1	1	1	480	640	1	..3.....
2504	62	91316	43600	501	751	1	1	1	480	640	1	...4.....
AVHRR of Wisconsin, Iowa, and Minnesota together:												
2701	61	92295	204700	3628	9400	1	1	1	1500	1200	1	1.....
2702	61	92295	204700	3628	9400	1	1	1	1500	1200	1	.2.....
2703	61	92295	204700	3628	9400	1	1	1	1500	1200	1	..3.....
2704	61	92295	204700	3628	9400	1	1	1	1500	1200	1	...4.....
Madison TM scene, 3 bands:												
3120	0	92000	0	0	0	1	1	3	600	800	1	123.....
3121	0	92000	0	0	0	1	1	1	600	800	1	1.....
Wisconsin AVHRR scene:												
3131	62	92232	135900	1221	816	1	1	1	500	500	1	1.....
3132	62	92232	135900	1221	816	1	1	1	500	500	1	.2.....
3133	62	92232	135900	1221	816	1	1	1	500	500	1	..3.....
3134	62	92232	135900	1221	816	1	1	1	500	500	1	...4.....
Spot scene of Jakarta, Indonesia:												
3150	0	92000	0	0	0	1	1	4	601	801	1	1234.....
3151	0	92000	0	0	0	1	1	1	601	800	1	1.....
3152	0	92000	0	0	0	1	1	1	601	800	1	1.....
Landsat agricultural scene of Wisconsin:												
3400	0	92000	0	0	0	1	1	4	600	600	1	1234.....
Example classifications, see "3400classes" for details:												
3401	0	92000	0	0	0	1	1	1	600	600	1	1.....
3402	0	92000	0	0	0	1	1	1	600	600	1	1.....
3403	0	92000	0	0	0	1	1	1	600	600	1	1.....
3414	0	92000	0	0	0	1	1	1	600	600	1	1.....
3415	0	92000	0	0	0	1	1	1	600	600	1	1.....

McIDAS utilities:

COMBIN - Combines several one-band areas into a multi-band area with one byte data. The navigation of the first area is copied.

LISTHEAD - Lists the contents of the header of an area in integer form.

FDEST - Subroutine to print output to a file (a mainframe routine).

ELLIPS - Draws signature ellipses of classes generated by a classification routine. Inputs can be in .SIG or .SBD (ERDAS) format.

McIDAS classifiers:

USCLAS - Main unsupervised classification routine, using a method based on the ISODATA method. Produces output classification area with .ET color table file, .log procedure summary file, and .SIG class statistics file.

MDCLAS - Uses classes developed by another classifier to classify a multi-band area. Uses minimum distance to mean.

ISO.FOR - Contains cluster splitting and merging routines for the standard (Tou and Gonzalez, 1974) ISODATA.

McIDAS to ERDAS file translation programs:

ATOERD - Converts McIDAS areas to ERDAS .lan or .gis files, converting McIDAS .ET color look-up table files to ERDAS .trl color look-up files if a .gis file is desired.

ERDTOA - Converts ERDAS .lan or .gis files to McIDAS areas, converting ERDAS .trl files to McIDAS .ET files if a .gis file is converted.

SBDSIG - Translates an ERDAS .sbd binary classification signatures file into a text readable .SIG file for use in McIDAS classifiers. Also translates .SIG files into .SBD format for use with SIGMAN in ERDAS.

```
      SUBROUTINE MAIN0
C-----------------------------------------------------------------------
C     COMBIN -- MAKE A MULTI-BAND AREA FROM SEVERAL SINGLE BAND AREAS.
C               MAY ALSO BE USED TO REDUCE 2-BYTE DATA TO 1-BYTE DATA.
C
C     USAGE  --          COMBIN OUTAREA BANDS=AREA1 AREA2...
C     PARAMETERS:
C                 OUTAREA - AREA WITH N BANDS.
C     KEYWORDS:   (MANDATORY)
C               BANDS:      AREA BANDS TO REGROUP.
C                           USER DEFINES THE BANDS TO USE:
C                           AREA1 WILL BE BAND1 OF OUTAREA, AREA2
C                           WILL BE BAND2 OF OUTAREA, ETC.
C                                       BANDS= AREA1 AREA2 ... AREAN
C               CUTOFF:     PERCENT OF DATA TO CUTOFF IN 2BYTE COMPRESSION.
C                                       DEFAULT = 1.0% OF DATA
C               BANDWIDTH: OUTPUT RANGE FOR 2 BYTE RAW DATA, FROM 2 TO 255.
C                                       DEFAULT = 255
C               DATA:       INPUT FORMAT OF DATA: BRIT, RAW
C                                       DEFAULT = RAW
C
C  Written by Gerard Peltzer
C  UW SSEC
C  Ver 10/29/1992
C-----------------------------------------------------------------------

C MXBANDS sets max number of bands allowed in input image:
C MAXRC sets maximum number of rows and cols in image:
      IMPLICIT CHARACTER*12 (C)
      IMPLICIT REAL*8 (D)
      PARAMETER (MXBNDS=5)
      PARAMETER (MAXRC=3584)
      PARAMETER (MAXCOL=3584)
      PARAMETER (MAXROW=1024)
      PARAMETER (STBNDS=4)
      PARAMETER (MAXOUT=17920)
      PARAMETER (MAX2B=32768)
      PARAMETER (MAX1B=255)
      PARAMETER (XMCUTOF=1.0)
      CHARACTER*3 CDDATA
      PARAMETER (CDDATA='RAW')

      CHARACTER*80 CMES
      CHARACTER*4 CTYPE(2), CDATA
      INTEGER*2 BUFFER(0:MAXRC), OUTDAT(0:MAXOUT), DATT(0:MAXOUT)
      INTEGER IDIR(64), JDIR(64), ABANDS, NBANDS, NROWS, NCOLS
      INTEGER I, J, ROW, COL, BAND, PACKING, DATYPE
      INTEGER CHECK, NRM1, NCM1, NBM1, IBWIDTH
      INTEGER VAL, DOC, CAL, LEV, STARTI, STARTO
      INTEGER*4 ITYPE(2), INAREA(MXBNDS+1), OTAREA
      INTEGER*4 IBUF(10), PBUF(100), ICALB(128), IMBAND
      INTEGER*4 MAX(MXBNDS), MIN(MXBNDS), NAVOFF,  NAVARR(256)
      REAL*8 CCDAVG(MXBNDS),SCALE(MXBNDS),HIST(0:MXBNDS,0:255)
      REAL*8 SMAX(MXBNDS),SMIN(MXBNDS)

      CALL SDEST('BEGIN: ',0)
      OTAREA=IPP(1,0)
      IF (OTAREA .LT. 1) THEN
        CALL SDEST('BAD OUTPUT AREA SPECIFIED',0)
        RETURN
      ENDIF
      WRITE(CMES,'(1X,A12,I4)') 'Output Area: ', OTAREA
      CALL SDEST(CMES,0)

C Read in bands to use:
      NBANDS=NKWP('BANDS')
        IF(NBANDS.EQ.0) THEN
          WRITE(CMES,'(1X,A40)')
     C    'USER SPECIFIED ILLEGAL NUMBER OF BANDS'
          CALL SDEST(CMES,0)
          RETURN
        ENDIF
      DO 10 I = 1, NBANDS
        INAREA(I) = IKWP('BANDS',I,I)
10    CONTINUE
      WRITE(CMES,'(A19,I5)') 'Bands to combine: ', NBANDS
       CALL SDEST(CMES,0)
      IF (NBANDS .GT. MXBNDS .OR. NBANDS .LT. 1) THEN
        WRITE(CMES,'(1X,A40)')
     C    'USER SPECIFIED ILLEGAL NUMBER OF BANDS'
         CALL SDEST(CMES,0)
        RETURN
      ENDIF

C Read in data cutoff:
      DCUTOF=DKWP('CUTOFF',1,XMCUTOF)/100.
C Check iter less than maximum:
      IF (DCUTOF .GT. 1. .OR. DCUTOF .LT. 0) THEN
        WRITE(CMES,'(A40)') ' BAD CUTOFF VALUE, USING DEFAULT'
         CALL SDEST(CMES,0)
         DCUTOF = XMCUTOF
      ENDIF
      WRITE(CMES,'(A16,F7.2)') ' Cutoff value = ', DCUTOF*100.
         CALL SDEST(CMES,0)

C Read in data bandwidth:
      IBWIDTH=IKWP('BANDWIDTH',1,MAX1B)
C Check iter less than maximum:
      IF (IBWIDTH .GT. MAX1B .OR. IBWIDTH .LT. 2) THEN
        WRITE(CMES,'(A40)') ' BAD BANDWIDTH VALUE, USING DEFAULT'
         CALL SDEST(CMES,0)
         IBWIDTH = MAX1B
      ENDIF
      WRITE(CMES,'(A26,I4)') ' Output bandwidth value = ', IBWIDTH
         CALL SDEST(CMES,0)

C Read in data type read:
      CDATA=CKWP('DATA',1,CDDATA)
C Check data type:
19     CONTINUE
      IF (CDATA .EQ. 'RAW' .OR. CDATA .EQ. 'raw') THEN
        DATYPE = RAW
        GOTO 29
      ENDIF
      IF (CDATA .EQ. 'BRIT' .OR. CDATA .EQ. 'brit') THEN
        DATYPE = BRIT
        GOTO 29
      ENDIF
        WRITE(CMES,'(A40)') ' USER SPECIFIED BAD DATA TYPE'
         CALL SDEST(CMES,0)
        CDATA = CDDATA
        WRITE(CMES,'(A23,A3)') ' USING DEFAULT = ',CDDATA
         CALL SDEST(CMES,0)
        GOTO 19
29    CONTINUE
        WRITE(CMES,'(1X,A11,A4,A6)') 'Reading in ',CDATA, ' data.'
         CALL SDEST(CMES,0)

C Open area to see how big, number of bands:
      CALL SDEST(' ',0)
```

```
      WRITE(CMES,'(1X,A20)') '---Image Contents---'
       CALL SDEST(CMES,0)
      DO 20 BAND = 1, NBANDS
       CALL HOWBIG(INAREA(BAND),NROWS,NCOLS)
       WRITE(CMES,'(1X,A7,I5)') 'Area: ', INAREA(BAND)
        CALL SDEST(CMES,0)
       WRITE(CMES,'(1X,A7,I5)') '  Rows ', NROWS
        CALL SDEST(CMES,0)
       WRITE(CMES,'(1X,A7,I5)') '  Cols ', NCOLS
        CALL SDEST(CMES,0)
       IF ((NROWS .GT. MAXROW) .OR. (NCOLS .GT. MAXCOL)) THEN
         CALL SDEST('AREA TOO BIG TO PROCESS - EXITING!',0)
         RETURN
       ENDIF
       CALL OPNARA(INAREA(BAND))
       CTYPE(1) = 'UNIT'
       ITYPE(1) = LIT(CDATA)
       CTYPE(2) = 'SPAC'
       ITYPE(2) = 2
       CALL ARAOPT(INAREA(BAND),2,CTYPE,ITYPE)
       CALL READD(INAREA(BAND),JDIR)
        IMBAND=NINT(ALOG10(REAL(JDIR(19)))/ ALOG10(2.)) +1
       WRITE(CMES,'(A12,I3,A11,I3)') 'Input band ',IMBAND,
     C                               ' output to ',BAND
       ABANDS= JDIR(14)
       IF (ABANDS .GT. 1) THEN
         WRITE(CMES,'(1X,A20,I5)') '     Bands in area: ', ABANDS
         CALL SDEST(CMES,0)
         CALL SDEST(' PROGRAM WILL USE 1 BAND ONLY',0)
       ELSE IF (ABANDS .LT. 1) THEN
        CALL SDEST('NOT ENOUGH BANDS TO PROCESS - EXITING!',0)
        RETURN
       ENDIF

C/*-----------------------------------------------
       IF (BAND .EQ. 1) THEN
C  Make header for output area:
        NRM1 = NROWS - 1
        NCM1 = NCOLS - 1
        CALL READD(INAREA(BAND),IDIR)
        NAVOFF = IDIR(35)
        CALL MOVCW('AREA COMBINATION                ',IDIR(25))
        IDIR(14) = NBANDS
        IDIR(19)= 0
        DO 15 I = 1, NBANDS
          IDIR(19) = IDIR(19) + 2**(I-1)
15      CONTINUE
        IF (IDIR(36) .NE. 0) THEN
          VAL = IDIR(15)-IDIR(49)-IDIR(50)-IDIR(51)
        ELSE
          VAL = 0
        ENDIF
        IDIR(36)= 0
        LEV = IDIR(51)
        DOC = IDIR(49)
        CAL = IDIR(50)
C        WRITE(CMES,11) 'VAL', VAL,'DOC',DOC,'CAL',CAL,'LEV',LEV
C             CALL SDEST(CMES,0)
11      FORMAT(4(1X,A3,':',1X,I5))
C       Copy DOC, CAL sections to new data:
C       Define where the start of data is in input, in bytes:
        STARTI = IDIR(15)
C        STARTO = STARTI - LEV - VAL + 8
        STARTO = 8
C       Modify LEV section to read bands in new area:
C       Ibuf(1 and 2) contain LEV information:
        IDIR(51) = 8
        IDIR(50) = 0
        IDIR(49) = 0
        INPACKING = IDIR(11)
        IF (INPACKING .EQ. 2 .AND. CDATA .EQ. 'RAW') THEN
          PACKING = 2
        ELSE
          PACKING = 1
        ENDIF
        IDIR(11) = 1
        IDIR(34) = 768
        IDIR(35) = 256
        IDIR(63) = 0
        IDIR(52) = LIT('VISR')
        IF (IDIR(3) .EQ. 55) IDIR(52) = LIT('MSAT')
C        IF ((IDIR(3) .EQ. 60) .OR. (IDIR(3) .EQ. 61) .OR.
C     C           (IDIR(3) .EQ. 62)) THEN
C          IDIR(52) = LIT('TIRO')
C        ENDIF
        IDIR(53) = LIT('BRIT')
        DO 22 I = 1, 8, 1
          IF (I .LE. NBANDS) THEN
            IBUF(I) = I
          ELSE
            IBUF(I) = 0
          ENDIF
22      CONTINUE
        CALL PACK(8,IBUF,IBUF)
        IF (STARTI .LT. 0) STARTI=0
        IF (STARTO .LT. 0) STARTO=0
C       Start position in int*4 is quarter of bytes:
        IDIR(15) = STARTO
        STARTI = STARTI/2
        STARTO = STARTO/2

        CALL MAKARA(OTAREA,IDIR)
C       Copy navigation from input area to the output area:
        CALL ARAGET(INAREA(1),NAVOFF,256,NAVARR)
        CALL ARAPUT(OTAREA,IDIR(35),256,NAVARR)
        CALL OPNARA(OTAREA)
       ENDIF

C    Loop over all input images, develop averages for each band:
       SKIPF = 2
       SCALE(BAND) = MAX1B*1./MAX2B
       MAX(BAND) = 0
       MIN(BAND) = 100000
       SMAX(BAND) = 0.
       SMIN(BAND) = 100000.
       CCDAVG(BAND) = 0.0
       DO 86 J = 0, 255
         HIST(BAND,J) = 0
86     CONTINUE
       DO 65 ROW = 0, NRM1, SKIPF
           CALL REDARA(INAREA(BAND), ROW, 0, MAXRC, IMBAND, BUFFER)
           DO 85 COL = 0, NCM1, SKIPF
             CCDAVG(BAND) = CCDAVG(BAND) + BUFFER(COL)
             IF (BUFFER(COL) .GT. MAX(BAND)) MAX(BAND)=BUFFER(COL)
             IF (BUFFER(COL) .LT. MIN(BAND)) MIN(BAND)=BUFFER(COL)
             IF (INPACKING .EQ. 2) THEN
               DSPOT=BUFFER(COL)*SCALE(BAND)+0.5
               HIST(BAND,DSPOT) = HIST(BAND,DSPOT) + 1
             ENDIF
C             IF (INPACKING .EQ. 1) THEN
```

```
C               DSPOT=BUFFER(COL)+0.5
C               HIST(BAND,DSPOT) = HIST(BAND,DSPOT) + 1
C             ENDIF
85          CONTINUE
65        CONTINUE
          CCDAVG(BAND) = CCDAVG(BAND)/(NROWS*NCOLS/SKIPF**2)
          WRITE(CMES,'(1X,A18,I2,A2,F8.1)') 'Average value of ',BAND,
     C                                      '=',CCDAVG(BAND)
          CALL SDEST(CMES,0)
C     Check to see that the DATA BRIT option is working:
          IF (CDATA .EQ. 'BRIT' .AND. CCDAVG(BAND) .GT. MAX1B) THEN
           PACKING = 2
           WRITE(CMES,'(A41)') 'Failed to get BRIT data, using raw data'
           CALL SDEST(CMES,0)
          ENDIF
C     Use histogram to find smin, smax for stretching:
          IF (PACKING .EQ. 2) THEN
              J = 0
              SUM = 0
55            CONTINUE
              SUM = SUM + HIST(BAND,J)
              IF (J .GE. 255) GOTO 56
              IF (SUM .LE. (NROWS*NCOLS)*DCUTOF/SKIPF**2) THEN
                J = J + 1
                GOTO 55
              ENDIF
              IF (SMIN(BAND) .GT. J) SMIN(BAND) = J
56            J = 255
              SUM = 0
57            CONTINUE
              SUM = SUM + HIST(BAND,J)
              IF (J .LE. 0) GOTO 57
              IF (SUM .LE. (NROWS*NCOLS)*DCUTOF/SKIPF**2) THEN
                J = J - 1
                GOTO 57
              ENDIF
            IF (SMAX(BAND) .LT. J) SMAX(BAND) = J
C           Smax and smin are now a 1 byte range:
            IF (SMAX(BAND) .LT. MAX1B) SMAX(BAND) = SMAX(BAND)+1
            IF (SMIN(BAND) .GT. 0) SMIN(BAND) = SMIN(BAND)-1
C           Expand smax and smin to full 2 byte range:
            SMAX(BAND) = SMAX(BAND)/SCALE(BAND)
            SMIN(BAND) = SMIN(BAND)/SCALE(BAND)
            IF (SMAX(BAND) .GT. MAX(BAND)) SMAX(BAND)=MAX(BAND)
            IF (SMIN(BAND) .LT. MIN(BAND)) SMIN(BAND)=MIN(BAND)
C           Scale to output bandwidth:
            SCALE(BAND)=IBWIDTH*1./(SMAX(BAND)-SMIN(BAND))
            WRITE(CMES,'(1X,A18,F9.1)') 'Statistic max = ',SMAX(BAND)
            CALL SDEST(CMES,0)
            WRITE(CMES,'(1X,A18,F9.1)') 'Statistic min = ',SMIN(BAND)
             CALL SDEST(CMES,0)
          ENDIF

          WRITE(CMES,'(1X,A18,I9)') 'Max data read = ',MAX(BAND)
           CALL SDEST(CMES,0)
          WRITE(CMES,'(1X,A18,I9)') 'Min data read = ',MIN(BAND)
           CALL SDEST(CMES,0)
          CALL SDEST(' ',0)

C/*-----------------------------------------------
20        CONTINUE


C/*  Loop over rows and columns, convert input to output:          */
       CALL SDEST(' ',0)
          DO 60 ROW = 0, NRM1, 1
            DO 21 BAND = 1, NBANDS
C             REDARA(AREA,LINE,STARTELEM,#ELEMENTS,BAND,IARRAY)
              CALL REDARA(INAREA(BAND),ROW,0,MAXCOL,IMBAND,BUFFER)
              M = BAND - 1
              DO 75 COL=0, NCM1, 1
               IF (PACKING .EQ. 2) DATT(M+STARO*2)=
     C              (BUFFER(COL)-SMIN(BAND))*SCALE(BAND)
               IF (PACKING .EQ. 1) DATT(M+STARTO*2) = BUFFER(COL)
               M = M + NBANDS
75            CONTINUE
21          CONTINUE

C     Write out to output file:
            CALL PACK2(MAXOUT, DATT, DATT)
C       Header items appended (new lev):
            CALL MOVC(8,IBUF,0,DATT,0)
C       Write file out to output file name
            CALL WRTARA(OTAREA,ROW,DATT)

60        CONTINUE
          DO 62 BAND = 1, NBANDS
             CALL CLSARA(INAREA(BAND))
62        CONTINUE
          CALL CLSARA(OTAREA)
          CALL STAMP(OTAREA)
          CALL SDEST('---Finished Combin---',0)
          RETURN
          END
```

```
      SUBROUTINE MAIN0
C?     LISTHEAD -- LIST THE HEADER OF A MULTI-BAND IMAGE
C?                 LISTHEAD INAREA
C?     PARAMETERS:
C?                INAREA  - AREA TO BE LISTED
C?
C?     OUTPUT LISTING OF HEADER SAVED TO FILE -->  INAREA.HED
C?
C     Written by Gerard Peltzer, UW SSEC 11/14/1991
C     For use on IBM RISC 6000 MCIDAS-AIX
C-------------------------------------------------------------
      INTEGER IDIR(64)
      IMPLICIT REAL*8 (D)
      IMPLICIT CHARACTER*12 (C)
      INTEGER*4 INAREA, NROWS,NCOLS,I
      CHARACTER*8 TABFIL
      CHARACTER*70 CMES

     INAREA=IPP(1,0)
     WRITE(CMES,'(1X,A12,I4)') ' AREA: ', INAREA
      CALL SDEST(CMES,0)
      IF (INAREA .LE. 0 .OR. INAREA .GT. 50000) THEN
        WRITE(CMES,'(1X,A15,1X,I6)') 'INVALID AREA: ', INAREA
        RETURN
      ENDIF
     CALL LWD(TABFIL)
     CNEWOUT = CFI(INAREA)
     TABFIL(1:4) = CNEWOUT(9:12)
     TABFIL(5:8) = '.HED'
      WRITE(CMES,'(A19,1X,A8)') 'HEADER FILE: ', TABFIL
       CALL SDEST(CMES,0)
       CALL FDEST(TABFIL,CMES)
     CALL OPNA(INAREA)
     CALL ARAOPT(INAREA,1,'SPAC',4)
     CALL READD(INAREA,IDIR)
     NROWS = IDIR(9)
     NCOLS = IDIR(10)
     WRITE(CMES,'(2(A10,I5,3X))') '  ROWS: ',NROWS,' COLUMNS: ',NCOLS
      CALL SDEST(CMES,0)
      CALL FDEST(TABFIL,CMES)
     DO 6 I = 1, 64
       WRITE(CMES,'(1X,I2,1X,I15)') I, IDIR(I)
        CALL SDEST(CMES,0)
        CALL FDEST(TABFIL,CMES)
     CONTINUE
     CALL SDEST('-----DONE----',0)
     CALL FDEST(TABFIL,'-----DONE----')
     RETURN
     END
```

```
#include <stdio.h>

#if defined(sun)
     void fdest_(char cfile[8], char ctext[70])
#else
     void fdest(char cfile[8], char ctext[70])
#endif
/*-------------------------------------------------------------*/
/*      FDEST - Sends text output to a disk file.
                Emulates the FDEST function on other McIDAS
                versions.
       Compile with "fx fdest cli" in McIDAS src directory.

       Written by Gerard Peltzer, UW SSEC 11/14/1991.
       For use on IBM RISC 6000 MCIDAS-AIX.                  */
/*-------------------------------------------------------------*/
{
/*  Print a line of text (CTEXT) to file (CFILE):             */
    char fname[9];
    FILE *outfil;

      strncpy(fname,cfile,8);
      fname[8] = '\0';
      while ((outfil = fopen(fname,"a+")) == NULL)
        { printf("\n Error opening FDEST output file %s (%s)",fname,ctext);
          return;
        }
      fprintf(outfil,"%s\n",ctext);
      fclose(outfil);
      return;
}
```

```
      SUBROUTINE MAIN0
C=====================================================================
C ?   ELLIPS  -  Draw signature ellipses from a USCLAS classification
C ?
C ?   ELLIPS INAREA
C ?
C ?   Parameters:
C ?               LCLASS -  lowest class # to display
C ?               HCLASS -  highest class # to display
C ?               MEAN   -  1 to display class means only
C ?               STD    -  2 is default.
C ?      Defaults are 0 to largest class present, ellipses displayed.
C ?
C ?---------------------------------------------------------------------
C
C  Compilation information:
C      This program uses ellip.c and graphics libraries contained
C      in glib.o.  To compile, use:
C            xlc ellip.c $3 -c -qsource -Daix -D_POSIX_SOURCE
C            ar r /u/mcidas/lib/libmcidas.a ellip.o
C            rm ellip.o
C            ar r /u/mcidas/lib/libmcidas.a glib.o
C            fx ellips 1
C
C
C  Written by Gerard Peltzer
C  UW SSEC 3/6/1992
C
C---------------------------------------------------------------------

       PARAMETER (MMEAN=0)
       PARAMETER (MLCLAS=0)
       PARAMETER (MHCLAS=127)
       PARAMETER (MSTD=2.0)

       IMPLICIT CHARACTER*12 (C)
       IMPLICIT REAL*8 (D)

       CHARACTER*70 CMES
       CHARACTER*9 INFIL
       CHARACTER*12 CTEMP
       INTEGER*4 INAREA, LCLASS4, HCLASS4, MEAN4
       INTEGER*4 LCLASS, HCLASS, MEAN
       REAL*4 STD
       COMMON/TFILE/ LOGFIL

      CALL SDEST('BEGIN: ',0)

C Open input text file:
       INAREA=IPP(1,0)
       IF (INAREA .LE. 0 .OR. INAREA .GT. 50000) THEN
         WRITE(CMES,'(1X,A15,1X,I6)') 'INVALID AREA: ', INAREA
         CALL SDEST(CMES,0)
         RETURN
       ENDIF
C Open output text file, use FDEST routine to print data to logfil:
      CTEMP = CFI(INAREA)
      INFIL(1:4) = CTEMP(9:12)
      INFIL(5:9) = '.SIG\0'
      WRITE(CMES,'(A14,1X,A8)') 'INFILE ', INFIL
       CALL SDEST(CMES,0)

C Read in LCLASS:
      LCLASS4=IKWP('LCLASS',1,MLCLAS)
      LCLASS = LCLASS4
C Check classes greater than 0, less than MXCLAS:
      IF (LCLASS .LT. 0 .OR. LCLASS .GT. MHCLAS) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED POOR CHOICE'
         CALL SDEST(CMES,0)
        LCLASS= MLCLASS
        WRITE(CMES,'(A25,I5)') ' LOW CLASS TO BE USED = ',LCLASS
         CALL SDEST(CMES,0)
      ELSE
        WRITE(CMES,'(A25,I5)') ' LOW CLASS TO BE USED = ',LCLASS
         CALL SDEST(CMES,0)
      ENDIF

C Read in HCLASS:
      HCLASS4=IKWP('HCLASS',1,MHCLAS)
      HCLASS = HCLASS4
C Check classes greater than 0, less than MXCLAS:
      IF (HCLASS .LT. 0 .OR. HCLASS .GT. MHCLAS) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED POOR CHOICE'
         CALL SDEST(CMES,0)
        HCLASS = MHCLASS
        WRITE(CMES,'(A25,I5)') ' HIGH CLASS TO BE USED = ',HCLASS
         CALL SDEST(CMES,0)
      ELSE
        WRITE(CMES,'(A25,I5)') ' HIGH CLASS TO BE USED = ',HCLASS
         CALL SDEST(CMES,0)
      ENDIF

C Read in MEAN:
      MEAN4=IKWP('MEAN',1,MMEAN)
      MEAN = MEAN4
      IF (MEAN .NE. 0 .AND. MEAN .NE. 1) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED POOR MEAN CHOICE'
         CALL SDEST(CMES,0)
        MEAN = MMEAN
        WRITE(CMES,'(A25)') ' ELLIPSES WILL BE PLOTTED'
         CALL SDEST(CMES,0)
      ENDIF

C Read in STD:
      DSTD=DKWP('STD',1,MSTD)
      IF (DSTD .LE. 0.01 .OR. DSTD .GT. 10) THEN
        DSTD = MSTD
      ENDIF
        WRITE(CMES,'(A25,F5.2)') ' USING STD OF ', DSTD
         CALL SDEST(CMES,0)


C Call ellipse program:
      CALL ELLIP(INFIL,LCLASS,HCLASS,MEAN,DSTD)

      CALL SDEST('-----DONE----',0)
      RETURN
      END
```

```
/*=====================================================================*/
/*                    ellip.c

  Routine to draw scatterplot ellipses of class signatures generated
  by spectral classification programs.

  Ellipses are generated from mean and covariance matrices read in
  from a .SIG file.  The four 'corner' points of the ellipse at the
  ends of the minor and major axes are plotted, with lines connecting
  them.

  Multiple X-Windows graphs are produced which may be sent to printer
  via these commands (in the prntscrn program):
      xwd -xy -bitmap -out scrndump
      xpr -device ps -output scrndump.xpr scrndump
      lpr -Premq scrndump.xpr
      rm scrndump
      rm scrndump.xpr

  A list of the important variables used:
      lclass                    Lowest class number to graph
      hclass                    Highest class number to graph
      mean                      Option to plot only class means (1)
      infile                    Names for the image input file.


      Written by Gerard Peltzer
      4/27/1992                                                      */
/*---------------------------------------------------------------------*/

#include <math.h>
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <malloc.h>
#define INPUTWIDTH 80       /* Number of chars in inputs.      */
#define MXCLAS    127
#define MAXSBD     16
#define MXBNDS      7
#define SUCCESS    -1
#define FAILURE     0
#define YES         1
#define NO          0
#define SBD         8
#define SIG         9
#define HISTBYTES 512*MXBNDS


typedef struct Sig{
             char signame[32];
             long scount;
             char blank[92];
             int minvector[MAXSBD];
             int maxvector[MAXSBD];
             float meanvector[MAXSBD];
             float covar[32];
             /*char histo[HISTBYTES];*/
                          } Signature;

typedef struct Sighead{
             char lanname[100];
             int classes;
             int bands;
             char blank[24];
                          } Sbdheader;


void ellip(char infile[9], int *lclass, int *hclass, int *mean, double *std)
{
/* Declarations of the functions used in this program:                */
      Signature *class;
      Sbdheader head;
      int readsig(char *infile,Sbdheader *head, Signature *class);
      int ellipsepts(char *infile,Sbdheader *head,Signature *class,
          int *lowclass, int *highclass, int *mean, double *std);
/* Variable declarations:   */
      int type;

/* Allocate memory for class:  */
      if ((class = (Signature *) malloc(MXCLAS*sizeof(Signature)))
          == NULL)
        { printf("\nNot enough memory to allocate classes!\n");
          return; }


/* Read in data from infile:   */
      if ( readsig(infile, &head, class)  == FAILURE    )
          { printf("Quitting due to sig read errors... \n");
            return; }

      if (ellipsepts(infile,&head,class,lclass,hclass,mean,std)
          == FAILURE)
        { printf("Quitting due to point errors... \n");
          return; }


      printf("\n...Ending... \n");
      free(class);
      return;
}


/*=====================================================================*/
/*              Function Readsig                                       */
/*       This routine reads data from McIDAS .SIG file.                */
/*                                                                     */
/*       The arrays are all indexed from 0 to n-1.                     */
/*                                                                     */
/* Read in Data:                                                       */
/*   1) name of sig file                                               */
/*   2) number of classes                                              */
/*   3) number of bands                                                */
/*   4) blank (says "--Max data values--")                             */
/*   5) max-B1 max-B2 ... max-BN                                       */
/*   6) blank (says "---BAND MEANS---")                                */
/*   7) blank (says "Class  Counts  " then bands)                      */
/*   8) class# counts mean-B1 mean-B2 ... mean-BN                      */
/*        C+1 of these...                                              */
/*   8+C+1) blank (says "Class covariance matrices")                   */
/*   8+C+2) class#                                                     */
/*   8+C+3) COVAR(0,0) COVAR(0,1) ... COVAR(0,N-1)                     */
/*          N of these...                                              */
/*    C of these...                                                    */
/*---------------------------------------------------------------------*/
      int readsig(char *infile,Sbdheader *head, Signature class[])
#define COV 32*MXCLAS
{
      int i,j,k;
      int clas, band, clases, nbands, eof;
```

```
      int max[MAXSBD], min[MAXSBD], smean[MAXSBD][MXCLAS];
      long count[MXCLAS];
      float fcount, fmean, cova[32];
/*      float covarm[COV];*/
      float *covarm;
      FILE *fpin;
      char *trlptr, nameline[32];
      char dataline[80];
      char firstline[100];
      char moreline[80];

/* Allocate memory for covarm:  */
/*      if ((covarm = (float *) malloc(COV*sizeof(float)))
        == NULL)
       { printf("\nNot enough memory to allocate covariance!\n");
         return(1);
       }*/

      if((fpin=fopen(infile,"rt")) == NULL)
      {  printf("\nError opening infile %s\n",infile);
      return FAILURE;
      }
      fseek(fpin,0L,SEEK_SET);

      i = 0;
      eof = NO;
/* File search:  */
      while (eof == NO)
        {
   /* Header information:    */
          /*  First line  */
        for (i=0; i< 100 ; i++)  firstline[i] = 0;
        for (i=0; i< 100 ; i++)  (*head).lanname[i] = 0;
        if (fgets(firstline,100,fpin) == NULL) eof = YES;     /* 1  */
        /*printf("\nHeader of data file says: ");
        puts(firstline);
        printf("\n"); */
        if ((trlptr=strstr(firstline,".")) != NULL)
        { strcpy(trlptr,"~   "); }
        strcpy((*head).lanname, firstline);

           /*  Classes  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 2  */
        j = sscanf(dataline, "%d ",&clases);
        if  (j < 1 || j == EOF) eof = YES;
        (*head).classes = clases;

           /*  Bands  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 3  */
        j = sscanf(dataline, "%d ",&nbands);
        if  (j < 1 || j == EOF) eof = YES;
        (*head).bands = nbands;

        for (i=0; i< 24 ; i++)  (*head).blank[i] = 0;


   /* Develop structures for each signature:   */

           /*  Get Maximum Values  */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 4  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 5  */
        for (i=0; i< MXBNDS ; i++)  max[i] = 0;
        j = sscanf(dataline, "%d %d %d %d %d %d %d",&max[0], &max[1],
          &max[2], &max[3], &max[4], &max[5], &max[6]);
        if  (j < 1 || j == EOF) eof = YES;

           /* 2blank lines */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 6  */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 7  */


           /*  Get Mean Values  */
        for (clas=0; clas< clases ; clas++)
          {
          for (band=0; band< MXBNDS; band++) smean[band][clas] = 0;
          for (i=0; i< 80 ; i++)  dataline[i] = 0;
          if (fgets(dataline,80,fpin) == NULL) eof = YES;     /* 8>8+C */
          j = sscanf(dataline, "%d %f %d %d %d %d %d %d %d", &i,
              &fcount,&smean[0][clas],&smean[1][clas],
              &smean[2][clas],&smean[3][clas],&smean[4][clas],
              &smean[5][clas],&smean[6][clas]);
          count[clas] = (long)fcount;
          if  (j < 1 || j == EOF) eof = YES;
          }

           /* 1 blank line */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 8+C+1 */


           /*  Get Covariances  */
        for (clas=0; clas< clases ; clas++)
          {
            /* 1 blank line */
          if (fgets(dataline,80,fpin) == NULL) eof = YES;     /* 8+C+2 */
          k = 0;
          for (band=0; band< nbands ; band++)
            {
            for (i=0; i< 80 ; i++)  moreline[i] = 0;
            strcpy(moreline,"\0");
            if (fgets(moreline,80,fpin) == NULL) eof = YES;  /* 8+C+3 */
            j = sscanf(moreline, "%f %f %f %f %f %f %f",&cova[0],
            &cova[1],&cova[2],&cova[3],&cova[4],&cova[5],&cova[6]);
            if  (j < 1 || j == EOF) eof = YES;
            if (k > 32)
              { printf("\nError in covar computation!");
                return FAILURE;
              }
            for (i=band; i< nbands ; i++)
              { /* covarm[k+clas*32] = cova[i];*/
                class[clas].covar[k] = cova[i];
                k++;
              }
            }
          }

        eof = YES;
        }

      for (clas=0; clas< clases ; clas++)
        {
           /*  Name  */
          for (i=0; i< 32 ; i++)  nameline[i] = 0;
          for (i=0; i< 32 ; i++)  class[clas].signame[i] = 0;
          sprintf(nameline,"CLASS %d~",clas);
```

```
        strcpy(class[clas].signame,nameline);

          /*  Blank  */
        for (i=0; i< 92 ; i++) class[clas].blank[i] = 0;

          /*  Minimum Values  */
        for (i=0; i< 16 ; i++) class[clas].minvector[i] = 0;

          /*  Maximum Values  */
        for (i=0; i< nbands; i++) class[clas].maxvector[i] = max[i];
        for (i=nbands; i< 16 ; i++) class[clas].maxvector[i] = 0;

          /*  Mean Values  */
        for (i=0; i<nbands; i++)
         { fmean = 1.0*smean[i][clas];
           class[clas].meanvector[i]=fmean;
         }
        for (i=nbands; i< 16 ; i++) class[clas].meanvector[i] = 0;

          /*  Counts  */
        class[clas].scount = count[clas];

          /*  Covariances  */
        for (i=0; i< 32 ; i++)
          { /*class[clas].covar[i] = covarm[i+clas*32];*/
            /*class[clas].covar[i] = 1.;*/
          }

          /* histo */
          for (i=0; i<HISTBYTES; i++) class[clas].histo[i] = 0; */

      }


    fclose(fpin);

    return SUCCESS;




==========================================================*/
              Function Ellipsepts                         */
----------------------------------------------------------*/
fine MXPAIR 21
    typedef struct ellipses{int band1;
                            int band2;
                            float x0[MXCLAS];
                            float y0[MXCLAS];
                            float x1[MXCLAS];
                            float y1[MXCLAS];
                            float x2[MXCLAS];
                            float y2[MXCLAS];
                            float x3[MXCLAS];
                            float y3[MXCLAS];
                            float x4[MXCLAS];
                            float y4[MXCLAS];
                               } Epoints;

t ellipsepts(char *infile,Sbdheader *head, Signature *class,
        int *lclass, int *hclass, int *mean, double *std)


    Epoints *classpt;
    int i,j,k, clas, band, clases, nbands, npairs;

    int zero, q1, q2, p1, p2, set ;
    float f0, fq1, fq2, fq3, fq4;
    int maxx[MXPAIR], minx[MXPAIR];
    FILE *fpout, *namout;
    char  string[4];
    char *trlptr;
    float covar[MXBNDS][MXBNDS],sigmap1, sigmap2, theta;
    float diff1, diff2, diff3, diff4;

    printf("\n Starting graph routine\n");

    nbands = (*head).bands;
    clases = (*head).classes;
    if (nbands <= 0 || nbands > MXBNDS || clases > MXCLAS)
      { printf("Error working signatures\n");
        return FAILURE;
      }

    npairs = 0;
    for (j=1; j<nbands; j++) { npairs = npairs + j; }

    if ((classpt = (Epoints *) malloc(MXPAIR*sizeof(Epoints)))
        == NULL)
      { printf("\nNot enough memory to allocate points!\n");
        return(1); }

    printf("\n %d bands, %d classes\n",nbands,clases);
    if (*hclass >= clases) *hclass = clases-1;
    printf("From class %d to class %d\n",*lclass, *hclass);
    if (*mean == YES) printf("Plotting means only\n");

      for (set=0; set < npairs; set++)
        {  maxx[set] = 1;
           minx[set] = 255; }

    for (clas=*lclass; clas<=*hclass; clas++)
      { k = 0;

        /* Unfold covariance */
        for (band=0; band< nbands ; band++)
          {
          if (k > 32)
            { printf("\nError in covar computation!");
              return FAILURE; }
          for (i=band; i< nbands ; i++)
            { covar[band][i] = class[clas].covar[k];
              covar[i][band] = covar[band][i];
              k++; }
          }

      set = 0;
      for (p1=0; p1<nbands; p1++)
        {
        sigmap1 = sqrt((double)covar[p1][p1]);
        for (p2=p1+1; p2<nbands; p2++)
          {
          classpt[set].x0[clas] = class[clas].meanvector[p1];
          classpt[set].y0[clas] = class[clas].meanvector[p2];
          classpt[set].band1 = p1;
          classpt[set].band2 = p2;

          sigmap2 = sqrt((double)covar[p2][p2]);
          theta = atan((double)(sigmap2/sigmap1));
          diff1 = (*std)*sigmap1*cos((double)theta);
          diff2 = (*std)*sigmap2*sin((double)theta);
```

```
        diff3 = (*std)*sigmap1*sin((double)theta);
        diff4 = (*std)*sigmap2*cos((double)theta);
        classpt[set].x1[clas] = class[clas].meanvector[p1] + diff1;
        classpt[set].y1[clas] = class[clas].meanvector[p2] + diff2;
        classpt[set].x2[clas] = class[clas].meanvector[p1] - diff3;
        classpt[set].y2[clas] = class[clas].meanvector[p2] + diff4;
        classpt[set].x3[clas] = class[clas].meanvector[p1] - diff1;
        classpt[set].y3[clas] = class[clas].meanvector[p2] - diff2;
        classpt[set].x4[clas] = class[clas].meanvector[p1] + diff3;
        classpt[set].y4[clas] = class[clas].meanvector[p2] - diff4;
        if (classpt[set].x1[clas] > maxx[set])
                                maxx[set] = classpt[set].x1[clas];
        if (classpt[set].x2[clas] > maxx[set])
                                maxx[set] = classpt[set].x2[clas];
        if (classpt[set].x3[clas] > maxx[set])
                                maxx[set] = classpt[set].x3[clas];
        if (classpt[set].x4[clas] > maxx[set])
                                maxx[set] = classpt[set].x4[clas];
        if (classpt[set].y1[clas] > maxx[set])
                                maxx[set] = classpt[set].y1[clas];
        if (classpt[set].y2[clas] > maxx[set])
                                maxx[set] = classpt[set].y2[clas];
        if (classpt[set].y3[clas] > maxx[set])
                                maxx[set] = classpt[set].y3[clas];
        if (classpt[set].y4[clas] > maxx[set])
                                maxx[set] = classpt[set].y4[clas];
        if (classpt[set].x1[clas] < minx[set])
                                minx[set] = classpt[set].x1[clas];
        if (classpt[set].x2[clas] < minx[set])
                                minx[set] = classpt[set].x2[clas];
        if (classpt[set].x3[clas] < minx[set])
                                minx[set] = classpt[set].x3[clas];
        if (classpt[set].x4[clas] < minx[set])
                                minx[set] = classpt[set].x4[clas];
        if (classpt[set].y1[clas] < minx[set])
                                minx[set] = classpt[set].y1[clas];
        if (classpt[set].y2[clas] < minx[set])
                                minx[set] = classpt[set].y2[clas];
        if (classpt[set].y3[clas] < minx[set])
                                minx[set] = classpt[set].y3[clas];
        if (classpt[set].y4[clas] < minx[set])
                                minx[set] = classpt[set].y4[clas];
        set++;
        }
      }
    }

  zero = 0;
  set = 0;
  q1 = 640;
  q2 = 480;
  ginit(&zero,&zero,&q1,&q2);

  gname(infile);

 while (set < npairs)
 {
  p1 = classpt[set].band1;
  p2 = classpt[set].band2;
  q1 = 60;
  q2 = 420;
  gplotarea(&q1,&q2,&q2,&q1);
  clas = 1;
  maxx[set] = (maxx[set]/10)*10;
  if (maxx[set] < 250) maxx[set]= maxx[set] + 10;
  if (maxx[set] > 255) maxx[set]= 255;
  if (minx[set] > 5) minx[set]= minx[set] - 5;
  if (minx[set] < 0) minx[set]= 0;
  minx[set] = (minx[set]/10)*10;
  f0 = minx[set];
  fq1 = maxx[set];
  fq2 = maxx[set];
  fq3 = 50.;
  fq4 = 10.;
  q1 = classpt[set].band1 + 1;
  sprintf(string,"%d",q1);
  q1 = 1;
  gxaxis(&f0, &fq1, &fq3, &fq4, &q1, string, "%2.0f");
  q1 = classpt[set].band2 + 1;
  sprintf(string,"%d",q1);
  q1 = 1;
  gyaxis(&f0, &fq2, &fq3, &fq4, &q1, string, "%4.0f");
  for (clas=*lclass; clas<=*hclass; clas++)
    {
     if (*mean != YES)
     {
     gplot(&classpt[set].x1[clas],&classpt[set].y1[clas],
           &classpt[set].x2[clas],&classpt[set].y2[clas],&q1,&clas);
     gplot(&classpt[set].x2[clas],&classpt[set].y2[clas],
           &classpt[set].x3[clas],&classpt[set].y3[clas],&q1,&clas);
     gplot(&classpt[set].x3[clas],&classpt[set].y3[clas],
           &classpt[set].x4[clas],&classpt[set].y4[clas],&q1,&clas);
     gplot(&classpt[set].x4[clas],&classpt[set].y4[clas],
           &classpt[set].x1[clas],&classpt[set].y1[clas],&q1,&clas);
     }
     else
     {
     gplot(&classpt[set].x0[clas],&classpt[set].y0[clas],
           &classpt[set].x0[clas],&classpt[set].y0[clas],&q1,&clas);
     }
    }
  gshow();
  gclear();
  set++;
 }
  gquit();

return SUCCESS;
}
```

```
c ellip.c $3 -c -qsource -Daix -D_POSIX_SOURCE
r /ul/mcidas/lib/libmcidas.a ellip.o
ellip.o
r /ul/mcidas/lib/libmcidas.a glib.o
ellips 1
```

```
   SUBROUTINE MAIN0
=================================================================
?    USCLAS -- SPECTRALLY CLASSIFY A MULTI-BAND IMAGE
?       --- UNSUPERVISED MULTISPECTRAL IMAGE CLASSIFICATION ---
?
?                 USCLAS INAREA OUTAREA
?    PARAMETERS:
?               INAREA  - AREA TO BE CLASSIFIED
?               OUTAREA - FINAL CLASSIFIED AREA WITH ~M CLASSES.
?
?    KEYWORDS:
?              BANDS:  NUMBER OF AREA BANDS TO CLASSIFY,
?                      DEFAULT IS ALL BANDS IN AREA.
?                      USER DEFINES THE BANDS TO USE:
?                           BANDS= BAND1 BAND2 ... BANDN
?             CLASES:  INITIAL # OF CLASSES PRESENTED.
?                           CLASES= M                DEFAULT IS 100
?               SKIP:  SKIP FACTOR FOR ITERATIVE
?                      CLASSIFICATION.  NUMBER OF ROWS
?                      AND COLUMNS SKIPPED. MUST BE < 8.
?                           SKIP= N                   DEFAULT IS 4
?               ITER:  MAXIMUM ALLOWED ITERATIONS
?                           ITER= P                  DEFAULT IS 35
?              MERGE:  CLUSTER MERGING FACTOR, 0 TO 2000,
?                      IF A DIVERGENCE < MERGE THEN MERGE.
?                      0 = NO MERGING
?                           MERGE= Q                 DEFAULT IS 1400
?              SPLIT:  SPLITTING FACTOR, 1 TO 10,
?                      IF BIG/SMALL DIMS. > SPLIT == SPLITTING
?                      0 = NO SPLITTING
?                           SPLIT= R                 DEFAULT IS 3.0
?               NULL:  DATA DROP-OUT DECISION.
?                      ANY: CLASSIFY AS ZERO IF ANY BAND HAS 0.
?                      ALL: CLASSIFY AS ZERO IF ALL BANDS = 0.
?                                                   DEFAULT IS ALL
?             MINPIX:  SMALLEST PIXEL COUNT ALLOWABLE IN A CLASS
?                                      DEFAULT = 0.01% OF DATA
?            STRETCH:  OUTPUT COLOR STRETCH TYPE.
?                      LINE: LINEAR STRETCH FOR CLASS COLORS
?                      HIST: HISTOGRAM EQUALIZATION STRETCH
?                                      DEFAULT = HIST
?
-----------------------------------------------------------------

 Written by Gerard Peltzer
 UW SSEC 5/29/1992


MXBNDS sets max number of bands allowed in input image:
MAXRC sets maximum number of rows and cols in image:
MXCLAS sets maximum number of output data classes:
MXSKIP sets maximum skip factor:
MXLUMP sets maximum lumping (merging) factor:
MXSPLT sets maximum splitting factor:
MDLUMP and MDSPLT set default lumping and splitting (none).
MDITER is default maximum number of iterations allowed.
ZMINP and ZMAXP are default and max % minimum pixel counts.
      PARAMETER (MXBNDS=7)
      PARAMETER (MAXRC=3584)
      PARAMETER (MAXROW=1024)
      PARAMETER (MAXCOL=3584)
      PARAMETER (MXCLAS=300)
      PARAMETER (MDCLAS=100)
      PARAMETER (MXSKIP=8)
      PARAMETER (MDSKIP=4)
      PARAMETER (ZXMERG=2000.)
      PARAMETER (ZDMERG=1400.)
      PARAMETER (ZXSPLT=10.)
      PARAMETER (ZMSPLT=1.)
      PARAMETER (ZDSPLT=3.0)
      PARAMETER (MDITER=35)
      PARAMETER (MXITER=60)
      PARAMETER (ZMINP=0.01)
      PARAMETER (ZMAXP=10.)
C-----------------------------------------------------------------

      IMPLICIT CHARACTER*12 (C)
      IMPLICIT REAL*8 (D)

      CHARACTER*70 CMES, CBLNK
      CHARACTER*8 LOGFIL
      INTEGER*4 INAREA,OTAREA,TEST, MINPIX
      INTEGER CLASES,NBANDS,BNDLOC(0:MXBNDS)
      REAL*8 LUMPF, SPLITF
      INTEGER IDIR(64),ABANDS
      INTEGER NROWS, NCOLS, SKIPF, ITERA, NULL, STRET
      COMMON/TFILE/ LOGFIL

     CALL SDEST('BEGIN: ',0)

     INAREA=IPP(1,0)
     OTAREA=IPP(2,0)
      IF (INAREA .LE. 0 .OR. INAREA .GT. 50000) THEN
        WRITE(CMES,'(1X,A15,1X,I6)') 'INVALID AREA: ', INAREA
        CALL SDEST(CMES,0)
        RETURN
      ENDIF
C Open output text file, use FDEST routine to print data to logfil:
     CTEMP = CFI(OTAREA)
     LOGFIL(1:4) = CTEMP(9:12)
     LOGFIL(5:8) = '.log'
     CALL LWD(LOGFIL)
     WRITE(CMES,'(70A1)') (' ', I = 1, 70)
      CALL FDEST(LOGFIL,CMES)
      CALL SDEST(CMES,0)
     WRITE(CMES,'(A14,1X,A12)') 'SUMMARY FILE ', LOGFIL
      CALL FDEST(LOGFIL,CMES)
      CALL SDEST(CMES,0)
     WRITE(CMES,'(1X,A34)') 'USCLAS UNSUPERVISED CLASSIFICATION '
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     WRITE(CMES,'(2X,A12,I4)') 'INPUT AREA: ', INAREA
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     WRITE(CBLNK,'(A1)') ' '
      CALL SDEST(CBLNK,0)
      CALL FDEST(LOGFIL,CBLNK)
     WRITE(CMES,'(1X,A19)') 'IMAGE CONTENTS '
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)

C Open area to see how big, number of bands:
     CALL HOWBIG(INAREA,NROWS,NCOLS)
     WRITE(CMES,'(2X,A12,I5)') '  ROWS:    ', NROWS
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     WRITE(CMES,'(2X,A12,I5)') '  COLUMNS: ', NCOLS
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     IF ((NROWS .GT. MAXROW) .OR. (NCOLS .GT. MAXCOL)) THEN
```

```
      CALL SDEST('AREA TOO BIG TO PROCESS - EXITING!',0)
      CALL FDEST(LOGFIL,CMES)
      RETURN
    ENDIF
    CALL OPNA(INAREA)
    CALL ARAOPT(INAREA,1,'SPAC',4)
    CALL READD(INAREA,IDIR)

    ABANDS= IDIR(14)
    WRITE(CMES,'(1X,A19,I5)') '    BANDS IN AREA: ', ABANDS
     CALL SDEST(CMES,0)
     CALL FDEST(LOGFIL,CMES)
    IF (ABANDS .LT. 1) THEN
      CALL SDEST('NOT ENOUGH BANDS TO PROCESS - EXITING!',0)
      CALL FDEST(LOGFIL,CMES)
      RETURN
    ENDIF
    CALL CLSARA(INAREA)

Read in bands to use in classification:
    NBANDS=NKWP('BANDS')
    IF (NBANDS .EQ. 0) THEN
      NBANDS = ABANDS
      DO 20 I=1, NBANDS
        BNDLOC(I-1) = I
      CONTINUE
    ENDIF
    DO 10 I = 1, NBANDS
      BNDLOC(I-1) = IKWP('BANDS',I,I)
    CONTINUE
    WRITE(CMES,'(1X,A20,I5)') 'BANDS TO CLASSIFY: ', NBANDS
     CALL SDEST(CMES,0)
     CALL FDEST(LOGFIL,CMES)
    IF (NBANDS .GT. ABANDS) THEN
      WRITE(CMES,'(1X,A40)')
   C    'USER SPECIFIED MORE BANDS THAN EXIST IN AREA'
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      RETURN
    ENDIF

Read in classes:
    CLASES=IKWP('CLASES',1,MDCLAS)
Check number of classes less than maximum:
    IF (CLASES .GT. MXCLAS) THEN
      WRITE(CMES,'(A40)') ' USER SPECIFIED TOO MANY CLASSES'
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A25,I5)') ' MAX CLASSES TO BE USED = ',CLASES
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
    ENDIF

Read in skip factor:
    SKIPF=IKWP('SKIP',1,MDSKIP)
Check skipf less than maximum:
    IF (SKIPF .GT. MXSKIP) THEN
      WRITE(CMES,'(A40)') ' USER SPECIFIED TOO LARGE A SKIP'
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      SKIPF = MXSKIP
      WRITE(CMES,'(A23,I5)') ' MAX SKIP TO BE USED = ',SKIPF
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
    ENDIF
      WRITE(CMES,'(A25,I5)') ' MAX SKIP TO BE USED = ',SKIPF
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)

C Read in merging (lump) factor:
      DMERG = ZDMERG
      LUMPF=DKWP('MERGE',1,DMERG)
C Check lump less than maximum:
      IF (LUMPF .GT. ZXMERG) THEN
        WRITE(CMES,'(A40)') ' USER GAVE TOO LARGE A MERGING FACTOR'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        LUMPF = ZXLUMP
        WRITE(CMES,'(A25,F9.1)') ' MAX T.DIV TO BE USED = ', LUMPF
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
      ENDIF

C Read in split factor:
      DSPLT = ZDSPLT
      SPLITF=DKWP('SPLIT',1,DSPLT)
C Check split less than maximum:
      IF (SPLITF .GT. ZXSPLT) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED TOO LARGE SPLIT FACTOR'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        SPLITF = ZXSPLT
        WRITE(CMES,'(A25,F6.3)') ' SPLIT TO BE USED = ', SPLITF
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
      ENDIF
      IF (SPLITF .LT. ZMSPLT .AND. SPLITF .NE. 0) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED BAD SPLIT FACTOR'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        SPLITF = ZMSPLT
        WRITE(CMES,'(A25,F6.3)') ' SPLIT TO BE USED = ', SPLITF
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
      ENDIF

C Read in maximum number of iterations:
      ITERA=IKWP('ITER',1,MDITER)
C Check iter less than maximum:
      IF (ITERA .GT. MXITER) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED TOO MANY ITERATIONS'
         CALL SDEST(CMES,0)
      ENDIF

C Read in maximum number of iterations:
      ITERA=IKWP('ITER',1,MDITER)
C Check iter less than maximum:
      IF (ITERA .GT. MXITER) THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED TOO MANY ITERATIONS'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        ITERA = MXITER
        WRITE(CMES,'(A25,I3)') ' MAX ITERATIONS TO BE USED = ',ITERA
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
      ENDIF

C Read in type of dropout handling desired in null:
      CNULL=CKWP('NULL',1,'ALL')
C Check NULL:
```

```
      IF (CNULL .NE. 'ALL' .AND. CNULL .NE. 'ANY') THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED INVALID NULL PARAMETER'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        CNULL = 'ALL'
        NULL = 0
      ENDIF
      IF (CNULL .EQ. 'ALL') NULL = 0
      IF (CNULL .EQ. 'ANY') NULL = 1
      WRITE(CMES,'(A31,A12)') ' DATA DROPOUT HANDLING USED = ',CNULL
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)

Read in minimum size of clusters:
      IPIX = ZMINP*NROWS*NCOLS/100
      MINPIX=IKWP('MINPIX',1,IPIX)
Check iter less than maximum:
      IF (MINPIX .GT. ZMAXP*NROWS*NCOLS/100) THEN
        WRITE(CMES,'(A40)') ' MINIMUM PIXEL COUNT TOO LARGE A VALUE'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        MINPIX = ZMAXP*NROWS*NCOLS/100
      ENDIF
        WRITE(CMES,'(A32,I7)') ' MINIMUM PIXELS IN A CLUSTER = ',MINPIX
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)

Read in type of output stretch desired:
      CSTRET=CKWP('STRETCH',1,'HIST')
Check STRET:
      IF (CSTRET .NE. 'LINE' .AND. CSTRET .NE. 'HIST') THEN
        WRITE(CMES,'(A41)') ' USER SPECIFIED INVALID STRETCH PARAMETER'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        CSTRET = 'HIST'
      ENDIF
      IF (CSTRET .EQ. 'HIST') STRET = 0
      IF (CSTRET .EQ. 'LINE') STRET = 1
      WRITE(CMES,'(A24,A12)') ' OUTPUT STRETCH USED = ', CSTRET
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)

      WRITE(CBLNK,'(A1)') ' '
       CALL SDEST(CBLNK,0)
       CALL FDEST(LOGFIL,CBLNK)
      WRITE(CMES,'(2X,A13,I4)') 'OUTPUT AREA: ', OTAREA
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      WRITE(CBLNK,'(A1)') ' '
       CALL SDEST(CBLNK,0)
       CALL FDEST(LOGFIL,CBLNK)
      WRITE(CMES,'(A20)') 'ENTERING USCLAS.....'
       CALL SDEST(CMES,0)

Classify the area:
      CALL USCLAS(INAREA,OTAREA,NBANDS,NROWS,NCOLS,BNDLOC,CLASES,SKIPF,
     C            LUMPF,SPLITF,ITERA,NULL,MINPIX,STRET)

      CALL SDEST('-----DONE----',0)
      CALL FDEST(LOGFIL,'-----DONE----')
      RETURN
      END
```

```
C ---------------------------------------------------------------
C       USCLAS (UNSUPERVISED MDM CLASSIFIER)
C
C  Recursive Subroutine to classify a multiband image using clustering.
C
C  This routine reads in the bands of an image, does a classification,
C       and writes the image to disk.
C
C  The algorithm used is loosely based on the ISODATA unsupervised
C       classifyer (see Duda and Hart, "Pattern Recognition and Scene
C       Analysis", 1973, New York, Wiley).
C
C  The routine repeatedly classifies a scene, allowing the initial
C       cluster means to drift to a final value.  For efficiency,
C       passes are made using a skip factor (i.e. only one in every
C       n pixels are analyzed).  When convergence is reached, the
C       entire scene is classified.
C
C  A list of the important variables used:
C       buf(N)              The buffer of band N: a row of input data.
C       outdata             The output data: a row of classifications.
C       smean(band,set)     The class mean for a set in each band.
C       clases              The number of current classes.
C       dsclas              The desired number of classes.
C       skipf               The iterating row/column skip factor.
C       lumpf               The parameter for combining classes together.
C       splitf              The parameter for splitting classes apart.
C       mxiter              The maximum number of iterations allowed.
C       null                Specification for how to handle 0 pixels.
C       minpix              The minimum # of pixels allowed in a class.
C       stret               The output stretch desired, 1=linear, 0=hist.
C
C  Routines usclas calls:
C       Function MDM(sets,row,col,buf,smean)
C                           Routine to perform Min. Dist. to Mean
C                           classification. Returns classification
C                           type as an int for pixel in column col.
C
C       Subroutine ICLUST(nrows,ncols,nbands,max,smean,clases)
C                           Routine to set initial class means.
C
C       Subroutine ENHNCE(IAR,NBANDS,MAX,SMEAN,MXCLAS)
C                           Routine to save enhancement tables with
C                           means of sets.  Saves class means from
C                           bands 1, 2, and 3 as colors for class.
C
C       Subroutine CXCOUT(TDIV,CLASES,MXCLAS,SCREEN)
C                           Routine to print out a square matrix.
C
C       Subroutine EMPTY(CLASES,NBANDS,ITER,CSKIP,SMEAN,SCOUNT,
C                        STDIJ,STMAXJ,DBARJ,COVAR,CORRE)
C                           Routine to remove classes with few pixels.
C
C       Subroutine DIVERG(COVAR,SMEAN,SCOUNT,NBANDS,CLASES,DIV,TDIV)
C                           Calculate Transformed Divergence of classes.
C
C       Subroutine SPLITI   Splits classes (see definition).
C
C       Subroutine LUMPTD   Merges classes with T. Div. (see definition).
C
C       Subroutine SIGOUT(OTAREA,NBANDS,MAX,SMEAN,SCOUNT,DBARJ,STDIJ,
C                         STMAXJ,CLASES,BNDLOC,COVAR)
C                           Routine to write out class signatures.
C
```

```
C-----------------------------------------------------------------
      SUBROUTINE USCLAS(INAREA,OTAREA,NBANDS,NROWS,NCOLS,BNDLOC,CLASES,
     C                  SKIPF,LUMPF,SPLITF,MXITER,NULL,MINPIX,STRET)

MXBNDS sets max number of bands allowed in input image.
MAXRC sets maximum number of rows and cols in image.
MXCLAS sets maximum number of output data classes.
THRESH sets default percent change of pixels allowed.
MXITER set maximum number of allowed iterations.
MCUTOF is the percent of data for practical lower/upper bounds.
      IMPLICIT CHARACTER*12 (C)
      IMPLICIT REAL*8 (D)
      PARAMETER (MXBNDS=7)
      PARAMETER (MAXRC=3584)
      PARAMETER (MAXROW=1024)
      PARAMETER (MAXCOL=3584)
      PARAMETER (MXCLAS=300)
      PARAMETER (THRESH=4)
      PARAMETER (DCUTOF=0.006)
      CHARACTER*70 CMES
      CHARACTER*8 TRLFIL
      INTEGER*4  INAREA, OTAREA, MDM, DATAW, NAV2, OUTDAT(0:MAXRC)
      INTEGER*2  BUF(0:MAXRC,0:MXBNDS), NEWIN(0:MAXRC)
      INTEGER*2  OLDOUT(0:MAXCOL,0:MAXROW)
      INTEGER    I,J,K,L, IDIR(64), ROW, COL, BAND, CLASES, DSCLAS
      INTEGER    NBANDS, NROWS, NCOLS, BNDLOC(0:MXBNDS), NULL, STRET
      INTEGER    SMEAN(0:MXBNDS,0:MXCLAS), SMIN(0:MXBNDS)
      INTEGER    MXITER, SKIPF, CSKIP, CHECK, NRM1, NCM1, NBM1
      INTEGER    VAL, LEV, STARTI, STARTO, ITER, STOP, CLASSP
      INTEGER    MEAN(0:MXBNDS), MAX(0:MXBNDS), SMAX(0:MXBNDS)
      REAL*8     NWMEAN(0:MXBNDS), NSMEAN(0:MXBNDS,0:MXCLAS)
      REAL*8     SUM, TOTAL, SCOUNT(0:MXCLAS), PERCH
      REAL*8     HIST(0:MXBNDS,0:255), LUMPF, SPLITF
      COMMON/TFILE/ LOGFIL
Lumping/splitting variables:
      INTEGER*4   OLDCLS, PREI, PREJ, II, JJ
      INTEGER*4   MINI(0:MXCLAS), MINJ(0:MXCLAS), MAXLMP
      REAL*8      STDIJ(0:MXBNDS,0:MXCLAS), STDMAX, STMAXJ(0:MXCLAS)
      REAL*8      STDAVG, STDMIN, STMINJ(0:MXCLAS)
      REAL*8      DBARJ(0:MXCLAS), DNETJ(0:MXBNDS,0:MXCLAS), DBAR
      REAL*8      SDIST(0:MXCLAS,0:MXCLAS), MINSD, MAXSD
      REAL*8      COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
      REAL*8      CORRE(0:MXCLAS,0:MXBNDS,0:MXBNDS)
      REAL*8      DIV(0:MXCLAS,0:MXCLAS)
      REAL*8      TDIV(0:MXCLAS,0:MXCLAS)
C-----------------------------------------------------------------


C-----------------------------------------------------------------
  --- Data File Headers ---
Open McIDAS areas, set header values for the output file:
   CALL OPNARA(INAREA)
   CALL ARAOPT(INAREA,1,'SPAC',2)
   CALL READD(INAREA,IDIR)
   CALL MOVCW('MDM CLASSIFICATION              ',IDIR(25))
   IDIR(11)= 1
   IDIR(14)= 1
   IDIR(19)= 1
   IDIR(52) = LIT('VISR')
   IDIR(53) = LIT('BRIT')
   DATAW = IDIR(11)
   NAV2 = IDIR(35)
   LEV = IDIR(51)
   IF (IDIR(36) .NE. 0) THEN
     VAL = IDIR(15)-IDIR(49)-IDIR(50)-IDIR(51)
      ELSE
        VAL = 0
      ENDIF
      IDIR(36)= 0
C    Define where the start of data is in input, in bytes:
      STARTI = IDIR(15)
C    Do not copy DOC, CAL to output:
      STARTO = 0
      IDIR(50) = 0
      IDIR(49) = 0
C    Modify LEV section to read just one band in new area:
      IDIR(51) = 0
      IDIR(15) = STARTO
      IF (STARTI .LT. 0) STARTI=0
C    Start position in int*2 is half of bytes:
      STARTI = STARTI/2
C    Copy navigation from input area to the output area:
      CALL MAKARA(OTAREA,IDIR)
      IF (NAV2 .GT. 0) THEN
        CALL ARAGET(INAREA,NAV2,256,NAVARR)
        CALL ARAPUT(OTAREA,NAV2,256,NAVARR)
      ENDIF
      CALL OPNARA(OTAREA)
C-----------------------------------------------------------------

C-----------------------------------------------------------------
C     --- Initial Statistics Extraction ---
C   Find the mean and maximum values for each data band:
C   Find image histogram, get max, min stretching values (smin,smax):
      DO 10 I=0, NBANDS, 1
           MEAN(I) = 0
           MAX(I) = 0
           SMIN(I) = 0
           SMAX(I) = 0
           NWMEAN(I) = 0
           DO 15 J = 0, 255
             HIST(I,J) = 0
15         CONTINUE
10    CONTINUE
      NCM1 = NCOLS - 1
      NBM1 = NBANDS - 1
      NRM1 = NROWS - 1
      DO 20 ROW=0, NRM1,  SKIPF
        DO 30 BAND=0, NBANDS-1, 1
C          REDARA(AREA,LINE,STARTELEM,#ELEMENTS,BAND,IARRAY)
           CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
          DO 35 COL= 0, NCM1, SKIPF
           NWMEAN(BAND) = NWMEAN(BAND) + NEWIN(COL)
           IF (MAX(BAND) .LT. NEWIN(COL)) THEN
             MAX(BAND) = NEWIN(COL)
           ENDIF
           HIST(BAND,NEWIN(COL)/(255**(DATAW-1))) =
     C                HIST(BAND,NEWIN(COL)/(255**(DATAW-1))) + 1
35        CONTINUE
30      CONTINUE
20    CONTINUE
51          FORMAT(1X,A14,I2,1X,A1,I1,A4,2X,I7)
      DO 50 BAND=0, NBM1, 1
        MEAN(BAND) = SKIPF**2*(NWMEAN(BAND)/(NCOLS*NROWS))
        WRITE(CMES,51)       'MEAN OF BAND ',BAND+1,' (',
     C                       BNDLOC(BAND),') = ',MEAN(BAND)
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,51) 'MAX OF BAND  ',BAND+1,' (',
     C                       BNDLOC(BAND),') = ',MAX(BAND)
```

```
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
   Use histogram to find a minimum for stretching:
          J = 0
          SUM = 0
          CONTINUE
          SUM = SUM + HIST(BAND,J)
          IF (J .GE. 255) THEN
            SMIN(BAND) = 0
            GOTO 56
          ENDIF
#
          IF (SUM .LE. (NROWS*NCOLS)*DCUTOF/SKIPF**2) THEN
            J = J + 1
            GOTO 55
          ENDIF
          SMIN(BAND) = J
   Use histogram to find a maximum for stretching:
          J = 255
          SUM = 0
          CONTINUE
          SUM = SUM + HIST(BAND,J)
          IF (J .LE. 0) THEN
            SMAX(BAND) = 0
            GOTO 57
          ENDIF
#
          IF (SUM .LE. (NROWS*NCOLS)*DCUTOF/SKIPF**2) THEN
            J = J - 1
            GOTO 57
          ENDIF
          SMAX(BAND) = J
          WRITE(CMES,'(5X,F6.2,A21,1X,I5)') DCUTOF*100,
   C                '% data lower bound:',SMIN(BAND)
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(5X,F6.2,A21,1X,I5)') (1-DCUTOF)*100,
   C                '% data upper bound:',SMAX(BAND)
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)

        CONTINUE
*-------------------------------------------------------------*/


 Call the initial clustering algorithm:
    CALL ICLUST(NROWS,NCOLS,NBANDS,MAX,SMAX,SMIN,SMEAN,CLASES)

Note the desired number of classes, set up for the loop:
    DSCLAS = CLASES
    STOP = 0
    ITER =1
    CSKIP = SKIPF
    WRITE(CMES,'(A25,F6.3)') ' '
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
    WRITE(CMES,'(A25,F7.1)') 'Merging factor used = ', LUMPF
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
    WRITE(CMES,'(A23,F6.3)') 'Split factor used = ', SPLITF
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
    WRITE(CMES,'(A28,I4)') 'Max Iterations allowed = ', MXITER
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
```

```
C   Begin iterative classification loop:
99    CONTINUE
        WRITE(CMES,'(A1)') ' '
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A30,1X,I4)') 'PROCESSING ITERATION #',ITER
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(8X,I3,1X,A12)')  CLASES, 'Classes used'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A31,1X,I3)') 'Row&column skip used = ',CSKIP
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)

C  Clear counts and means of classes:
        DO 95 I=0, CLASES, 1
          SCOUNT(I)=0
          DO 105 BAND=0, NBM1, 1
            NSMEAN(BAND,I) = 0
105       CONTINUE
95      CONTINUE
        PERCH = 0.0

C   Start loop over rows and columns, convert input to output:
        DO 60 ROW=0, NRM1, CSKIP
          DO 70 BAND=0, NBM1,1
C            function redara(AREA,LINE,STARTELEM,#ELEMENTS,BAND,IARRAY)
             CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
             DO 75 COL=0, NCM1, CSKIP
                BUF(COL,BAND) = NEWIN(COL)
75           CONTINUE
70        CONTINUE

C  Classify:
          DO 80 COL=0, NCM1, CSKIP
            OUTDAT(COL)= MDM(CLASES,ROW,COL,NBANDS,BUF,SMEAN,NULL)
80        CONTINUE

C  Develop new smean and point count for data:
          DO 110 COL=0, NCM1, CSKIP
            DO 120 BAND=0, NBM1, 1
               NSMEAN(BAND,OUTDAT(COL))= NSMEAN(BAND,OUTDAT(COL))+
     C                                   BUF(COL,BAND)
120         CONTINUE
            SCOUNT(OUTDAT(COL)) = SCOUNT(OUTDAT(COL))+1
110       CONTINUE

C    Get in previous classification, save to array:
          IF (STOP .EQ. 0) THEN
            DO 130 COL=0, NCM1, CSKIP
              IF (ITER .GT. 1) THEN
                IF (OLDOUT(COL,ROW) .NE. OUTDAT(COL)) THEN
                   PERCH=PERCH+1
                ENDIF
              ENDIF
              OLDOUT(COL,ROW) = OUTDAT(COL)
130         CONTINUE
          ENDIF
          IF (STOP .EQ. 1 .AND. CSKIP .EQ. 1) THEN
            DO 135 COL=0, NCM1, 1
              OLDOUT(COL,ROW) = OUTDAT(COL)
135         CONTINUE
          ENDIF
```

```
      CONTINUE

    IF (STOP .EQ. 1) THEN
      WRITE(CMES,'(A33)') '-- Processing final iteration. --'
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
    ENDIF

  Write out smeans used in classification to screen:
    IF (STOP .EQ. 0) THEN
    WRITE(CMES,'(A35)') 'Cluster means used this iteration: '
     CALL FDEST(LOGFIL,CMES)
    WRITE(CMES,'(A36)') '                    ----Band Means----'
     CALL FDEST(LOGFIL,CMES)
    WRITE(CMES,'(A13,5X,7(A1,I1,A1,3X))') 'Class  Counts',
   C                          ('(',BNDLOC(I),')',I=0,NBM1)
     CALL FDEST(LOGFIL,CMES)
    DO 137 I=0, CLASES, 1
      WRITE(CMES,'(I3,2X,F8.1,1X,7(1X,I5))') I,SCOUNT(I)*(CSKIP**2),
   C          (SMEAN(BAND,I),BAND=0,NBM1)
       CALL FDEST(LOGFIL,CMES)
7    CONTINUE
    ENDIF


 Calculate new smeans:
    DO 160 I=1, CLASES, 1
       DO 150 BAND=0, NBM1, 1
         IF (SCOUNT(I) .GE. 1) THEN
           SMEAN(BAND,I) = NSMEAN(BAND,I)/SCOUNT(I)
         ELSE
           SMEAN(BAND,I) = 0
         ENDIF
0      CONTINUE
0   CONTINUE


 Find percent of pixels that changed classes:
    IF (ITER .GT. 1 .AND. STOP .EQ. 0) THEN
      PERCH = PERCH*(CSKIP**2)/(NCOLS*NROWS)*100.0
      WRITE(CMES,'(8X,A10,I3,A16,1X,F8.4)') 'Iteration ',ITER,
   C             ', PERCENT CHANGE: ',PERCH
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      IF (PERCH .LT. THRESH) STOP = STOP + 1
    ENDIF


-------------------------------------------------------
 Apply lumping (merging) and splitting of classes:
 Variable names after Tou & Gonzalez, "Pattern Recognition Principles"
 Some definitions:
 STDIJ(BAND,CLASS)    Std deviation of each class, for each band.
 STMAXJ(CLASS)        The maximum Std deviation for each class.
 STMINJ(CLASS)        The minimum Std deviation for each class.
 STDMAX               The maximum Std deviation for all classes.
 STDMIN               The minimum Std deviation for all classes.
 STDAVG               The average Std deviation for all classes.
 DNETJ(BAND,CLASS)    The average distance of samples in each class from
                      the class mean, for each band.
 DBARJ(CLASS)         The average distance of samples from their means.
 DBAR                 Overall average distance of samples from their means.
 SDIST(1,2)           Spectral distance between means of classes 1 and 2.
 MINSD, MAXSD         The smallest and largest SDISTs.
```

```
C  MAXLMP              The maximum number of lumpings allowed (classes/7).
C  COVAR(CLASS,1,2)    Set of CLASS covariance matrices.
C  CORRE(CLASS,1,2)    Set of CLASS correlation matrices.
C  TDIV(1,2)           Transformed Divergence between classes 1 and 2.
C-----------------

C-------------------------------------------
C   Extract the class statistics:
C      Initialize variables:
        OLDCLS = CLASES
        DBAR = 0
        STDAVG = 0
        STDMAX = 0
        STDMIN = 100000
        DO 225 I = 0, MXCLAS, 1
          DBARJ(I) = 0
          STMAXJ(I) = 0
          STMINJ(I) = 100000
          DO 235 J = 0, MXCLAS, 1
            SDIST(I,J) =  0
235       CONTINUE
          DO 215 BAND=0, NBM1,1
            DNETJ(BAND,I) = 0
            STDIJ(BAND,I) = 0
            DO 245 J=0, NBM1,1
              COVAR(I,BAND,J) = 0
245         CONTINUE
215       CONTINUE
225     CONTINUE
C         Find pairwise cluster distances:
          DO 320 I=0, CLASES-1, 1
            MINI(I) = 0
            MINJ(J) = 0
            DO 330 J=I+1, CLASES, 1
              DO 340 BAND=0, NBM1, 1
               SDIST(I,J) =SDIST(I,J)+(SMEAN(BAND,I)-SMEAN(BAND,J))**2
340           CONTINUE
              SDIST(I,J) = SQRT(SDIST(I,J))
330         CONTINUE
320       CONTINUE
          MINJ(CLASES) = 0
C       Loop over rows and columns, compute dbar, stds:
C       Develop average distance of samples from cluster centers:
        DO 210 ROW=0, NRM1, CSKIP
          DO 220 BAND=0, NBM1,1
            CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
             DO 230 COL=0, NCM1, CSKIP
              BUF(COL,BAND) = NEWIN(COL)
              DNETJ(BAND,OLDOUT(COL,ROW)) = DNETJ(BAND,OLDOUT(COL,ROW))
     C               + ABS(NEWIN(COL) - SMEAN(BAND,OLDOUT(COL,ROW)))
              STDIJ(BAND,OLDOUT(COL,ROW)) = STDIJ(BAND,OLDOUT(COL,ROW))
     C               + (ABS(NEWIN(COL)-SMEAN(BAND,OLDOUT(COL,ROW))))**2
230           CONTINUE
220       CONTINUE
C       Covariance calculations:
          DO 550 COL=0, NCM1, CSKIP
            DO 560 I=0, NBM1, 1
              DO 570 J=0, I, 1
                IF ( I .NE. J) THEN
                  COVAR(OLDOUT(COL,ROW),I,J)=COVAR(OLDOUT(COL,ROW),I,J)+
     C              (BUF(COL,I)-SMEAN(I,OLDOUT(COL,ROW)))*
     C              (BUF(COL,J)-SMEAN(J,OLDOUT(COL,ROW)))
                ENDIF
570           CONTINUE
560         CONTINUE
```

```
0       CONTINUE
0     CONTINUE
  End file read.
      DO 260 I=1, CLASES, 1
          DO 270 BAND=0, NBM1, 1
               Diagonal covariance elements:
               COVAR(I,BAND,BAND) = STDIJ(BAND,I)
           IF (SCOUNT(I) .GT. 1) THEN
             DNETJ(BAND,I) = DNETJ(BAND,I)/SCOUNT(I)
             STDIJ(BAND,I) = SQRT(STDIJ(BAND,I)/(SCOUNT(I)-1))
             STDAVG = STDAVG + STDIJ(BAND,I)
           ELSE
              STDIJ(BAND,I) = 0
           ENDIF
           DBARJ(I) =  DBARJ(I) + DNETJ(BAND,I)**2
           IF (STMAXJ(I) .LT. STDIJ(BAND,I)) STMAXJ(I)=STDIJ(BAND,I)
           IF (STMINJ(I) .GT. STDIJ(BAND,I)) STMINJ(I)=STDIJ(BAND,I)
           Covariance elements:
               DO 580 J=0, BAND, 1
                 IF (SCOUNT(I) .GT. 1) THEN
                   COVAR(I,BAND,J) = COVAR(I,BAND,J)/(SCOUNT(I)-1)
                 ELSE
                   COVAR(I,BAND,J) = 0
                 ENDIF
                 Fill other half of symmetric covariance matrix:
                 IF (J .NE. BAND) COVAR(I,J,BAND) = COVAR(I,BAND,J)
0              CONTINUE
0           CONTINUE
           Don't count 0s for STMIN due to 1 pixel classes:
           IF (STDMIN .GT. STMINJ(I) .AND. STMINJ(I) .GT. 0.01)
C              STDMIN = STMINJ(I)
           IF (STDMAX .LT. STMAXJ(I)) STDMAX = STMAXJ(I)
           DBARJ(I) = SQRT(DBARJ(I))
           DBAR = DBAR + DBARJ(I)*SCOUNT(I)
0       CONTINUE
           DBAR = DBAR*(CSKIP**2)/(NCOLS*NROWS)
           STDAVG = STDAVG/(NBANDS*CLASES)
-----------------------------------------------

      WRITE(CMES,'(A19)') '  For all classes: '
         CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A11,F9.2)') 'STDMIN = ',STDMIN
         CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A11,F9.2)') 'STDMAX = ',STDMAX
         CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A11,F9.2)') 'STDAVG = ',STDAVG
         CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A11,F9.2)') '  DBAR = ',DBAR
         CALL FDEST(LOGFIL,CMES)

-----------------------------------------------------
 Don't loop through lumping/splitting routines if final iteration:
    IF ( STOP .EQ. 0)  THEN

      Split clusters with largest mean distances, if odd iteration:
       CALL SPLITI(CLASES,NBANDS,DSCLAS,ITER,SPLITF,SKIPF,
     C                 SMEAN,SCOUNT,STDIJ,STMAXJ,STMINJ,STDMAX,
     C                 STDMIN,STDAVG,DBARJ,DBAR,COVAR,SMAX,MINPIX)
      CLASSP = CLASES

      Remove classes with few pixels present:
       CALL EMPTY(CLASES,NBANDS,ITER,CSKIP,SMEAN,SCOUNT,
     C              STDIJ,STMAXJ,DBARJ,COVAR,MINPIX)

      Calculate divergence, transformed divergence:
```

```
c----------
C   Convert covariance to correlation:
      DO 591 I = 1, CLASES
        DO 601 BAND = 0, NBM1
          DO 611 J = 0, BAND
            IF (COVAR(I,BAND,J) .NE. 0 .AND.
     C          STDIJ(BAND,I) .NE. 0 .AND.
     C          STDIJ(J,I) .NE. 0 ) THEN
               CORRE(I,BAND,J) = COVAR(I,BAND,J)/
     C                    (STDIJ(BAND,I)*STDIJ(J,I))
            ELSE
               CORRE(I,BAND,J) = 0
            ENDIF
C           Fill other half of symmetric correlation matrix:
            IF (J .NE. BAND) CORRE(I,J,BAND) = CORRE(I,BAND,J)
611       CONTINUE
601     CONTINUE
591   CONTINUE
c----------
C     Work on lumping only if no splitting this iteration:
        IF (MOD(ITER,2) .EQ. 0 .OR. CLASSP .EQ. OLDCLS) THEN
C          CALL DIVERG(COVAR,SMEAN,SCOUNT,NBANDS,CLASES,DIV,TDIV)
          CALL DIVERG(COVAR,SMEAN,SCOUNT,NBANDS,CLASES,DIV,TDIV,CORRE)

C         Lump clusters together using the pairwise distances:
          CLASSP = CLASES
          CALL LUMPTD(CLASES,NBANDS,CLASSP,ITER,LUMPF,SMEAN,SCOUNT,
     C           SDIST,STDIJ,STMAXJ,STDMAX,DBARJ,DBAR,DIV,TDIV,DSCLAS
     C           ,MINPIX)
        ENDIF
      ENDIF
C-----------------------------------------------------

C     End the lumping/splitting of classes.
C-------------------------------------------------------

C   Write out smean array to screen:
      IF (STOP .EQ. 1) THEN
        WRITE(CMES,'(A21)') 'Final cluster means:'
         CALL FDEST(LOGFIL,CMES)
      ELSE
        WRITE(CMES,'(2X,A23)') 'Adjusted cluster means:'
         CALL FDEST(LOGFIL,CMES)
      ENDIF
      WRITE(CMES,'(34X,A17)') '---Band Means---'
       CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A5,2X,A6,2X,A6,2X,A4,7(3X,A1,I1,A1))')
     C 'Class','Counts','Stdmax','Dbar', ('(',BNDLOC(I),')',I=0,NBM1)
       CALL FDEST(LOGFIL,CMES)
      DO 450 I=0, CLASES, 1
         WRITE(CMES,'(I3,2X,F7.0,1X,F7.2,1X,F7.2,7(1X,I5))') I,
     C   SCOUNT(I)*(CSKIP**2), STMAXJ(I), DBARJ(I),
     C   (SMEAN(BAND,I),BAND=0,NBM1)
         CALL FDEST(LOGFIL,CMES)
450    CONTINUE


C   Write out correlation matrix, pairwise distances matrix:
C   Convert covariance to correlation:
      DO 590 I = 1, CLASES
        DO 600 BAND = 0, NBM1
          DO 610 J = 0, BAND
            IF (COVAR(I,BAND,J) .NE. 0 .AND.
     C          STDIJ(BAND,I) .NE. 0 .AND.
     C          STDIJ(J,I) .NE. 0 ) THEN
```

```
            CORRE(I,BAND,J) = COVAR(I,BAND,J)/
     C                        (STDIJ(BAND,I)*STDIJ(J,I))
           ELSE
              CORRE(I,BAND,J) = 0
           ENDIF
           Fill other half of symmetric correlation matrix:
           IF (J .NE. BAND) CORRE(I,J,BAND) = CORRE(I,BAND,J)
0        CONTINUE
0      CONTINUE
0    CONTINUE
     IF ( STOP .EQ. 1 )  THEN
        Write out tdiv matrix:
         WRITE(CMES,'(A39)') 'Transformed Divergence Matrix:'
           CALL FDEST(LOGFIL,CMES)
         CALL CXCOUT(TDIV,CLASES,MXCLAS,0)
       WRITE(CMES,'(A28)') 'Class correlation matrices:'
        CALL FDEST(LOGFIL,CMES)
       DO 595 I = 1, CLASES
         WRITE(CMES,'(A11,I3)') '   CLASS: ',I
          CALL FDEST(LOGFIL,CMES)
         DO 606 BAND = 0, NBM1
          WRITE(CMES,'(10(F5.3,1X))') (CORRE(I,BAND,J), J=0,NBM1)
            CALL FDEST(LOGFIL,CMES)
6        CONTINUE
5      CONTINUE
       WRITE(CMES,'(A39)') 'Distances between Cluster means:'
         CALL FDEST(LOGFIL,CMES)
       CALL CXCOUT(TDIV,CLASES,MXCLAS,0)
     ENDIF

     ITER = ITER + 1

  If percent changed not small or not too many iterations, loop:
  If we reached convergance, perform a full classification
  converting input to output using final classes, skipf of one:
     IF (STOP .EQ. 1 .OR. ITER .EQ. MXITER) THEN
       CSKIP = 1
       DO 61 ROW=0, NRM1, CSKIP
         DO 71 BAND=0, NBM1,1
            CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
            DO 72 COL=0, NCM1, CSKIP
               BUF(COL,BAND) = NEWIN(COL)
            CONTINUE
         CONTINUE
         DO 73 COL=0, NCM1, CSKIP
           OUTDAT(COL)= MDM(CLASES,ROW,COL,NBANDS,BUF,SMEAN,NULL)
           SCOUNT(OUTDAT(COL)) = SCOUNT(OUTDAT(COL))+1
           OLDOUT(COL,ROW) = OUTDAT(COL)
        CONTINUE
       CONTINUE
     ELSE
      IF (STOP .EQ. 0 .AND. ITER .LE. MXITER) GOTO 99
     ENDIF

   Write file out to output file name
    DO 170 ROW=0, NRM1, 1
        DO 180 COL=0, NCM1,1
          OUTDAT(COL) = OLDOUT(COL,ROW)*2
        CONTINUE
        CALL PACK(NCOLS,OUTDAT,OUTDAT)
        CALL WRTARA(OTAREA,ROW,OUTDAT)
     CONTINUE
     CALL STAMP(OTAREA)
     CALL CLSARA(OTAREA)
     CALL CLSARA(INAREA)
```

```
C  Save an enhancement table along with the output image:
            WRITE(CMES,'(A30)') 'OUTPUT COLOR ASSIGNMENTS: '
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
            WRITE(CMES,'(A24,2X,A1,1X,I3,1X,A1)') '  RED FROM BAND 1 ',
     C            '(', BNDLOC(0),')'
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
            WRITE(CMES,'(A24,2X,A1,1X,I3,1X,A1)') 'GREEN FROM BAND 2 ',
     C            '(', BNDLOC(1),')'
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
            WRITE(CMES,'(A24,2X,A1,1X,I3,1X,A1)') ' BLUE FROM BAND 3 ',
     C            '(', BNDLOC(2),')'
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
C  Write McIDAS .ET color look-up table file:
       CALL ENHNCE(OTAREA,NBANDS,MAX,SMAX,SMIN,SMEAN,CLASES,HIST,STRET)
        WRITE(CMES,'(A1)') ' '
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)

C  Write class signatures data file:
       CALL SIGOUT(OTAREA,NBANDS,MAX,SMEAN,SCOUNT,DBARJ,STDIJ,
     C                  STMAXJ,CLASES,BNDLOC,COVAR)

        WRITE(CMES,'(A1)') ' '
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A19,1X,A7)') 'Log file: ', LOGFIL
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A60)')
     C  'Contains a detailed log of the procedure, including final   '
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A60)')
     C  'class statistics, mean distances, and Transformed divergence'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A60)')
     C  'matrices.                                                   '
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)

       RETURN
       END



C ================================================================*/
C        ICLUST (INITIAL CLUSTER)
C
C        Function to find initial cluster means.
C
C ----------------------------------------------------------------*/
       SUBROUTINE ICLUST(NROWS,NCOLS,NBANDS,MAX,SMAX,SMIN,SMEAN,CLASES)
       PARAMETER (MXCLAS=300)
       PARAMETER (MXBNDS=7)
       CHARACTER*70 CMES
       INTEGER NROWS, NCOLS, NBANDS, CLASES
       INTEGER MAX(0:MXBNDS), SMAX(0:MXBNDS), SMIN(0:MXBNDS)
       INTEGER SMEAN(0:MXBNDS,0:MXCLAS)
       INTEGER I,ROW, COL, BAND, SET
```

```
      REAL*8 DELTA
*-------------------------------------------------
      Develop initial means for each cluster:
*     Note: iterate set from 1 to nsets, save set=0 for unclassified. */
       DO 10 BAND=0, NBANDS-1, 1
          DELTA = MAX(BAND)/FLOAT(CLASES)
          IF (DELTA .LT. 1) DELTA = 1
          DO 20 SET=0, CLASES, 1
            SMEAN(BAND,SET) = SET * DELTA
          CONTINUE
       CONTINUE
      RETURN
      END
*-----------------------------------------------------------------------*/

*=======================================================================*/
      EMPTY

      Function to delete clusters containing few pixels as per the
      ISODATA definition in  "Pattern Recognition Principles".

*-----------------------------------------------------------------------*/
      SUBROUTINE EMPTY(CLASES,NBANDS,ITER,CSKIP,SMEAN,SCOUNT,
     C                 STDIJ,STMAXJ,DBARJ,COVAR,MINPIX)
      PARAMETER (MXBNDS=7)
      PARAMETER (MXCLAS=300)
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS),NBANDS,CLASES,I,J,K,BAND,CSKIP
      REAL*8  STDIJ(0:MXBNDS,0:MXCLAS), STMAXJ(0:MXCLAS)
      REAL*8  DBARJ(0:MXCLAS), SCOUNT(0:MXCLAS)
      REAL*8  COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
      COMMON/TFILE/ LOGFIL
      CHARACTER*70 CMES
        I=1
        J = CLASES
0       CONTINUE
          IF ((SCOUNT(I)*(CSKIP**2) .LT. MINPIX) .OR.
     C        (SCOUNT(I) .LE. 4)) THEN
            J =  J - 1
            DO 144 K= I, CLASES-1, 1
              SCOUNT(K) = SCOUNT(K+1)
              STMAXJ(K) = STMAXJ(K+1)
              DBARJ(K)  = DBARJ(K+1)
              DO 146 BAND=0, NBANDS-1, 1
               STDIJ(BAND,K) = STDIJ(BAND,K+1)
               SMEAN(BAND,K)=SMEAN(BAND,K+1)
                 DO 147 L=0, NBANDS-1, 1
                   COVAR(K,BAND,L) = COVAR(K+1,BAND,L)
7                147 CONTINUE
6             CONTINUE
4           CONTINUE
          ELSE IF (SCOUNT(I)*(CSKIP**2) .GE. MINPIX) THEN
            I = I + 1
          ENDIF
        IF (J .LE. 0) THEN
          CALL SDEST('ERROR REDUCING CLASSES',0)
          CALL FDEST(LOGFIL,'ERROR REDUCING CLASSES')
          RETURN
        ENDIF
        IF (I .LE. J) GOTO 140
        IF (J .LT. CLASES) THEN
          WRITE(CMES,'(2X,A25,I4,A4,I4)') 'Empty cluster reduction: ',
     C                                    CLASES,' to ',J,' classes'
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          CLASES = J
          ENDIF
        RETURN
        END


C ======================================================================*/
C             CXCOUT
C       Function to write out a triangular CLASES by CLASES matrix
C       Matrix elements divided by SIZE in output.
C       SCREEN toggle writes out to screen if a 1 is input.
C ----------------------------------------------------------------------*/
      SUBROUTINE CXCOUT(RMAT,CLASES,MXCLAS,SCREEN)
      REAL*8  RMAT(0:MXCLAS,0:MXCLAS)
      INTEGER CLASES,I,J,II,JJ,CHECK,SIZE,SCREEN
      INTEGER DMAT(0:20)
      COMMON/TFILE/ LOGFIL
      CHARACTER*70 CMES
C  Check the maximum digit size of the matrix:
      DO 468 II = 0, CLASES -1
        DO 469 JJ = 0, II
          IF (RMAT(II,JJ) .GT. MAX) MAX=RMAT(II,JJ)
469     CONTINUE
468   CONTINUE
      IF (MAX .GT. 9999) THEN
        SIZE = 10
        WRITE(CMES,'(5X,A24,I3,A1)') '(Value shown = distance/',
     C         SIZE,')'
          IF (SCREEN .EQ. 1) CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
      ELSE
        SIZE = 1
      ENDIF
C  Printout:
      DO 470 II = 0, CLASES/13
        WRITE(CMES,'(A1)') ' '
         IF (SCREEN .EQ. 1) CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        IF (13+13*II .LT. CLASES) THEN
          JJ = 12+13*II
        ELSE
          JJ = CLASES
        ENDIF
        WRITE(CMES,'(A5,13(I3,2X))') 'Clust', (I,I=13*II,JJ)
         IF (SCREEN .EQ. 1) CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        DO 460 I=II*13, CLASES, 1
        IF (I-II*13 .GT. 12) THEN
          CHECK = II*13 + 12
        ELSE
          CHECK = I
        ENDIF
         DO 11 J = II*13,CHECK
           DMAT(J) = RMAT(J,I)/SIZE
11       CONTINUE
         WRITE(CMES,'(I3,1X,13(I4,1X))') I,
     C    (DMAT(J),J=II*13,CHECK)
          IF (SCREEN .EQ. 1) CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
460      CONTINUE
470    CONTINUE
      RETURN
      END


C ----------------------------------------------------------------------*/
```

```
      SPLITI

      Function to split apart clusters using Principal Axes of
      Inertia.

      Calls EIGENS, a routine for finding the Eigenvalues and
      Eigenvectors for each class.

-----------------------------------------------------------------------*/
    SUBROUTINE SPLITI(CLASES,NBANDS,DSCLAS,ITER,SPLITF,SKIPF,
   C                  SMEAN,SCOUNT,STDIJ,STMAXJ,STMINJ,STDMAX,
   C                  STDMIN,STDAVG,DBARJ,DBAR,COVAR,SMAX,MINPIX)
     PARAMETER (MXBNDS=7)
     PARAMETER (MXCLAS=300)
     PARAMETER (NEG1 = -1)
     PARAMETER (YES = -1)
     PARAMETER (NO = 0)
    INTEGER   SMEAN(0:MXBNDS,0:MXCLAS),OLDCLS
    REAL*8    STDIJ(0:MXBNDS,0:MXCLAS), STMAXJ(0:MXCLAS), STDAVG
    REAL*8    DBARJ(0:MXCLAS), SCOUNT(0:MXCLAS), STMINJ(0:MXCLAS)
    REAL*8    STDMAX, STDMIN, DBAR, SPLITF,SMAX(0:MXBNDS)
    REAL*8    COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
    INTEGER   NBANDS,CLASES,DSCLAS,ITER,BAND,SKIPF,SPLIT
    INTEGER   H,I,J,K,L,IBNDS,BADB(0:MXBNDS-1),NBM1,MAXSPL
    REAL*8    IMAT(0:MXBNDS-1,0:MXBNDS-1),DIFF,MAX,SMALL
    REAL*8    EVECTR(0:MXBNDS-1,0:MXBNDS-1), EVALUE(0:MXBNDS-1)
    COMMON/TFILE/ LOGFIL
    CHARACTER*70 CMES

 Exit if splitting operation is not enabled, or if odd iteration:
   IF (SPLITF .LT. 0.001 .OR. MOD(ITER,2) .EQ. 0) RETURN

 Tell log file splitting is being performed:
   WRITE(CMES,'(2X,A34)') 'Running Cluster splitting routine.'
    CALL SDEST(CMES,0)
    CALL FDEST(LOGFIL,CMES)

   MAXSPL is maximum number of cluster pairs which can be split.
   MAXSPL = CLASES/3
   OLDCLS = CLASES
   NBM1 = NBANDS -1
   I = 1

   CONTINUE
     SPLIT = NO
     SMALL = NO

 Quit if we already have too many classes:
     IF (CLASES-OLDCLS .GT. MAXSPL) RETURN

 Split clusters no matter what if there are few classes:
 Find the class with the largest STD and split it:
     IF ( CLASES .LE. DSCLAS/20 ) THEN
       MAX = 0
       DO 10 J = 1, CLASES
         IF (STMAXJ(J) .GT. MAX) THEN
           MAX = STMAXJ(J)
           I = J
         ENDIF
       CONTINUE
       SMALL = YES
       SPLIT = YES
     ELSE

        Move to next class if not enough pixels:

2          IF (SCOUNT(I)*SKIPF**2 .LT. 10*MINPIX .AND.
     C           I .LE. CLASES)  THEN
             I = I + 1
             GOTO 2
           ENDIF
             IF (I .GT. CLASES) RETURN

C           Run check to see if one or more of I's bands have mean 0:
           IBNDS = NBANDS
           DO 210 J = 0, NBM1
             IF (SMEAN(J,I) .EQ. 0) THEN
               IBNDS = IBNDS-1
               BADB(J) = YES
             ELSE
               BADB(J) = NO
             ENDIF
210        CONTINUE

C  Implement Inertial Matrix for multiple bands:
C    Build inertial matrix out of Covariance matrix:
           NBM1 = IBNDS - 1
           DO 41 J = 0, NBANDS - 1
             EVALUE(J) = 0
             DO 43 K = 0, NBANDS - 1
               IMAT(J,K) = 0
               EVECTR(J,K) = 0
43           CONTINUE
41         CONTINUE
           K = 0
           DO 36 L = 0, NBANDS - 1
             IF (BADB(L) .EQ. NO) THEN
               H = 0
               DO 46 J = 0, L-1
                 IF (BADB(J) .EQ. NO) THEN
                   IMAT(K,H) = NEG1*COVAR(I,L,J)
                   IMAT(H,K) = NEG1*COVAR(I,J,L)
                   H = H + 1
                 ENDIF
46             CONTINUE
               IMAT(K,K) = 0
               DO 131 J = 0, NBANDS - 1
                 IF (L .NE. J .AND. BADB(J) .EQ. NO) THEN
                   IMAT(K,K) = IMAT(K,K) + COVAR(I,J,J)
                 ENDIF
131            CONTINUE
               K = K + 1
             ENDIF
36         CONTINUE


C             Find Eigenvalues and Eigenvectors for each IMAT:
C  If only one band, use ratio approach:
           IF (IBNDS .EQ. 1 ) THEN
C            WRITE(CMES,'(A20,1X,I3,1X,F9.3,F9.2)') 'Cluster: ',I,
C     C           STMAXJ(I),STDAVG
C              CALL SDEST(CMES,0)
C              CALL FDEST(LOGFIL,CMES)
             IF ( (DBARJ(I) .GT. DBAR) .AND. (STMAXJ(I)/STDAVG .GT.
     C           SPLITF) .AND. (SCOUNT(I)*SKIPF**2 .GT. 10*MINPIX)
     C          ) THEN
C              WRITE(CMES,'(A20,1X,I3,1X,F9.3,F9.2)') 'Split: ',I,
C     C             SCOUNT(I)*SKIPF**2,10*MINPIX
C                CALL SDEST(CMES,0)
C                CALL FDEST(LOGFIL,CMES)
               SPLIT = YES
```

```
          ELSE
            I = I + 1
          ENDIF
        ELSE

-----------
Information printouts:
          WRITE(CMES,'(A15,1X,I5)') 'COVAR matrix:', I
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          DO 603 K = 0, NBANDS-1
          WRITE(CMES,'(10(F8.3,1X))') (COVAR(I,K,J), J=0,NBANDS-1)
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
603       CONTINUE
          WRITE(CMES,'(A15,1X,I5)') 'I matrix:', I
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          DO 606 K = 0, NBM1
           WRITE(CMES,'(10(F8.3,1X))') (IMAT(K,J), J=0,NBM1)
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
606       CONTINUE
-----------

          CALL EIGENS(IMAT,IBNDS,MXBNDS,EVECTR,EVALUE)

-----------
Information printouts:
          WRITE(CMES,'(A15,1X,I5)') 'EVALUE:', I
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(10(F8.3,1X))') (EVALUE(J), J=0,NBM1)
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(A15,1X,I5)') 'EVECTR:', I
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          DO 609 K = 0, NBM1
          WRITE(CMES,'(10(F8.3,1X))') (EVECTR(K,J), J=0,NBM1)
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
609       CONTINUE
          IF(EVALUE(NBM1) .NE. 0) THEN
           WRITE(CMES,'(A20,1X,I3,1X,F9.3,F9.2,F9.3)') 'Cluster: ',
     C          I,EVALUE(0),EVALUE(NBM1), EVALUE(0)/EVALUE(NBM1)
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
          ENDIF
-----------

          IF(EVALUE(NBM1) .NE. 0) THEN
            IF( (EVALUE(0)/EVALUE(NBM1) .GT. SPLITF**2) .AND.
     C          (SCOUNT(I)*SKIPF**2 .GT. 10*MINPIX) ) THEN
              SPLIT = YES
            ENDIF
          ENDIF
          IF (SPLIT .EQ. NO) I = I + 1
        ENDIF
      ENDIF

      IF (SPLIT .EQ. YES) THEN
          CLASES = CLASES + 1
          WRITE(CMES,'(9X,A20,1X,I3)') 'Splitting cluster: ',I
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          STMINJ(I) = 0
          STMAXJ(I) = 0
          DO 290 K= CLASES, I+1, -1
            SCOUNT(K) = SCOUNT(K-1)
            STMAXJ(K) = STMAXJ(K-1)
            STMINJ(K) = STMINJ(K-1)
            DBARJ(K) = DBARJ(K-1)
            DO 300 BAND=0, NBM1, 1
              STDIJ(BAND,K) = STDIJ(BAND,K-1)
              SMEAN(BAND,K) = SMEAN(BAND,K-1)
              DO 305 J=0, NBM1, 1
                COVAR(K,BAND,J) = COVAR(K-1,BAND,J)
305           CONTINUE
300         CONTINUE
290       CONTINUE
          IF (NBANDS .EQ. 1) THEN
              SMEAN(0,I+1) = SMEAN(0,I) + STDIJ(0,I)/1.5
              SMEAN(0,I) = SMEAN(0,I) - STDIJ(0,I)/1.5
              IF (SMEAN(0,I) .LT. 0) SMEAN(0,I) = 0
          ELSE
C          Split along principal axis:
            DO 310 BAND=0, NBANDS-1, 1
C             Expand EVECTR back into real space:
              DIFF = 0.
              IF (BADB(BAND) .EQ. NO) THEN
                DIFF = EVECTR(BAND,NBM1)*SQRT(EVALUE(0))/2.0
                IF (DIFF .GT. 10 .AND. SMAX(BAND) .LT. 255) DIFF=10
                IF (DIFF .GT. 2550 .AND. SMAX(BAND) .GT. 255)
     C            DIFF=2550
                SMEAN(BAND,I+1) = SMEAN(BAND,I) + DIFF
                SMEAN(BAND,I) = SMEAN(BAND,I) - DIFF
                IF (SMEAN(BAND,I) .LT. 0) SMEAN(BAND,I) = 0
                IF (SMEAN(BAND,I+1) .LT. 0) SMEAN(BAND,I+1)= 0
              ENDIF
310         CONTINUE
          ENDIF
          I = I + 2
      ENDIF

888   CONTINUE
      IF (SMALL .EQ. YES) I = 1
      IF (I .LE. CLASES) GOTO 1

999   CONTINUE
      RETURN
      END



C ------------------------------------------------------------------*/
C     EIGENS
C
C   Computes all eigenvectors and eigenvalues of a real symmetric
C   matrix A(1:N,1:N).  Non diagonal elements of A are destroyed.
C   EVALUE(1:N) returns eigenvalues, EVECTR(1:N,1:N) is a matrix whose
C   columns contain, on output, the normalized eigenvectors of A.
C   Output is ordered in descending order.
C
C   This routine is based on "Numerical Recipes" routines JACOBI
C   and EIGSRT.
C ------------------------------------------------------------------*/
      SUBROUTINE EIGENS(IMAT,NBANDS,MXBNDS,EVECTR,EVALUE)

      REAL*8  IMAT(1:MXBNDS,1:MXBNDS)
```

```
      REAL*8  EVECTR(1:MXBNDS,1:MXBNDS), EVALUE(1:MXBNDS)
      INTEGER CLASS, I, J, NROT

      CALL JACOBI(IMAT,NBANDS,MXBNDS,EVALUE,EVECTR,NROT)
      CALL EIGSRT(EVALUE,EVECTR,NBANDS,MXBNDS)
      RETURN
      END

------------------------------
      SUBROUTINE JACOBI(A,N,NP,D,V,NROT)
      PARAMETER (NMAX=100)
      REAL*8 A(NP,NP),D(NP),V(NP,NP),B(NMAX),Z(NMAX)
      DO 12 IP=1,N
        DO 11 IQ=1,N
          V(IP,IQ)=0.
        CONTINUE
        V(IP,IP)=1.
      CONTINUE
      DO 13 IP=1,N
        B(IP)=A(IP,IP)
        D(IP)=B(IP)
        Z(IP)=0.
      CONTINUE
      NROT=0
      DO 24 I=1,50
        SM=0.
        DO 15 IP=1,N-1
          DO 14 IQ=IP+1,N
            SM=SM+ABS(A(IP,IQ))
          CONTINUE
        CONTINUE
        IF(SM.EQ.0.)RETURN
        IF(I.LT.4)THEN
          TRESH=0.2*SM/N**2
        ELSE
          TRESH=0.
        ENDIF
        DO 22 IP=1,N-1
          DO 21 IQ=IP+1,N
            G=100.*ABS(A(IP,IQ))
            IF((I.GT.4).AND.(ABS(D(IP))+G.EQ.ABS(D(IP)))
     *         .AND.(ABS(D(IQ))+G.EQ.ABS(D(IQ))))THEN
              A(IP,IQ)=0.
            ELSE IF(ABS(A(IP,IQ)).GT.TRESH)THEN
              H=D(IQ)-D(IP)
              IF(ABS(H)+G.EQ.ABS(H))THEN
                T=A(IP,IQ)/H
              ELSE
                THETA=0.5*H/A(IP,IQ)
                T=1./(ABS(THETA)+SQRT(1.+THETA**2))
                IF(THETA.LT.0.)T=-T
              ENDIF
              C=1./SQRT(1+T**2)
              S=T*C
              TAU=S/(1.+C)
              H=T*A(IP,IQ)
              Z(IP)=Z(IP)-H
              Z(IQ)=Z(IQ)+H
              D(IP)=D(IP)-H
              D(IQ)=D(IQ)+H
              A(IP,IQ)=0.
              DO 16 J=1,IP-1
                G=A(J,IP)
                H=A(J,IQ)
                A(J,IP)=G-S*(H+G*TAU)
                A(J,IQ)=H+S*(G-H*TAU)
16            CONTINUE
              DO 17 J=IP+1,IQ-1
                G=A(IP,J)
                H=A(J,IQ)
                A(IP,J)=G-S*(H+G*TAU)
                A(J,IQ)=H+S*(G-H*TAU)
17            CONTINUE
              DO 18 J=IQ+1,N
                G=A(IP,J)
                H=A(IQ,J)
                A(IP,J)=G-S*(H+G*TAU)
                A(IQ,J)=H+S*(G-H*TAU)
18            CONTINUE
              DO 19 J=1,N
                G=V(J,IP)
                H=V(J,IQ)
                V(J,IP)=G-S*(H+G*TAU)
                V(J,IQ)=H+S*(G-H*TAU)
19            CONTINUE
              NROT=NROT+1
            ENDIF
21        CONTINUE
22      CONTINUE
        DO 23 IP=1,N
          B(IP)=B(IP)+Z(IP)
          D(IP)=B(IP)
          Z(IP)=0.
23      CONTINUE
24    CONTINUE
      PAUSE '50 iterations should never happen'
      RETURN
      END

C------------------------------
      SUBROUTINE EIGSRT(D,V,N,NP)
      REAL*8 D(NP),V(NP,NP)
      DO 13 I=1,N-1
        K=I
        P=D(I)
        DO 11 J=I+1,N
          IF(D(J).GE.P)THEN
            K=J
            P=D(J)
          ENDIF
11      CONTINUE
        IF(K.NE.I)THEN
          D(K)=D(I)
          D(I)=P
          DO 12 J=1,N
            P=V(J,I)
            V(J,I)=V(J,K)
            V(J,K)=P
12        CONTINUE
        ENDIF
13    CONTINUE
      RETURN
      END



C ===================================================================*/
C       LUMPTD
C
C       Function to merge together clusters by analysis of Transformed
```

```
      Divergence.
      LUMPF is the threshold transformed divergence between classes
      to perform lumping.  Pairs with a t. divergence less than the
      merging factor will be merged.  1/3 of the cluster pairs is
      the maximum number of mergings allowed.
-----------------------------------------------------------------*/
     SUBROUTINE LUMPTD(CLASES,NBANDS,OLDCLS,ITER,LUMPF,SMEAN,SCOUNT,
    C           SDIST,STDIJ,STMAXJ,STDMAX,DBARJ,DBAR,DIV,TDIV,DSCLAS
    C           ,MINPIX)
     PARAMETER (MXBNDS=7)
     PARAMETER (MXCLAS=300)
     REAL*8  STDIJ(0:MXBNDS,0:MXCLAS), SDIST(0:MXCLAS,0:MXCLAS)
     REAL*8  DBARJ(0:MXCLAS), SCOUNT(0:MXCLAS), STMAXJ(0:MXCLAS)
     REAL*8  STDMAX,  DBAR, MINTD, MAXTD, LUMPF
     REAL*8  COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
     REAL*8  DIV(0:MXCLAS,0:MXCLAS)
     REAL*8  TDIV(0:MXCLAS,0:MXCLAS)
     INTEGER SMEAN(0:MXBNDS,0:MXCLAS), ROW, PREI, PREJ, II, JJ
     INTEGER NBANDS,CLASES,OLDCLS,ITER,I,K,BAND,DSCLAS
     INTEGER MINI(0:MXCLAS), MINJ(0:MXCLAS), MAXLMP
     COMMON/TFILE/ LOGFIL
     CHARACTER*70 CMES

  Exit if lumping operation is not enabled:
     IF (LUMPF .LT. 0.01) RETURN

       Sort, find lowest divergences for lumping:
       ROW = 0
       MAXTD = 0
       MAXLMP is maximum number of cluster pairs which can be lumped.
       MAXLMP = CLASES/3
       CONTINUE
         MINTD = 1000000
         DO 360 I=1, CLASES, 1
           DO 370 J=1, I-1, 1
             IF ( CLASES .LE. DSCLAS/20 ) THEN
               WRITE(CMES,'(A50)') 'Too few classes for lumping'
               CALL SDEST(CMES,0)
               CALL FDEST(LOGFIL,CMES)
               RETURN
             ENDIF
             IF (ROW .EQ. 0 .AND. TDIV(I,J) .GT. MAXTD)
    C            MAXTD = TDIV(I,J)
             IF (TDIV(I,J) .LT. MINTD .AND.
    C            TDIV(I,J) .GT. 0.01) THEN
               JJ = 0
               DO 400 II=0, ROW
                 IF (I .EQ. MINI(II) .OR. J .EQ. MINJ(II))  THEN
                   We have already found this one, or one of these
                   classes is to be lumped somewhere else.
                   JJ = 1
                 ENDIF
               CONTINUE
               IF (JJ .EQ. 0) THEN
                 PREI = I
                 PREJ = J
                 MINTD = TDIV(I,J)
               ENDIF
             ENDIF
           CONTINUE
         CONTINUE
         If no distances are less than the minimum ,exit the loop!
         IF (ROW .EQ. 0) THEN
          WRITE(CMES,'(2X,A32)')
    C       'Running Cluster merging routine.'
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,'(4X,A44)')
    C       'Transformed Divergences used between classes:'
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,'(3X,A19,1X,F7.0)') 'Smallest = ',MINTD
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,'(3X,A19,1X,F7.0)') 'Largest  = ',MAXTD
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(3X,A32,1X,F6.1)') 'Threshold for lumping = '
    C                                     ,LUMPF
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
           ENDIF
           MINI(ROW) = PREI
           MINJ(ROW) = PREJ
           IF (TDIV(MINI(0),MINJ(0)) .GT. LUMPF) GOTO 390
           IF (ROW .GE. 2*MAXLMP) GOTO 350
           ROW = ROW + 1
         GOTO 380
350      CONTINUE
         MINTD = TDIV(MINI(0),MINJ(0))
C        Write out the MAXLMP smallest distances:
         WRITE(CMES,'(3X,I4,1X,A23)') MAXLMP,' Least Divergences:'
          CALL FDEST(LOGFIL,CMES)
         WRITE(CMES,'(3X,A30)') 'Class1  Class2  T.Divergence'
          CALL FDEST(LOGFIL,CMES)
         DO 435 II= 0, MAXLMP-1, 1
          WRITE(CMES,'(3X,I4,5X,I4,5X,F6.1)')  MINI(II), MINJ(II),
    C                                 TDIV(MINI(II),MINJ(II))
           CALL FDEST(LOGFIL,CMES)
435      CONTINUE
C      Do the lumping, replacing two classes with an average:
         DO 440 II= 0, MAXLMP-1, 1
410        CONTINUE

           IF (TDIV(MINI(II),MINJ(II)) .LE. LUMPF) THEN
C            Change the means of the lumped cluster:
             WRITE(CMES,'(10X,A17,1X,I3,1X,A1,1X,I3)')
    C         'Merging classes:', MINI(II), '+', MINJ(II)
              CALL SDEST(CMES,0)
              CALL FDEST(LOGFIL,CMES)
             DO 420 BAND=0, NBANDS-1, 1
               SMEAN(BAND,MINI(II)) = ( SMEAN(BAND,MINI(II))*
    C               SCOUNT(MINI(II)) + SMEAN(BAND,MINJ(II))*
    C               SCOUNT(MINJ(II)) ) / (SCOUNT(MINI(II)) +
    C                                     SCOUNT(MINJ(II)) )
420          CONTINUE
C            Wipe out the old second cluster:
             SCOUNT(MINI(II))=SCOUNT(MINI(II))+SCOUNT(MINJ(II))
             DO 430 K= MINJ(II)+1, CLASES-1, 1
               SCOUNT(K) = SCOUNT(K+1)
               STMAXJ(K) = STMAXJ(K+1)
               DBARJ(K) = DBARJ(K+1)
               DO 425 BAND=0, NBANDS-1, 1
                 SMEAN(BAND,K) = SMEAN(BAND,K+1)
                 STDIJ(BAND,K) = STDIJ(BAND,K+1)
425            CONTINUE
430          CONTINUE
             CLASES = CLASES - 1
           ENDIF
440      CONTINUE
```

```
0       CONTINUE
        IF (OLDCLS .GT. CLASES) THEN
        WRITE(CMES,'(6X,A20,I4,A4,I4,A8)') 'Merging total: ',OLDCLS,
     C                                     ' to ',CLASES,' classes'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        ENDIF

      RETURN
      END


=====================================================================*/
       ENHNCE

        Function to save enhancement tables with means of sets.
        Saves class means from bands 1, 2, and 3 as colors for class.

        Currently, for 3 or more data bands, a histogram equalization
        stretch is applied to the 1st three bands of the data to
        produce the color table.  A linear stretch could instead be
        enabled by activating the commented code and commenting the
        Histoeq parts.

        Note that a stretch factor of 2 has been used throughout this
        program because of the 7 bit nature of the color display.

        McIDAS LWFILE operations are not used due to their tendancy
        to append unwanted data at EOF.  Unit 19 is used to write
        the .ET enhancement table file.

        Stretch parameter: 0=histogram equalization, 1=linear stretch.

---------------------------------------------------------------------*/
      SUBROUTINE ENHNCE(IAR,NBANDS,MAX,SMAX,SMIN,SMEAN,CLASES,HIST,
     C                  STRET)
      IMPLICIT CHARACTER*12 (C)
      PARAMETER (MXBNDS=7)
      PARAMETER (MXCLAS=300)
      PARAMETER (STRETCH=2)
      CHARACTER*70 CMES
      INTEGER NROWS, NCOLS, NBANDS, CLASES, STRET
      INTEGER MAX(0:MXBNDS), SMAX(0:MXBNDS), SMIN(0:MXBNDS)
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS)
      INTEGER MNRED(0:MXCLAS), MNGRE(0:MXCLAS),MNBLU(0:MXCLAS)
      INTEGER MXRED, MXGRE,MXBLU
      INTEGER MINRED, MINGRE, MINBLU
      INTEGER I, BAND, SET, TTAB(816), SIZE
      INTEGER*4 IAR
      REAL*8  HIST(0:MXBNDS,0:255),HCOUNT(0:2),HISRED,HISGRE,HISBLU
      REAL*4 REDSTR, GRESTR, BLUSTR
      CHARACTER*7 TABFIL
      COMMON/TFILE/ LOGFIL
Parameters for enhancement tables:
      DIMENSION IRED(15),IGREEN(15),IBLUE(15)
      DATA FULL/816/,GRE/256/,BLU/512/,GRED/769/,GGRE/785/,GBLU/801/
      DATA IRED/255,0,255,0,255,0,255,255,255,237,0,227,255,0,255/
      DATA IBLUE/255,255,0,0,0,255,255,203,127,127,255,67,0,115,127/
      DATA IGREEN/0,255,255,255,0,0,255,127,127,0,163,255,127,0,171/
      CNEWOUT = CFI(IAR)
      TABFIL(1:4) = CNEWOUT(9:12)
      TABFIL(5:7) = '.ET'
      CALL LWD(TABFIL)
       WRITE(CMES,'(A19,1X,A7)') 'Enhancement file: ', TABFIL
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A28,1X,I4,A9)') 'Contains look up table for ',
     C       CLASES+1,' Classes'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A45)') 'Class values doubled for 7 bit display.'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)

C--------------
C  (Histoeq) Find total number of pixels:
       IF (STRET .EQ. 0) THEN
         DO 9 I = 0, NBANDS-1
          HCOUNT(I) = 0
          DO 8 J = 1, 255
            HCOUNT(I) = HCOUNT(I) + HIST(I,J)
8         CONTINUE
9        CONTINUE
       ENDIF
C--------------


       WRITE(CMES,'(A25)') 'CLASS  RED  GREEN  BLUE '
        CALL FDEST(LOGFIL,CMES)
             MXRED=0
             MXGRE=0
             MXBLU=0
             DO 10 I = 0, NBANDS-1
               IF (MAX(I) .GT. 255) THEN
                 SIZE = 255
               ELSE
                 SIZE = 1
               ENDIF
10           CONTINUE
             MINRED=255*SIZE
             MINGRE=255*SIZE
             MINBLU=255*SIZE
             MNRED(0) = 0
             MNGRE(0) = 0
             MNBLU(0) = 0
             DO 20 I = 1, CLASES*STRETCH
                J = STRETCH
                IF (MOD(I,J) .EQ. 0) THEN
                  J = I/STRETCH
C--------------
                 IF (NBANDS .EQ. 1) THEN
                   IF (STRET .EQ. 1) THEN
                     MNRED(I) = SMEAN(0,J)
                     MNGRE(I) = SMEAN(0,J)
                     MNBLU(I) = SMEAN(0,J)
                     MINRED = SMIN(0)
                     MINGRE = SMIN(0)
                     MINBLU = SMIN(0)
                     MXRED = SMAX(0)
                     MXGRE = SMAX(0)
                     MXBLU = SMAX(0)
                   ENDIF
                   IF (STRET .EQ. 0) THEN
                     HISRED = 0
                     DO 12 K = 0, SMEAN(0,J)
                       HISRED = HISRED + HIST(0,K)
12                   CONTINUE
                     HISGRE = HISRED
                     HISBLU = HISRED
                     MNRED(I) =  255*HISRED/HCOUNT(0)
```

```
                MNGRE(I) =  MNRED(I)
                MNBLU(I) =  MNRED(I)
              ENDIF
-------------
            ELSE IF (NBANDS .EQ. 2) THEN
              IF (STRET .EQ. 1) THEN
                MNRED(I) = SMEAN(1,J)
                MNGRE(I) = SMEAN(0,J)
                MNBLU(I) = SMEAN(0,J)
                MINRED = SMIN(1)
                MINGRE = SMIN(0)
                MINBLU = SMIN(0)
                MXRED = SMAX(1)
                MXGRE = SMAX(0)
                MXBLU = SMAX(0)
              ENDIF
              IF (STRET .EQ. 0) THEN
                HISRED = 0
                HISGRE = 0
                DO 16 K = 0, SMEAN(1,J)
                  HISRED = HISRED + HIST(1,K)
                CONTINUE
                DO 14 K = 0, SMEAN(0,J)
                  HISGRE = HISGRE + HIST(0,K)
                CONTINUE
                HISBLU = HISGRE
                MNRED(I) =  255*HISRED/HCOUNT(1)
                MNGRE(I) =  255*HISGRE/HCOUNT(0)
                MNBLU(I) =  MNGRE(I)
              ENDIF
-------------
            ELSE IF (NBANDS .GE. 3) THEN
 (Histoeq) Setup color positions by using Histogram table:
              IF (STRET .EQ. 0) THEN
                HISRED = 0
                HISGRE = 0
                HISBLU = 0
                DO 18 K = 1, SMEAN(2,J)
                  HISRED = HISRED + HIST(2,K)
                CONTINUE
                DO 22 K = 1, SMEAN(1,J)
                  HISGRE = HISGRE + HIST(1,K)
                CONTINUE
                DO 24 K = 1, SMEAN(0,J)
                  HISBLU = HISBLU + HIST(0,K)
                CONTINUE
                MNRED(I) =  255*HISRED/HCOUNT(2)
                MNGRE(I) =  255*HISGRE/HCOUNT(1)
                MNBLU(I) =  255*HISBLU/HCOUNT(0)
              ENDIF
Alternate linear color stretch:
              IF (STRET .EQ. 1) THEN
                MNRED(I) = SMEAN(2,J)
                MNGRE(I) = SMEAN(1,J)
                MNBLU(I) = SMEAN(0,J)
                MXRED = SMAX(2)
                MXGRE = SMAX(1)
                MXBLU = SMAX(0)
                MINRED = SMIN(2)
                MINGRE = SMIN(1)
                MINBLU = SMIN(0)
              ENDIF
-------------

            ENDIF
```

```
                ELSE
                      MNRED(I) = 0
                      MNGRE(I) = 0
                      MNBLU(I) = 0
                ENDIF
20            CONTINUE
                IF (STRET .EQ. 1) THEN
                  REDSTR = 255./((MXRED-MINRED)*SIZE)
                  GRESTR = 255./((MXGRE-MINGRE)*SIZE)
                  BLUSTR = 255./((MXBLU-MINBLU)*SIZE)
                ENDIF
              DO 25 I = 1, CLASES*STRETCH
                J = STRETCH
                IF (MOD(I,J) .EQ. 0) THEN
                  IF (STRET .EQ. 1) THEN
                      MNRED(I) = (MNRED(I)-MINRED)*REDSTR
                      MNGRE(I) = (MNGRE(I)-MINGRE)*GRESTR
                      MNBLU(I) = (MNBLU(I)-MINBLU)*BLUSTR
                  ENDIF
                  IF (MNRED(I) .LT. 0) MNRED(I) = 0
                  IF (MNGRE(I) .LT. 0) MNGRE(I) = 0
                  IF (MNBLU(I) .LT. 0) MNBLU(I) = 0
                  IF (MNRED(I) .GT. 255) MNRED(I) = 255
                  IF (MNGRE(I) .GT. 255) MNGRE(I) = 255
                  IF (MNBLU(I) .GT. 255) MNBLU(I) = 255
                ELSE
                  MNRED(I) = 0
                  MNGRE(I) = 0
                  MNBLU(I) = 0
                ENDIF
25            CONTINUE
                J = STRETCH
              DO 30 I= 0,CLASES*STRETCH
                  TTAB(I+1)= MNRED(I)
                  TTAB(BLU+I+1)= MNBLU(I)
                  TTAB(GRE+I+1)= MNGRE(I)
                IF (MOD(I,J) .EQ. 0) THEN
                  WRITE(CMES,'(4(I4,2X))') I,MNRED(I),MNGRE(I),MNBLU(I)
                   CALL FDEST(LOGFIL,CMES)
                ENDIF
30            CONTINUE
                DO 40 I=0,14
                  TTAB(GRED+I)=IRED(I+1)
                  TTAB(GGRE+I)=IGREEN(I+1)
                  TTAB(GBLU+I)=IBLUE(I+1)
40              CONTINUE
      OPEN(UNIT=19,FILE=TABFIL,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
      WRITE(UNIT=19)   (TTAB(J),J=1,GBLU+I)
      CLOSE(UNIT=19)
      RETURN
      END



C ------------------------------------------------------------------*/
C      MDM CLASSIFICATION ROUTINE
C  This routine classifies a pixel, given its values in each band and
C  its associated statistical data in global arrays
C
C ------------------------------------------------------------------*/
      INTEGER*4 FUNCTION MDM(NSETS, ROW, COL, NBANDS, BUF, SMEAN, NULL)

       PARAMETER (MXBNDS=7)
       PARAMETER (MAXRC=3584)
       PARAMETER (MXCLAS=300)
```

```
      PARAMETER (YES=-1)
      PARAMETER (NO=0)
      INTEGER ROW, COL, NBANDS, NULL, NSETS, ZERO
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS)
      INTEGER*2 BUF(0:MAXRC,0:MXBNDS)
     /* class to be returned      */
     INTEGER*2 OUTCLS
     INTEGER I, J, SET, BAND
     /* distances to the mean of a set  */
     INTEGER D(MXBNDS)
     REAL*8 DISTSQ, MIN
*-------------------------------------------------

 For NULL = ALL option:
    IF (NULL .EQ. 0) THEN
      If pixel is zero in all elements, set class = 0, exit:
      ZERO = YES
      DO 5 BAND=0, NBANDS-1, 1
          IF (BUF(COL,BAND) .NE. 0) THEN
            ZERO = NO
          ENDIF
      CONTINUE
      IF (ZERO .EQ. YES) THEN
        MDM = 0
        RETURN
      ENDIF
    ENDIF
 For NULL = ANY option:
    IF (NULL .EQ. 1) THEN
      If pixel is zero in any elements, set class = 0, exit:
      ZERO = NO
      DO 4 BAND=0, NBANDS-1, 1
          IF (BUF(COL,BAND) .EQ. 0) THEN
            ZERO = YES
          ENDIF
      CONTINUE
      IF (ZERO .EQ. YES) THEN
        MDM = 0
        RETURN
      ENDIF
    ENDIF

    /* Set initially unclassified */
    OUTCLS = 0
    /* set initial minimum distance to something large */
    MIN = 1.0E10
    DO 10 SET=1, NSETS, 1
      /* distsq is squared distance from mean of set to point */
      DISTSQ = 0
      BAND = 0
      Simulated WHILE loop:
      IF (BAND .GE. NBANDS) THEN
        GOTO 15
      ELSE
        D(BAND) = SMEAN(BAND,SET) - BUF(COL,BAND)
        IF (D(BAND)+DISTSQ .GT. MIN) THEN
          BAND = NBANDS
        ELSE
          DISTSQ = D(BAND)*D(BAND) + DISTSQ
          IF (DISTSQ .GT. MIN) THEN
              BAND = NBANDS
          ELSEIF (BAND .EQ. NBANDS-1) THEN
              /* set new min distance to beat */
              MIN = DISTSQ
              OUTCLS = SET
            ENDIF
          ENDIF
          BAND = BAND + 1
        ENDIF
        GOTO 20
15     CONTINUE
10    CONTINUE
      MDM = OUTCLS
      RETURN
      END


C ================================================================*/
C         DIVERG
C  This routine calculates the divergence and Transformed Divergance
C  for every possible combination of classes.  The divergence is an
C  indicator of seperability between two classes.
C
C  Formula is adapted from "Introductory Digital Image Processing",
C  Jensen, 1986.
C
C  Subroutines DIVERG uses:
C                              MMULT    - Multiply two matrices.
C                              MINV     - Invert matrix.
C                              MADD     - Add or subract two matrices.
C                              MTRACE   - trace of matrix.
C                              MTRANS   - transpose matrix.
C                              MDET     - determinant of matrix.
C                              LUDCMP   - LU decompostion, used by MDET.
C ----------------------------------------------------------------*/
      SUBROUTINE DIVERG(COVAR,SMEAN,SCOUNT,NBANDS,CLASES,DIV,TDIV,CORRE)
      PARAMETER (MXBNDS=7)
      PARAMETER (MAXRC=3584)
      PARAMETER (MXCLAS=300)
      PARAMETER (NEG8 = -8.0)
      PARAMETER (YES=-1)
      PARAMETER (NO=0)
      IMPLICIT CHARACTER*12 (C)
      IMPLICIT REAL*8 (T)
      IMPLICIT REAL*8 (S)
      INTEGER H,I,J,K,B1,B2, BAND, NBANDS, NBM1, CLASES, BCOMP
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS)
      REAL*8  COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
      REAL*8  CORRE(0:MXCLAS,0:MXBNDS,0:MXBNDS)
      REAL*8  DIV(0:MXCLAS,0:MXCLAS), SUM1, SUM2
      REAL*8  TDIV(0:MXCLAS,0:MXCLAS)
      REAL*8  SCOUNT(0:MXCLAS), DET1, DET2
      REAL*8  TCVB1(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TCVB2(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TCVIB1(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TCVIB2(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TEMP1(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TEMP2(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TEMP3(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TEMP4(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  SB1(0:MXBNDS-1,0:0), SB2(0:MXBNDS-1,0:0)
      REAL*8  STEMP1(0:MXBNDS-1,0:0), STEMP2(0:0,0:MXBNDS-1)
      REAL*8  TCORR1(0:MXBNDS-1,0:MXBNDS-1)
      REAL*8  TCORR2(0:MXBNDS-1,0:MXBNDS-1)
      INTEGER B1BNDS,B2BNDS,BADB1(0:MXBNDS-1),BADB2(0:MXBNDS-1)
      CHARACTER*70 CMES
      CHARACTER*7 TABFIL
      COMMON/TFILE/ LOGFIL
C-----------------------------------------------
C   Simple calculation if only one band in analysis:
```

```
    IF (NBANDS .EQ. 1) THEN
      DO 5 B1 = 1, CLASES
        DO 15 B2 = 1, B1
          IF (COVAR(B1,0,0) .NE. 0 .AND.
C             COVAR(B2,0,0) .NE. 0) THEN
            DIV(B1,B2) = (COVAR(B1,0,0)-COVAR(B2,0,0))*
C                        (1./COVAR(B1,0,0)-1./COVAR(B2,0,0)) +
C                        ((1./COVAR(B1,0,0)+1./COVAR(B2,0,0))*
C                        (SMEAN(0,B1)-SMEAN(0,B2))**2)
            DIV(B1,B2) = DIV(B1,B2)/2.
          ELSE
            DIV(B1,B2) = 0.
          ENDIF
          TDIV(B1,B2) = 2000 - 2000.*(EXP(DIV(B1,B2)/NEG8))
          IF (B2 .NE. B1) DIV(B2,B1) = DIV(B1,B2)
          IF (B2 .NE. B1) TDIV(B2,B1) = TDIV(B1,B2)
        CONTINUE
      CONTINUE
      RETURN
    ENDIF

  Initialize Output matrices DIV and TDIV:
    DO 10 I= 0, MXCLAS
      DO 20 J= 0, MXCLAS
        DIV(I,J) = 0
        TDIV(I,J) = 0
      CONTINUE
    CONTINUE

 Loop over all possible band combinations, get elements of DIV:
    DO 30 B1 = 1, CLASES
      NBM1 = NBANDS-1
      TDIV(B1,B1) = 0.0
      IF (SCOUNT(B1) .GT. 0) THEN
        Handle data dropout in individual bands:
        Run check to see if one or more of B1's bands have mean 0:
        B1BNDS = NBANDS
        DO 200 I = 0, NBM1
          IF (SMEAN(I,B1) .EQ. 0) THEN
            B1BNDS = B1BNDS-1
            BADB1(I) = YES
          ELSE
            BADB1(I) = NO
          ENDIF
0       CONTINUE
        Copy class B1's mean and covariance matrix:
        K = 0
        DO 34 I = 0, NBM1
             IF (BADB1(I) .EQ. NO) THEN
                 SB1(K,0) = SMEAN(I,B1)
                 H = 0
                 DO 44 J = 0, NBM1
                    IF (BADB1(J) .EQ. NO) THEN
                      TCVB1(K,H) = COVAR(B1,I,J)
                      TCORR1(K,H) = CORRE(B1,I,J)
                      H = H + 1
                    ENDIF
                 CONTINUE
                 K = K + 1
             ENDIF
        CONTINUE
      ENDIF
      DO 40 B2 = 1, B1-1

----------
```

```
C Information printouts:
C             WRITE(CMES,'(A9,I3,A6,I3)') 'Comparing',B1,' with ',B2
C                   CALL SDEST(CMES,0)
C                   CALL FDEST(LOGFIL,CMES)
C-----------------------

          IF (SCOUNT(B1) .GT.0 .AND. SCOUNT(B2) .GT. 0) THEN
C          Run check to see if one or more of B2's bands have mean 0:
           B2BNDS = NBANDS
           DO 210 I = 0, NBM1
             IF (SMEAN(I,B2) .EQ. 0) THEN
               B2BNDS = B2BNDS-1
               BADB2(I) = YES
             ELSE
               BADB2(I) = NO
             ENDIF
210         CONTINUE
C          Only compare classes if they have the same mean 0 bands:
           IF (B2BNDS .EQ. B1BNDS) THEN
             BCOMP = YES
             DO 220 I = 0, B1BNDS - 1
               IF (BADB1(I) .NE. BADB2(I)) BCOMP=NO
220          CONTINUE
           ENDIF
           IF (BCOMP .EQ. NO .OR. B2BNDS .NE. B1BNDS) THEN
             TDIV(B1,B2) = 2000.0
             GOTO 999
           ENDIF

C          Copy class B2's mean and covariance matrix:
           NBM1 = B1BNDS - 1
           K = 0
           DO 36 I = 0, NBANDS - 1
                IF (BADB2(I) .EQ. NO) THEN
                    SB2(K,0) = SMEAN(I,B2)
                    H = 0
                    DO 46 J = 0, NBANDS - 1
                       IF (BADB2(J) .EQ. NO) THEN
                         TCVB2(K,H) = COVAR(B2,I,J)
                         TCORR2(K,H) = CORRE(B2,I,J)
                         H = H + 1
                       ENDIF
46                  CONTINUE
                    K = K + 1
                ENDIF
36         CONTINUE

C       Simple calculation if only one non-zero band in analysis:
           IF (B1BNDS .EQ. 1) THEN
             IF (TCVB1(0,0) .NE. 0 .AND. TCVB2(0,0) .NE. 0) THEN
                  DIV(B1,B2) = (TCVB1(0,0)-TCVB2(0,0))*
C                              (1./TCVB1(0,0)-1./TCVB2(0,0)) +
C                              ((1./TCVB1(0,0)+1./TCVB2(0,0))*
C                              (SB1(0,0)-SB2(0,0))**2)
                  DIV(B1,B2) = DIV(B1,B2)/2.
             ELSE
                  DIV(B1,B2) = 0.
                  TDIV(B1,B2) = 0.
             ENDIF
             TDIV(B1,B2) = 2000 - 2000.*(EXP(DIV(B1,B2)/NEG8))
             GOTO 999
           ENDIF

C          Assemble the 5 individual parts, combine:
             CALL MDET(TCVB1,B1BNDS,DET1,MXBNDS)
```

```
          CALL MDET(TCVB2,B1BNDS,DET2,MXBNDS)
   Check if there is no inverse to covar. matrices by checking if
   determinant is 0:
          IF (DET2 .LT. 0.001 .AND. DET2 .GT. -0.001) THEN
              WRITE(CMES,'(A48,1X,I5,F9.5)')
     C         'Found a singular covariance matrix, class ',B2,DET2
                 CALL SDEST(CMES,0)
                 CALL FDEST(LOGFIL,CMES)
              DIV(B1,B2) = 0.
              TDIV(B1,B2) = 0.
              GOTO 999
          ELSE
            IF (DET1 .LT. 0.001 .AND. DET1 .GT. -0.001) THEN
              WRITE(CMES,'(A48,1X,I5,F9.5)')
     C         'Found a singular covariance matrix, class ',B1,DET1
                 CALL SDEST(CMES,0)
                 CALL FDEST(LOGFIL,CMES)
               DIV(B1,B2) = 0.
               TDIV(B1,B2) = 0.
               GOTO 999
            ELSE
              CALL MINV(TCVB1,B1BNDS,TCVIB1,MXBNDS)
              CALL MINV(TCVB2,B1BNDS,TCVIB2,MXBNDS)
            ENDIF
          ENDIF

          CALL MADD(TCVB1,TCVB2,TEMP1,B1BNDS,B1BNDS,-1,MXBNDS,
     C              MXBNDS)
          CALL MADD(TCVIB2,TCVIB1,TEMP2,B1BNDS,B1BNDS,-1,MXBNDS,
     C              MXBNDS)
          CALL MMULT(TEMP1,TEMP2,TEMP3,B1BNDS,B1BNDS,B1BNDS,MXBNDS,
     C              MXBNDS,MXBNDS)
          CALL MTRACE(TEMP3,B1BNDS,SUM1,MXBNDS)
          CALL MADD(TCVIB1,TCVIB2,TEMP1,B1BNDS,B1BNDS,1,MXBNDS,MXBNDS)
          CALL MADD(SB1,SB2,STEMP1,B1BNDS,1,-1,MXBNDS,1)
          CALL MTRANS(STEMP1,STEMP2,B1BNDS,1,MXBNDS,1)
          CALL MMULT(STEMP1,STEMP2,TEMP2,B1BNDS,1,B1BNDS,MXBNDS,
     C              1,MXBNDS)
          CALL MMULT(TEMP1,TEMP2,TEMP3,B1BNDS,B1BNDS,B1BNDS,
     C              MXBNDS,MXBNDS,MXBNDS)
          CALL MTRACE(TEMP3,B1BNDS,SUM2,MXBNDS)
          DIV(B1,B2) = (SUM1+SUM2)/2
         Develop Transformed Divergence TDIV from DIV:
          TDIV(B1,B2) = 2000 - 2000.*EXP(DIV(B1,B2)/NEG8)
9         CONTINUE

-----------------------
Information printouts:
         WRITE(CMES,'(A15,1X,I5)') 'Covar matrix:', B1
              CALL SDEST(CMES,0)
              CALL FDEST(LOGFIL,CMES)
         DO 609 I = 0, NBM1
          WRITE(CMES,'(10(F9.2,1X))') (TCVB1(I,J), J=0,NBM1)
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
09       CONTINUE
         WRITE(CMES,'(A15,1X,I5)') 'Covar matrix:', B2
              CALL SDEST(CMES,0)
              CALL FDEST(LOGFIL,CMES)
         DO 669 I = 0, NBM1
          WRITE(CMES,'(10(F9.2,1X))') (TCVB2(I,J), J=0,NBM1)
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
69       CONTINUE
              WRITE(CMES,'(A4,I3,A1,I3,A3,F9.3)') 'Div(',B1,',',B2,
C     C               '): ', DIV(B1,B2)
C                    CALL SDEST(CMES,0)
C                    CALL FDEST(LOGFIL,CMES)
C                 WRITE(CMES,'(A5,I3,A1,I3,A3,F8.3)') 'TDiv(',B1,',',
C     C                B2,'): ', TDIV(B1,B2)
C                    CALL SDEST(CMES,0)
C                    CALL FDEST(LOGFIL,CMES)
C-----------------------

C          Fill upper corner of DIV (symmetric):
            DIV(B2,B1) = DIV(B1,B2)
            TDIV(B2,B1) = TDIV(B1,B2)
          ELSE
C          No counts in class, can't have a divergence:
            DIV(B1,B2) = 0
            TDIV(B1,B2) = 0
            DIV(B2,B1) = 0
            TDIV(B2,B1) = 0
          ENDIF
40      CONTINUE
30    CONTINUE
      RETURN
      END


C ---------------------------------------------------------------------
C           MADD
C  Adds MAT1+MAT2 to get MATOUT if SIGN=1
C  Subtracts MAT1-MAT2 to get MATOUT if SIGN=-1
C  Working part of Matrices are NR rows and NC cols, starting at zero.
C  Matrices are dimensioned PR rows and PC cols in size.
C ---------------------------------------------------------------------
      SUBROUTINE MADD(MAT1,MAT2,MATOUT,NR,NC,SIGN,PR,PC)
      REAL*8 MAT1(0:PR-1,0:PC-1), MAT2(0:PR-1,0:PC-1)
      REAL*8 MATOUT(0:PR-1,0:PC-1)
      INTEGER NR, NC, SIGN, I, J, PR, PC
      DO 10 I=0,NR-1
        DO 20 J=0,NC-1
          MATOUT(I,J) = MAT1(I,J)+SIGN*MAT2(I,J)
20      CONTINUE
10    CONTINUE
      RETURN
      END
C ---------------------------------------------------------------------
C           MTRACE
C  Finds the trace of MAT1, that is, the sum of the diagonal elements.
C  Matrices are dimensioned PR rows and PR cols in size.
C ---------------------------------------------------------------------
      SUBROUTINE MTRACE(MAT1,NR,TRACE,PR)
      REAL*8 MAT1(0:PR-1,0:PR-1)
      INTEGER NR, NC, I, J, PR, PC
      REAL*8 TRACE
      TRACE= 0.0
      DO 10 I=0,NR-1
        TRACE = TRACE + MAT1(I,I)
10    CONTINUE
      RETURN
      END
C ---------------------------------------------------------------------
C           MTRANS
C  Makes a transpose of MAT1, NR by NC, in MAT2 NC by NR.
C  MAT1 is dimensioned PR rows and PR cols in size.
C ---------------------------------------------------------------------
      SUBROUTINE MTRANS(MAT1,MAT2,NR,NC,PR,PC)
      REAL*8 MAT1(0:PR-1,0:PC-1), MAT2(0:PC-1,0:PR-1)
```

```
      INTEGER NR, NC, I, J, PR, PC
      DO 10 I=0,NR-1
        DO 20 J=0,NC-1
          MAT2(J,I) = MAT1(I,J)
0       CONTINUE
0     CONTINUE
      RETURN
      END
C=====================================================================
C           MMULT
C  Multiply(MA,MB,MC,n,m,p)  Multiplies matrix MA (n rows by m cols)
C  by matrix MB (m rows by p cols) to get matrix
C  MC (n rows by p cols).
C  Matrices are zero indexed.
C  Matrices are dimensioned PN, PM, and PP in size.
C---------------------------------------------------------------------
      SUBROUTINE MMULT(MA,MB,MC,N,M,P,PN,PM,PP)
      REAL*8 MC(0:PN-1,0:PP-1),MA(0:PN-1,0:PM-1)
      REAL*8 MB(0:PM-1,0:PP-1)
      INTEGER I,J,K,N,M,P,PN,PM,PP
      DO 10 I=0, N-1, 1
        DO 20 J=0, P-1, 1
         MC(I,J) = 0.0
          DO 30 K=0, M-1, 1
            MC(I,J)= MC(I,J) + MA(I,K) * MB(K,J)
0         CONTINUE
0       CONTINUE
0     CONTINUE
      RETURN
      END
C=====================================================================
C      MINV
C                         Invert(A,n,B)
C              Inverts matrix A  (square, n row, n col, zero indexed)
C                 into matrix B (same dimensions).
C  Matrices are dimensioned PR rows and PR cols in size.
C---------------------------------------------------------------------
      SUBROUTINE MINV(A,N,B,PR)
      REAL*8 A(0:PR-1,0:PR-1), B(0:PR-1,0:PR-1)
      INTEGER I,J,K,N,PR
C N is size of matrix (square).
C B starts as temporary matrix for putting A into.
C ( because the input matrix is destroyed. )
      DO 10 I = 0, N-1, 1
        DO 20 K = 0, N-1, 1
          B(I,K) = A(I,K)
0       CONTINUE
0     CONTINUE
      DO 30 K = 0, N-1, 1
        DO 40 J = 0, N-1, 1
          IF (J .NE. K)  B(K,J) = B(K,J)/B(K,K)
0       CONTINUE
        B(K,K) = 1./B(K,K)
       DO 50 I = 0, N-1, 1
          IF (I .NE. K) THEN
            DO 60 J = 0, N-1, 1
              IF (J .NE. K)  B(I,J) = B(I,J) - B(I,K)*B(K,J)
0           CONTINUE
            B(I,K) =  -1.*B(I,K)*B(K,K)
          ENDIF
0       CONTINUE
0     CONTINUE
      RETURN
      END
```

```
C=====================================================================
C      MDET
C                          MDET(A,n,B)
C        Determinant of matrix A  (square, n row, n col, zero indexed)
C        Returns B, the determinant of A.
C  Matrices are dimensioned PR rows and PR cols in size.
C  MDET calls LUDCMP routine.
C---------------------------------------------------------------------
      SUBROUTINE MDET(A,N,B,PR)
      PARAMETER (MXBNDS=7)
      REAL*8 A(0:PR-1,0:PR-1), B
      REAL*8 C(MXBNDS,MXBNDS),INDX(MXBNDS)
      INTEGER I,J,K,N,PR
C N is size of matrix (square).
C C starts as temporary matrix for putting A into.
C ( because the input matrix is destroyed. )
      MAX = 0.
      DO 10 I = 0, N-1, 1
        DO 20 K = 0, N-1, 1
          C(I+1,K+1) = A(I,K)
          IF (A(I,K) .GT. MAX) MAX = A(I,K)
20      CONTINUE
10    CONTINUE
      IF (MAX .EQ. 0.) THEN
        B = 0
      ELSE
        CALL LUDCMP(C,N,MXBNDS,INDX,B)
        DO 30 K = 1, N, 1
          B = B * C(K,K)
30      CONTINUE
      ENDIF
      RETURN
      END

C=====================================================================
C   LUDCMP
C
C   Computes LU decomposition of a matrix.
C   From "Numerical Recipes", Press, Flannery et al. Cambridge
C   University Press, Oxford.
C---------------------------------------------------------------------
      SUBROUTINE LUDCMP(A,N,NP,INDX,D)
      PARAMETER (NMAX=100,TINY=1.0E-20)
      REAL*8 A(NP,NP),INDX(N),VV(NMAX), D
      INTEGER NP
      D=1.
      DO 12 I=1,N
        AAMAX=0.
        DO 11 J=1,N
          IF (ABS(A(I,J)).GT.AAMAX) AAMAX=ABS(A(I,J))
11      CONTINUE
        IF (AAMAX.EQ.0.) PAUSE 'Singular matrix.'
        VV(I)=1./AAMAX
12    CONTINUE
      DO 19 J=1,N
        IF (J.GT.1) THEN
          DO 14 I=1,J-1
            SUM=A(I,J)
            IF (I.GT.1)THEN
              DO 13 K=1,I-1
                SUM=SUM-A(I,K)*A(K,J)
13            CONTINUE
              A(I,J)=SUM
            ENDIF
```

```
4         CONTINUE
        ENDIF
        AAMAX=0.
        DO 16 I=J,N
          SUM=A(I,J)
          IF (J.GT.1)THEN
            DO 15 K=1,J-1
              SUM=SUM-A(I,K)*A(K,J)
5           CONTINUE
            A(I,J)=SUM
          ENDIF
          DUM=VV(I)*ABS(SUM)
          IF (DUM.GE.AAMAX) THEN
            IMAX=I
            AAMAX=DUM
          ENDIF
6       CONTINUE
        IF (J.NE.IMAX)THEN
          DO 17 K=1,N
            DUM=A(IMAX,K)
            A(IMAX,K)=A(J,K)
            A(J,K)=DUM
7         CONTINUE
          D=-D
          VV(IMAX)=VV(J)
        ENDIF
        INDX(J)=IMAX
        IF(J.NE.N)THEN
          IF(A(J,J).EQ.0.)A(J,J)=TINY
          DUM=1./A(J,J)
          DO 18 I=J+1,N
            A(I,J)=A(I,J)*DUM
8         CONTINUE
        ENDIF
9     CONTINUE
      IF(A(N,N).EQ.0.)A(N,N)=TINY
      RETURN
      END




C=====================================================================*/
      SIGOUT

      Function to save signature classes data with means of sets,
      and covariances.

      Note that a stretch factor of 2 has been used throughout this
      program because of the 7 bit nature of the color display.

      McIDAS LWFILE operations are not used due to their tendancy
      to append unwanted data at EOF.  Unit 19 is used to write
      the .SIG signature file.

C---------------------------------------------------------------------*/
      SUBROUTINE SIGOUT(OTAREA,NBANDS,MAX,SMEAN,SCOUNT,DBARJ,STDIJ,
     C                  STMAXJ,CLASES,BNDLOC,COVAR)
      IMPLICIT CHARACTER*12 (C)
      PARAMETER (MXBNDS=7)
      PARAMETER (MXCLAS=300)
      PARAMETER (STRETCH=2)
      CHARACTER*70 CMES
      REAL*8  COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
      REAL*8  STDIJ(0:MXBNDS,0:MXCLAS), STMAXJ(0:MXCLAS)
      REAL*8  SCOUNT(0:MXCLAS)
      REAL*8  DBARJ(0:MXCLAS)
      INTEGER NBANDS, CLASES
      INTEGER MAX(0:MXBNDS)
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS), BNDLOC(0:MXBNDS)
      INTEGER I, BAND, SET, SIZE, ISTRETCH
      INTEGER*4 IAR
      CHARACTER*8 TABFIL
      COMMON/TFILE/ LOGFIL
C  Parameters for enhancement tables:
      DIMENSION IRED(15),IGREEN(15),IBLUE(15)
      DATA IRED/255,0,255,0,255,0,255,255,255,237,0,227,255,0,255/
      CNEWOUT = CFI(OTAREA)
      NBM1 = NBANDS - 1
      ISTRETCH = STRETCH
      TABFIL(1:4) = CNEWOUT(9:12)
      TABFIL(5:8) = '.SIG'
      CALL LWD(TABFIL)
       WRITE(CMES,'(A19,1X,A8)') 'Signature file: ', TABFIL
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A28,1X,I4,A9)') 'Contains signatures for ',
     C       CLASES+1,' Classes'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A45)') 'Class values doubled for 7 bit display.'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)

       WRITE(CMES,'(A8,24X)') TABFIL
        CALL FDEST(TABFIL,CMES)
       WRITE(CMES,'(I3,1X,A10)') CLASES+1, 'Classes '
        CALL FDEST(TABFIL,CMES)
       WRITE(CMES,'(I3,1X,A10)') NBANDS, 'Bands '
        CALL FDEST(TABFIL,CMES)
       WRITE(CMES,'(A29)') '--Max Data values per band--'
        CALL FDEST(TABFIL,CMES)
       WRITE(CMES,'(7(I5,1X))')   (MAX(I),I=0,NBM1)
        CALL FDEST(TABFIL,CMES)


C   Write out smean array to file:
      WRITE(CMES,'(25X,A17)') '---Band Means---'
        CALL FDEST(TABFIL,CMES)
      WRITE(CMES,'(A5,2X,A6,1X,7(3X,A1,I1,A1))')
     C 'Class','Counts', ('(',BNDLOC(I),')',I=0,NBM1)
       CALL FDEST(TABFIL,CMES)
      DO 450 I=0, CLASES, 1
         WRITE(CMES,'(I4,2X,F7.0,7(1X,I5))')
     C   I*ISTRETCH, SCOUNT(I), (SMEAN(BAND,I),BAND=0,NBM1)
         CALL FDEST(TABFIL,CMES)
450    CONTINUE

       WRITE(CMES,'(A28)') 'Class covariance matrices:'
         CALL FDEST(TABFIL,CMES)
         WRITE(CMES,'(I4,A11)') 0, '   (CLASS) '
         CALL FDEST(TABFIL,CMES)
         DO 601 BAND = 0, NBM1
          WRITE(CMES,'(7(F9.3,1X))') (0.0, J=0,NBM1)
            CALL FDEST(TABFIL,CMES)
601      CONTINUE
       DO 595 I = 1, CLASES
         WRITE(CMES,'(I4,A11)') I*ISTRETCH, '   (CLASS) '
         CALL FDEST(TABFIL,CMES)
```

```
        DO 606 BAND = 0, NBM1
         WRITE(CMES,'(7(F9.3,1X))') (COVAR(I,BAND,J), J=0,NBM1)
           CALL FDEST(TABFIL,CMES)
606     CONTINUE
595    CONTINUE

C   Write out stds to file:
      WRITE(CMES,'(27X,A17)') '---Band Stds---'
       CALL FDEST(TABFIL,CMES)
      WRITE(CMES,'(A5,2X,A6,5X,A4,7(3X,A1,I1,A1))')
     C 'Class','Counts','dbar', ('(',BNDLOC(I),')',I=0,NBM1)
       CALL FDEST(TABFIL,CMES)
      DO 455 I=0, CLASES, 1
         WRITE(CMES,'(I4,2X,F8.1,1X,F7.2,7(1X,F5.1))') I*ISTRETCH,
     C    SCOUNT(I), DBARJ(I), (STDIJ(BAND,I),BAND=0,NBM1)
         CALL FDEST(TABFIL,CMES)
155    CONTINUE

      RETURN
      END
```

```
      SUBROUTINE MAIN0
C=====================================================================
C ?    MDCLAS -- SPECTRALLY CLASSIFY A MULTI-BAND IMAGE
C ?       --- MDM CLASSIFICATION USING .SIG STATISTICS ---
C ?
C ?                  MDCLAS INAREA OUTAREA SIGAREA
C ?    PARAMETERS:
C ?               INAREA  - AREA TO BE CLASSIFIED
C ?               OUTAREA - FINAL CLASSIFIED AREA WITH N CLASSES.
C ?               SIGAREA - AREA WITH .SIG STATISTICS FILE
C ?
C ?    KEYWORDS:
C ?             BANDS:  NUMBER OF AREA BANDS TO CLASSIFY,
C ?                     DEFAULT IS ALL BANDS IN AREA.
C ?                     USER DEFINES THE BANDS TO USE:
C ?                          BANDS= BAND1 BAND2 ... BANDN
C ?
C ?              NULL:  DATA DROP-OUT DECISION.
C ?                     ANY: CLASSIFY AS ZERO IF ANY BAND IN IMAGE=0.
C ?                     ALL: CLASSIFY AS ZERO IF ALL BANDS = 0.
C---------------------------------------------------------------------
C     This program must be linked with mdsigin.c when compiling.
C---------------------------------------------------------------------
C
C  Written by Gerard Peltzer
C  UW SSEC 5/1/1992
C---------------------------------------------------------------------
C
C
C MXBNDS sets max number of bands allowed in input image:
C MAXRC sets maximum number of rows and cols in image:
C MXCLAS sets maximum number of output data classes:
      PARAMETER (MXBNDS=7)
      PARAMETER (MAXRC=3584)
      PARAMETER (MAXROW=1024)
      PARAMETER (MAXCOL=3584)
      PARAMETER (MXCLAS=127)
      PARAMETER (MXSKIP=8)
      PARAMETER (MDSKIP=4)
C---------------------------------------------------------------------

      IMPLICIT CHARACTER*12 (C)
      IMPLICIT REAL*8 (D)

      CHARACTER*70 CMES, CBLNK
      CHARACTER*8 LOGFIL, SIGFIL
      INTEGER*4 INAREA,OTAREA,SGAREA,TEST
      INTEGER CLASES,NBANDS,BNDLOC(0:MXBNDS)
      INTEGER IDIR(64),ABANDS
      INTEGER NROWS, NCOLS, NULL
      COMMON/TFILE/ LOGFIL

     CALL SDEST('BEGIN: ',0)

     INAREA=IPP(1,0)
     OTAREA=IPP(2,0)
     SGAREA=IPP(3,0)
      IF (INAREA .LE. 0 .OR. INAREA .GT. 50000) THEN
        WRITE(CMES,'(1X,A15,1X,I6)') 'INVALID AREA: ', INAREA
        CALL SDEST(CMES,0)
        RETURN
      ENDIF

C Open output text file, use FDEST routine to print data to logfil:
     CTEMP = CFI(OTAREA)
     LOGFIL(1:4) = CTEMP(9:12)
     LOGFIL(5:8) = '.log'
     CALL LWD(LOGFIL)
     WRITE(CMES,'(A14,1X,A12)') 'SUMMARY FILE ', LOGFIL
      CALL FDEST(LOGFIL,CMES)
      CALL SDEST(CMES,0)
     WRITE(CMES,'(1X,A34)') 'MDCLAS UNSUPERVISED CLASSIFICATION '
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     WRITE(CMES,'(1X,A12,I4)') 'INPUT AREA: ', INAREA
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)

C Set up signature file:
     CTEMP = CFI(SGAREA)
     SIGFIL(1:4) = CTEMP(9:12)
     SIGFIL(5:8) = '.SIG'
     WRITE(CMES,'(1X,A16,1X,A12)') 'STATISTICS FILE ', SIGFIL
      CALL FDEST(LOGFIL,CMES)
      CALL SDEST(CMES,0)

     WRITE(CBLNK,'(A1)') ' '
      CALL SDEST(CBLNK,0)
      CALL FDEST(LOGFIL,CBLNK)
     WRITE(CMES,'(1X,A20)') 'IMAGE CONTENTS '
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)

C Open area to see how big, number of bands:
     CALL HOWBIG(INAREA,NROWS,NCOLS)
     WRITE(CMES,'(1X,A12,I5)') '  ROWS:    ', NROWS
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     WRITE(CMES,'(1X,A12,I5)') '  COLUMNS: ', NCOLS
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     IF ((NROWS .GT. MAXROW) .OR. (NCOLS .GT. MAXCOL)) THEN
       CALL SDEST('AREA TOO BIG TO PROCESS - EXITING!',0)
       CALL FDEST(LOGFIL,CMES)
       RETURN
     ENDIF
     CALL OPNA(INAREA)
     CALL ARAOPT(INAREA,1,'SPAC',4)
     CALL READD(INAREA,IDIR)

     ABANDS= IDIR(14)
     WRITE(CMES,'(1X,A20,I5)') '    BANDS IN AREA: ', ABANDS
      CALL SDEST(CMES,0)
      CALL FDEST(LOGFIL,CMES)
     IF (ABANDS .LT. 1) THEN
       CALL SDEST('NOT ENOUGH BANDS TO PROCESS - EXITING!',0)
       CALL FDEST(LOGFIL,CMES)
       RETURN
     ENDIF
     CALL CLSARA(INAREA)

C Read in bands to use in classification:
     NBANDS=NKWP('BANDS')
     IF (NBANDS .EQ. 0) THEN
       NBANDS = ABANDS
       DO 20 I=1, NBANDS
         BNDLOC(I-1) = I
20     CONTINUE
     ENDIF
     DO 10 I = 1, NBANDS
```

```
      BNDLOC(I-1) = IKWP('BANDS',I,I)
0     CONTINUE
      WRITE(CMES,'(1X,A20,I5)') 'BANDS TO CLASSIFY: ', NBANDS
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      IF (NBANDS .GT. ABANDS) THEN
        WRITE(CMES,'(1X,A40)')
     C    'USER SPECIFIED MORE BANDS THAN EXIST IN AREA'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        RETURN
      ENDIF

Read in type of dropout handling desired in null:
      CNULL=CKWP('NULL',1,'ALL')
Check NULL:
      IF (CNULL .NE. 'ALL' .AND. CNULL .NE. 'ANY') THEN
        WRITE(CMES,'(A40)') ' USER SPECIFIED INVALID NULL PARAMETER'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        CNULL = 'ALL'
        NULL = 0
      ENDIF
      IF (CNULL .EQ. 'ALL') NULL = 0
      IF (CNULL .EQ. 'ANY') NULL = 1
      WRITE(CMES,'(A32,A12)') ' DATA DROPOUT HANDLING USED = ',CNULL
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)


      WRITE(CMES,'(1X,A13,I4)') 'OUTPUT AREA: ', OTAREA
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      WRITE(CBLNK,'(A1)') ' '
       CALL SDEST(CBLNK,0)
       CALL FDEST(LOGFIL,CBLNK)
      WRITE(CMES,'(A20)') 'ENTERING MDCLAS.....'
       CALL SDEST(CMES,0)

Classify the area:
      CALL MDCLAS(INAREA,OTAREA,SGAREA,NBANDS,NROWS,NCOLS,BNDLOC,NULL)

      CALL SDEST('-----DONE----',0)
      CALL FDEST(LOGFIL,'-----DONE----')
      RETURN
      END
```

MDCLAS (MDM CLASSIFIER)

Function to classify image using clustering.

This routine reads in the bands of an image, does a classification, and writes the image to disk.

A list of the important variables used:

buf(N)	The buffer of band N: a row of input data.
outdata	The output data: a row of classifications.
smean(band,set)	The class mean for a set in each band.
clases	The number of classes.

```
C  Routines usclas calls:
C          Function MDM(sets,row,col,buf,smean)
C                              Routine to perform Min. Dist. to Mean
C                              classification. Returns classification
C                              type as an int for pixel in column col.
C
C          Subroutine ENHNCE(IAR,NBANDS,MAX,SMEAN,MXCLAS)
C                              Routine to save enhancement tables with
C                              means of sets.  Saves class means from
C                              bands 1, 2, and 3 as colors for class.
C
C          Subroutine CXCOUT(TDIV,CLASES,MXCLAS)
C                              Routine to print out a square matrix.
C
C          Subroutine SIGIN(SIGFIL,CLASES,SBANDS,SMEAN)
C                              Routine to read in class signatures.
C
C          Subroutine SIGOUT(OTAREA,NBANDS,MAX,SMEAN,SCOUNT,DBARJ,STDIJ,
C                            STMAXJ,CLASES,BNDLOC,COVAR)
C                              Routine to write out class signatures.
C-----------------------------------------------------------------------
       SUBROUTINE MDCLAS(INAREA,OTAREA,SGAREA,NBANDS,NROWS,NCOLS,
      C                  BNDLOC,NULL)

C MXBNDS sets max number of bands allowed in input image.
C MAXRC sets maximum number of rows and cols in image.
C MXCLAS sets maximum number of output data classes.
C THRESH sets default percent change of pixels allowed.
C MXITER set maximum number of allowed iterations.
C MCUTOF is the percent of data for practical lower/upper bounds.
       IMPLICIT CHARACTER*12 (C)
       IMPLICIT REAL*8 (D)
       PARAMETER (MXBNDS=7)
       PARAMETER (MAXRC=3584)
       PARAMETER (MAXROW=1024)
       PARAMETER (MAXCOL=3584)
       PARAMETER (MXCLAS=127)
       PARAMETER (THRESH=4)
       PARAMETER (MINPIX=64)
       PARAMETER (DCUTOF=0.006)
       CHARACTER*70 CMES
       CHARACTER*8 TRLFIL, SIGFIL
       INTEGER    NBANDS, NROWS, NCOLS, BNDLOC(0:MXBNDS), NULL
       INTEGER*4  INAREA,OTAREA,SGAREA, MDM, DATAW, NAV2
       INTEGER*4  OUTDAT(0:MAXRC), OLDOUT(0:MAXCOL,0:MAXROW)
       INTEGER*2  BUF(0:MAXRC,0:MXBNDS), NEWIN(0:MAXRC)
       INTEGER    SMEAN(0:MXBNDS,0:MXCLAS), SMIN(0:MXBNDS)
       INTEGER    NWSMEAN(0:MXBNDS), CLASSP
       INTEGER    IDIR(64),I,J,K,L, ROW, COL, BAND, CLASES
       INTEGER    MXITER, SKIPF, CSKIP, CHECK, NRM1, NCM1, NBM1
       INTEGER    VAL, LEV, STARTI, STARTO, SBANDS
       INTEGER    MEAN(0:MXBNDS), MAX(0:MXBNDS), SMAX(0:MXBNDS)
       REAL*8     NWMEAN(0:MXBNDS), NSMEAN(0:MXBNDS,0:MXCLAS)
       REAL*8     SUM, TOTAL, SCOUNT(0:MXCLAS)
       REAL*8     HIST(0:MXBNDS,0:255)
       COMMON/TFILE/ LOGFIL
C  Statistics variables:
       INTEGER*4  OLDCLS, PREI, PREJ, II, JJ
       INTEGER*4  MINI(0:MXCLAS), MINJ(0:MXCLAS)
       REAL*8     STDIJ(0:MXBNDS,0:MXCLAS), STDMAX, STMAXJ(0:MXCLAS)
       REAL*8     STDAVG, STDMIN, STMINJ(0:MXCLAS)
       REAL*8     DBARJ(0:MXCLAS), DNETJ(0:MXBNDS,0:MXCLAS), DBAR
       REAL*8     SDIST(0:MXCLAS,0:MXCLAS), MINSD, MAXSD
       REAL*8     COVAR(0:MXCLAS,0:MXBNDS,0:MXBNDS)
       REAL*8     CORRE(0:MXCLAS,0:MXBNDS,0:MXBNDS)
```

```
*-------------------------------------------------------


*-------------------------------------------------------
   --- Data File Headers ---
 Open McIDAS areas, set header values for the output file:
    CALL OPNARA(INAREA)
    CALL ARAOPT(INAREA,1,'SPAC',2)
    CALL READD(INAREA,IDIR)
    CALL MOVCW('MDM CLASSIFICATION                ',IDIR(25))
    IDIR(11)= 1
    IDIR(14)= 1
    IDIR(19)= 1
    IDIR(52) = LIT('VISR')
    IDIR(53) = LIT('BRIT')
    DATAW = IDIR(11)
    NAV2 = IDIR(35)
    LEV = IDIR(51)
    IF (IDIR(36) .NE. 0) THEN
      VAL = IDIR(15)-IDIR(49)-IDIR(50)-IDIR(51)
    ELSE
      VAL = 0
    ENDIF
    IDIR(36)= 0
   Define where the start of data is in input, in bytes:
    STARTI = IDIR(15)
   Do not copy DOC, CAL to output:
    STARTO = 0
    IDIR(50) = 0
    IDIR(49) = 0
   Modify LEV section to read just one band in new area:
    IDIR(51) = 0
    IDIR(15) = STARTO
    IF (STARTI .LT. 0) STARTI=0
   Start position in int*2 is half of bytes:
    STARTI = STARTI/2
   Copy navigation from input area to the output area:
    CALL MAKARA(OTAREA,IDIR)
    IF (NAV2 .GT. 0) THEN
      CALL ARAGET(INAREA,NAV2,256,NAVARR)
      CALL ARAPUT(OTAREA,NAV2,256,NAVARR)
    ENDIF
    CALL OPNARA(OTAREA)
-------------------------------------------------------

--- .SIG file read ---
    WRITE(CMES,'(70A1)') (' ', I = 1, 70)
     CALL FDEST(LOGFIL,CMES)
     CALL SDEST(CMES,0)
Set up signature file:
    CTEMP = CFI(SGAREA)
    SIGFIL(1:4) = CTEMP(9:12)
    SIGFIL(5:8) = '.SIG'
 Clear counts and means of classes:
      SBANDS = NBANDS
      NBM1 = NBANDS - 1
      DO 95 I=0, MXCLAS, 1
        SCOUNT(I)=0
        DO 105 BAND=0, NBM1, 1
          NSMEAN(BAND,I) = 0
           SMEAN(BAND,I) = 0
5       CONTINUE
      CONTINUE

 Call .SIG file to read means:
        CALL SIGIN(SIGFIL,CLASES,SBANDS,SMEAN)
        IF (NBANDS .GT. SBANDS) THEN
          WRITE(CMES,'(A59)')
     C     'CLASSIFIER NEEDS MORE BANDS THAN AVAILABLE'
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          RETURN
        ENDIF
        IF (CLASES .LT. 1 ) THEN
          WRITE(CMES,'(A39)') 'SIGNATURE READ ERROR (NO CLASSES)!'
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
          RETURN
        ENDIF



C-------------------------------------------------------
C      --- Initial Statistics Extraction ---
C   Find the mean and maximum values for each data band:
C   Find image histogram, get max, min stretching values (smin,smax):
      SKIPF = 1
      CSKIP = 1
      DO 10 I=0, NBANDS, 1
           MEAN(I) = 0
           MAX(I) = 0
           SMIN(I) = 0
           SMAX(I) = 0
           NWMEAN(I) = 0
           DO 15 J = 0, 255
             HIST(I,J) = 0
15         CONTINUE
10    CONTINUE
      NCM1 = NCOLS - 1
      NBM1 = NBANDS - 1
      NRM1 = NROWS - 1
      DO 20 ROW=0, NRM1,  SKIPF
        DO 30 BAND=0, NBANDS-1, 1
C          REDARA(AREA,LINE,STARTELEM,#ELEMENTS,BAND,IARRAY)
           CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
          DO 35 COL= 0, NCM1, SKIPF
           NWMEAN(BAND) = NWMEAN(BAND) + NEWIN(COL)
           IF (MAX(BAND) .LT. NEWIN(COL)) THEN
             MAX(BAND) = NEWIN(COL)
           ENDIF
           HIST(BAND,NEWIN(COL)/(255**(DATAW-1))) =
     C                HIST(BAND,NEWIN(COL)/(255**(DATAW-1))) + 1
35        CONTINUE
30      CONTINUE
20    CONTINUE
      DO 50 BAND=0, NBM1, 1
        MEAN(BAND) = SKIPF**2*(NWMEAN(BAND)/(NCOLS*NROWS))
        WRITE(CMES,51)       'MEAN OF BAND ',BAND+1,'(',
     C                       BNDLOC(BAND),')',MEAN(BAND)
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,51) 'MAX OF BAND  ',BAND+1,'(',
     C                     BNDLOC(BAND),')',MAX(BAND)
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
C    Use histogram to find a minimum for stretching:
           J = 0
           SUM = 0
55         CONTINUE
           SUM = SUM + HIST(BAND,J)
```

```
          IF (J .GE. 255) THEN
            SMIN(BAND) = 0
            GOTO 56
          ENDIF
          IF (SUM .LE. (NROWS*NCOLS)*DCUTOF/SKIPF) THEN
            J = J + 1
            GOTO 55
          ENDIF
          SMIN(BAND) = J
  Use histogram to find a maximum for stretching:
          J = 255
          SUM = 0
          CONTINUE
          SUM = SUM + HIST(BAND,J)
          IF (J .LE. 0) THEN
            SMAX(BAND) = 0
            GOTO 57
          ENDIF
          IF (SUM .LE. (NROWS*NCOLS)*DCUTOF/SKIPF) THEN
            J = J - 1
            GOTO 57
          ENDIF
          SMAX(BAND) = J
          WRITE(CMES,'(F6.2,A21,1X,I5)') DCUTOF*100,
     C                  '% data lower bound:',SMIN(BAND)
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(F6.2,A21,1X,I5)') (1-DCUTOF)*100,
     C                  '% data upper bound:',SMAX(BAND)
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)

        CONTINUE
          FORMAT(1X,A14,I2,1X,A1,I1,A1,2X,I7)
*-------------------------------------------------------*/



  Start loop over rows and columns, convert input to output:
      DO 60 ROW=0, NRM1, CSKIP
        DO 70 BAND=0, NBM1,1
           function redara(AREA,LINE,STARTELEM,#ELEMENTS,BAND,IARRAY)
           CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
           DO 75 COL=0, NCM1, CSKIP
              BUF(COL,BAND) = NEWIN(COL)
           CONTINUE
        CONTINUE

 Classify:
        DO 80 COL=0, NCM1, CSKIP
          OUTDAT(COL)= MDM(CLASES,ROW,COL,NBANDS,BUF,SMEAN,NULL)
        CONTINUE

 Develop new smean and point count for data:
        DO 110 COL=0, NCM1, CSKIP
          DO 120 BAND=0, NBM1, 1
             NSMEAN(BAND,OUTDAT(COL))= NSMEAN(BAND,OUTDAT(COL))+
     C                                  BUF(COL,BAND)
0         CONTINUE
          SCOUNT(OUTDAT(COL)) = SCOUNT(OUTDAT(COL))+1
0       CONTINUE

   Save to array:
        DO 135 COL=0, NCM1, 1
          OLDOUT(COL,ROW) = OUTDAT(COL)
```

```
135         CONTINUE


60      CONTINUE


C   Write out smeans used in classification to screen:
      WRITE(CMES,'(A38)') 'Cluster means used in classification: '
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A34)') '                    ---Band Means---'
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      WRITE(CMES,'(A13,5X,7(A1,I1,A1,3X))') 'Class  Counts',
     C                          ('(',BNDLOC(I),')',I=0,NBM1)
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
      DO 137 I=0, CLASES, 1
        WRITE(CMES,'(I3,2X,F8.1,1X,7(1X,I5))') I,SCOUNT(I)*(CSKIP**2),
     C          (SMEAN(BAND,I),BAND=0,NBM1)
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
137     CONTINUE



C-------------------------------------------------------
C  Some definitions:
C  STDIJ(BAND,CLASS)    Std deviation of each class, for each band.
C  STMAXJ(CLASS)        The maximum Std deviation for each class.
C  STMINJ(CLASS)        The minimum Std deviation for each class.
C  STDMAX               The maximum Std deviation for all classes.
C  STDMIN               The minimum Std deviation for all classes.
C  STDAVG               The average Std deviation for all classes.
C  DNETJ(BAND,CLASS)    The average distance of samples in each class from
C                       the class mean, for each band.
C  DBARJ(CLASS)         The average distance of samples from their means.
C  DBAR                 Overall average distance of samples from their means.
C  SDIST(1,2)           Spectral distance between means of classes 1 and 2.
C  MINSD, MAXSD         The smallest and largest SDISTs.
C  COVAR(CLASS,1,2)     Set of CLASS covariance matrices.
C  CORRE(CLASS,1,2)     Set of CLASS correlation matrices.
C------------------

C---------------------------------------------
C   Extract the class statistics:
C      Initialize variables:
        DBAR = 0
        STDAVG = 0
        STDMAX = 0
        STDMIN = 100000
        DO 225 I = 0, MXCLAS, 1
          DBARJ(I) = 0
          STMAXJ(I) = 0
          STMINJ(I) = 100000
          DO 235 J = 0, MXCLAS, 1
            SDIST(I,J) =  0
235       CONTINUE
          DO 215 BAND=0, NBM1,1
            DNETJ(BAND,I) = 0
            STDIJ(BAND,I) = 0
            DO 245 J=0, NBM1,1
              COVAR(I,BAND,J) = 0
245       CONTINUE
215       CONTINUE
```

```
5     CONTINUE
        Find pairwise cluster distances:
        DO 320 I=0, CLASES-1, 1
          MINI(I) = 0
          MINJ(J) = 0
          DO 330 J=I+1, CLASES, 1
            DO 340 BAND=0, NBM1, 1
              SDIST(I,J) =SDIST(I,J)+(SMEAN(BAND,I)-SMEAN(BAND,J))**2
0           CONTINUE
            SDIST(I,J) = SQRT(SDIST(I,J))
0         CONTINUE
0       CONTINUE
        MINJ(CLASES) = 0
      Loop over rows and columns, compute dbar, stds:
      Develop average distance of samples from cluster centers:
       DO 210 ROW=0, NRM1, CSKIP
         DO 220 BAND=0, NBM1,1
           CALL REDARA(INAREA,ROW,0,NCOLS,BNDLOC(BAND),NEWIN)
            DO 230 COL=0, NCM1, CSKIP
             BUF(COL,BAND) = NEWIN(COL)
             DNETJ(BAND,OLDOUT(COL,ROW)) = DNETJ(BAND,OLDOUT(COL,ROW))
     C              + ABS(NEWIN(COL) - SMEAN(BAND,OLDOUT(COL,ROW)))
             STDIJ(BAND,OLDOUT(COL,ROW)) = STDIJ(BAND,OLDOUT(COL,ROW))
     C              + (ABS(NEWIN(COL)-SMEAN(BAND,OLDOUT(COL,ROW))))**2
0            CONTINUE
0         CONTINUE
      Covariance calculations:
         DO 550 COL=0, NCM1, CSKIP
           DO 560 I=0, NBM1, 1
             DO 570 J=0, I, 1
               IF ( I .NE. J) THEN
                 COVAR(OLDOUT(COL,ROW),I,J)=COVAR(OLDOUT(COL,ROW),I,J)+
     C             (BUF(COL,I)-SMEAN(I,OLDOUT(COL,ROW)))*
     C             (BUF(COL,J)-SMEAN(J,OLDOUT(COL,ROW)))
               ENDIF
0            CONTINUE
0          CONTINUE
0        CONTINUE
0      CONTINUE
    End file read.
      DO 260 I=1, CLASES, 1
          DO 270 BAND=0, NBM1, 1
               Diagonal covariance elements:
               COVAR(I,BAND,BAND) = STDIJ(BAND,I)
           IF (SCOUNT(I) .GT. 1) THEN
             DNETJ(BAND,I) = DNETJ(BAND,I)/SCOUNT(I)
             STDIJ(BAND,I) = SQRT(STDIJ(BAND,I)/(SCOUNT(I)-1))
             STDAVG = STDAVG + STDIJ(BAND,I)
           ELSE
              STDIJ(BAND,I) = 0
           ENDIF
           DBARJ(I) =  DBARJ(I) + DNETJ(BAND,I)**2
           IF (STMAXJ(I) .LT. STDIJ(BAND,I)) STMAXJ(I)=STDIJ(BAND,I)
           IF (STMINJ(I) .GT. STDIJ(BAND,I)) STMINJ(I)=STDIJ(BAND,I)
           Covariance elements:
               DO 580 J=0, BAND, 1
                 IF (SCOUNT(I) .GT. 1) THEN
                   COVAR(I,BAND,J) = COVAR(I,BAND,J)/(SCOUNT(I)-1)
                 ELSE
                   COVAR(I,BAND,J) = 0
                 ENDIF
                 Fill other half of symmetric covariance matrix:
                 IF (J .NE. BAND) COVAR(I,J,BAND) = COVAR(I,BAND,J)
0              CONTINUE
0          CONTINUE
```

```
C            Don't count 0s for STMIN due to 1 pixel classes:
             IF (STDMIN .GT. STMINJ(I) .AND. STMINJ(I) .GT. 0.01)
     C           STDMIN = STMINJ(I)
             IF (STDMAX .LT. STMAXJ(I)) STDMAX = STMAXJ(I)
             DBARJ(I) = SQRT(DBARJ(I))
             DBAR = DBAR + DBARJ(I)*SCOUNT(I)
260       CONTINUE
             DBAR = DBAR*(CSKIP**2)/(NCOLS*NROWS)
             STDAVG = STDAVG/(NBANDS*CLASES)
C-----------------------------------------------

        WRITE(CMES,'(A19)') '  For all classes: '
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A11,F9.2)') 'STDMIN = ',STDMIN
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A11,F9.2)') 'STDMAX = ',STDMAX
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A11,F9.2)') 'STDAVG = ',STDAVG
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A11,F9.2)') '  DBAR = ',DBAR
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)

C-------------------------------------------------

C    Write out smean array to screen:
       WRITE(CMES,'(A34)') 'Adjusted cluster means:'
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(34X,A17)') '---Band Means---'
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A5,2X,A6,2X,A6,2X,A4,7(3X,A1,I1,A1))')
      C 'Class','Counts','Stdmax','Dbar', ('(',BNDLOC(I),')',I=0,NBM1)
        CALL FDEST(LOGFIL,CMES)
       DO 450 I=0, CLASES, 1
          WRITE(CMES,'(I3,2X,F7.0,1X,F7.2,1X,F7.2,7(1X,I5))') I,
      C   SCOUNT(I)*(CSKIP**2), STMAXJ(I), DBARJ(I),
      C   (SMEAN(BAND,I),BAND=0,NBM1)
          CALL FDEST(LOGFIL,CMES)
450    CONTINUE


C    Write out correlation matrix, pairwise distances matrix:
C    Convert covariance to correlation:
       DO 590 I = 1, CLASES
         DO 600 BAND = 0, NBM1
           DO 610 J = 0, BAND
             IF (COVAR(I,BAND,J) .NE. 0 .AND.
     C           STDIJ(BAND,I) .NE. 0 .AND.
     C           STDIJ(J,I) .NE. 0 ) THEN
                CORRE(I,BAND,J) = COVAR(I,BAND,J)/
     C                          (STDIJ(BAND,I)*STDIJ(J,I))
             ELSE
                CORRE(I,BAND,J) = 0
             ENDIF
C            Fill other half of symmetric correlation matrix:
             IF (J .NE. BAND) CORRE(I,J,BAND) = CORRE(I,BAND,J)
610        CONTINUE
600      CONTINUE
590    CONTINUE
         WRITE(CMES,'(A28)') 'Class correlation matrices:'
         DO 595 I = 1, CLASES
```

```
      WRITE(CMES,'(A11,I3)') '   CLASS: ',I
       CALL FDEST(LOGFIL,CMES)
      DO 606 BAND = 0, NBM1
       WRITE(CMES,'(10(F5.3,1X))') (CORRE(I,BAND,J), J=0,NBM1)
         CALL FDEST(LOGFIL,CMES)
6     CONTINUE
5    CONTINUE
     WRITE(CMES,'(A39)') 'Distances between Cluster means:'
      CALL FDEST(LOGFIL,CMES)
      CALL SDEST(CMES,0)
     CALL CXCOUT(SDIST,CLASES,MXCLAS)


  Write file out to output file name
   DO 170 ROW=0, NRM1, 1
       DO 180 COL=0, NCM1,1
         OUTDAT(COL) = OLDOUT(COL,ROW)*2
0      CONTINUE
       CALL PACK(NCOLS,OUTDAT,OUTDAT)
       CALL WRTARA(OTAREA,ROW,OUTDAT)
0   CONTINUE
    CALL STAMP(OTAREA)
    CALL CLSARA(OTAREA)
    CALL CLSARA(INAREA)

Save an enhancement table along with the output image:
          WRITE(CMES,'(A30)') 'OUTPUT COLOR ASSIGNMENTS: '
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(A24,2X,A1,1X,I3,1X,A1)') '  RED FROM BAND 1 ',
  C            '(', BNDLOC(0),')'
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(A24,2X,A1,1X,I3,1X,A1)') 'GREEN FROM BAND 2 ',
  C            '(', BNDLOC(1),')'
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(A24,2X,A1,1X,I3,1X,A1)') ' BLUE FROM BAND 3 ',
  C            '(', BNDLOC(2),')'
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
Write McIDAS .ET color look-up table file:
   CALL ENHNCE(OTAREA,SGAREA,NBANDS,MAX,SMAX,SMIN,SMEAN,CLASES)

   RETURN
   END




==========================================================================*/
         CXCOUT
     Function to write out a triangular CLASES by CLASES matrix
     Matrix elements divided by SIZE in output.
--------------------------------------------------------------------------*/
   SUBROUTINE CXCOUT(RMAT,CLASES,MXCLAS)
   REAL*8  RMAT(0:MXCLAS,0:MXCLAS)
   INTEGER CLASES,I,J,II,JJ,CHECK,SIZE
   INTEGER DMAT(0:20)
   COMMON/TFILE/ LOGFIL
   CHARACTER*70 CMES
Check the maximum digit size of the matrix:
   DO 468 II = 0, CLASES -1
     DO 469 JJ = 0, II
       IF (RMAT(II,JJ) .GT. MAX) MAX=RMAT(II,JJ)
469     CONTINUE
468   CONTINUE
      IF (MAX .GT. 9999) THEN
        SIZE = 10
        WRITE(CMES,'(5X,A24,I3,A1)') '(Value shown = distance/',
     C         SIZE,')'
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
      ELSE
        SIZE = 1
      ENDIF
C  Printout:
      DO 470 II = 0, CLASES/13
        WRITE(CMES,'(A1)') ' '
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        IF (13+13*II .LT. CLASES) THEN
          JJ = 12+13*II
        ELSE
          JJ = CLASES
        ENDIF
        WRITE(CMES,'(A5,13(I3,2X))') 'Clust', (I,I=13*II,JJ)
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        DO 460 I=II*13, CLASES, 1
        IF (I-II*13 .GT. 12) THEN
          CHECK = II*13 + 12
        ELSE
          CHECK = I
        ENDIF
         DO 11 J = II*13,CHECK
           DMAT(J) = RMAT(J,I)/SIZE
11       CONTINUE
         WRITE(CMES,'(I3,1X,13(I4,1X))') I,
     C     (DMAT(J),J=II*13,CHECK)
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
460      CONTINUE
470    CONTINUE
      RETURN
      END



C ==========================================================================*/
C       ENHNCE
C
C       This routine copies the .SIG file .ET color scheme, if present.
C       If not, it generates a new one.
C
C       Function will save enhancement tables with means of sets.
C       Saves class means from bands 1, 2, and 3 as colors for class.
C
C       Note that a stretch factor of 2 has been used throughout this
C       program because of the 7 bit nature of the color display.
C
C       McIDAS LWFILE operations are not used due to their tendancy
C       to append unwanted data at EOF.  Unit 19 is used to write
C       the .ET enhancement table file.
C
C ---------------------------------------------------------------------------*/
      SUBROUTINE ENHNCE(IAR,SGAREA,NBANDS,MAX,SMAX,SMIN,SMEAN,CLASES)
      IMPLICIT CHARACTER*12 (C)
      PARAMETER (MXBNDS=7)
```

```
      PARAMETER (MXCLAS=127)
      PARAMETER (STRETCH=2)
      CHARACTER*70 CMES
      INTEGER NROWS, NCOLS, NBANDS, CLASES, SGAREA
      INTEGER MAX(0:MXBNDS), SMAX(0:MXBNDS), SMIN(0:MXBNDS)
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS)
      INTEGER MNRED(0:MXCLAS), MNGRE(0:MXCLAS),MNBLU(0:MXCLAS)
      INTEGER MXRED, MXGRE,MXBLU
      INTEGER MINRED, MINGRE, MINBLU
      INTEGER I, BAND, SET, TTAB(816), SIZE
      INTEGER*4 IAR
      REAL*4 REDSTR, GRESTR, BLUSTR
      CHARACTER*7 TABFIL
      COMMON/TFILE/ LOGFIL
Parameters for enhancement tables:
      DIMENSION IRED(15),IGREEN(15),IBLUE(15)
      DATA FULL/816/,GRE/256/,BLU/512/,GRED/769/,GGRE/785/,GBLU/801/
      DATA IRED/255,0,255,0,255,0,255,255,255,237,0,227,255,0,255/
      DATA IBLUE/255,255,0,0,0,255,255,203,127,127,255,67,0,115,127/
      DATA IGREEN/0,255,255,255,0,0,255,127,127,0,163,255,127,0,171/

Attempt to read in old .ET file and copy it to output .ET file:
      CTEMP = CFI(SGAREA)
      TABFIL(1:4) = CTEMP(9:12)
      TABFIL(5:7) = '.ET'
      OPEN(UNIT=39,FILE=TABFIL,ACCESS='SEQUENTIAL',FORM='UNFORMATTED',
     C       STATUS='OLD',ERR=99)
      READ(UNIT=39,ERR=99,END=9)   (TTAB(J),J=1,GBLU+14)
      CLOSE(UNIT=39)
      CONTINUE
      IF (J .GE. GBLU+13) THEN
        CNEWOUT = CFI(IAR)
        TABFIL(1:4) = CNEWOUT(9:12)
        TABFIL(5:7) = '.ET'
        CALL LWD(TABFIL)
        OPEN(UNIT=19,FILE=TABFIL,ACCESS='SEQUENTIAL',FORM='UNFORMATTED',
     C         ERR=99)
        WRITE(UNIT=19,ERR=99)   (TTAB(J),J=1,GBLU+14)
        CLOSE(UNIT=19)
        WRITE(CMES,'(A16,1X,A12)') 'STATISTICS FILE ', TABFIL
         CALL FDEST(LOGFIL,CMES)
         CALL SDEST(CMES,0)
        RETURN
      ENDIF

If here, than transferring previous .ET didn't work.  Develop new one:
      CONTINUE
      CNEWOUT = CFI(IAR)
      TABFIL(1:4) = CNEWOUT(9:12)
      TABFIL(5:7) = '.ET'
      CALL LWD(TABFIL)
      WRITE(CMES,'(A31,A9)') 'Building new enhancement file:',TABFIL
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A28,1X,I4,A9)') 'Contains look up table for ',
     C         CLASES+1,' Classes'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)
       WRITE(CMES,'(A45)') 'Class values doubled for 7 bit display.'
        CALL SDEST(CMES,0)
        CALL FDEST(LOGFIL,CMES)


      WRITE(CMES,'(A25)') 'CLASS  RED  GREEN  BLUE '
       CALL SDEST(CMES,0)
       CALL FDEST(LOGFIL,CMES)
       MXRED=0
       MXGRE=0
       MXBLU=0
       DO 10 I = 0, NBANDS-1
         IF (MAX(I) .GT. 255) THEN
           SIZE = 255
          WRITE(CMES,'(A10,I3))') 'Size = ',SIZE
           CALL SDEST(CMES,0)
           CALL FDEST(LOGFIL,CMES)
         ELSE
           SIZE = 1
         ENDIF
10     CONTINUE
       MINRED=255*SIZE
       MINGRE=255*SIZE
       MINBLU=255*SIZE
              MNRED(0) = 0
              MNGRE(0) = 0
              MNBLU(0) = 0
       DO 20 I = 1, CLASES*STRETCH
          J = STRETCH
          IF (MOD(I,J) .EQ. 0) THEN
            J = I/STRETCH
            IF (NBANDS .EQ. 1) THEN
                MNRED(I) = SMEAN(0,J)
                MNGRE(I) = SMEAN(0,J)
                MNBLU(I) = SMEAN(0,J)
                MINRED = SMIN(0)
                MINGRE = SMIN(0)
                MINBLU = SMIN(0)
                MXRED = SMAX(0)
                MXGRE = SMAX(0)
                MXBLU = SMAX(0)
            ELSE IF (NBANDS .EQ. 2) THEN
                MNRED(I) = SMEAN(0,J)
                MNGRE(I) = SMEAN(1,J)
                MNBLU(I) = (SMEAN(0,J)+SMEAN(1,J))/2
                MINRED = SMIN(0)
                MINGRE = SMIN(1)
                MINBLU = (SMIN(0)+SMIN(1))/2
                MXRED = SMAX(0)
                MXGRE = SMAX(1)
                MXBLU = (SMAX(0)+SMAX(1))/2
            ELSE IF (NBANDS .GE. 3) THEN
                MNRED(I) = SMEAN(0,J)
                MNGRE(I) = SMEAN(1,J)
                MNBLU(I) = SMEAN(2,J)
                MINRED = SMIN(0)/2
                MINGRE = SMIN(1)/2
                MINBLU = SMIN(2)/2
                MXRED = SMAX(0)
                MXGRE = SMAX(1)
                MXBLU = SMAX(2)
C  Alternate lower/upper bound scheme: (not used)
C                 IF (MNRED(I) .LT. MINRED) MINRED=MNRED(I)
C                 IF (MNGRE(I) .LT. MINGRE) MINGRE=MNGRE(I)
C                 IF (MNBLU(I) .LT. MINBLU) MINBLU=MNBLU(I)
C                 IF (MNRED(I) .GT. MXRED) MXRED=MNRED(I)
C                 IF (MNGRE(I) .GT. MXGRE) MXGRE=MNGRE(I)
C                 IF (MNBLU(I) .GT. MXBLU) MXBLU=MNBLU(I)
            ENDIF
          ELSE
                MNRED(I) = 0
                MNGRE(I) = 0
```

```
                MNBLU(I) = 0
            ENDIF
        CONTINUE
            WRITE(CMES,'(3(I4,2X))') MINRED,MINGRE,MINBLU
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
            WRITE(CMES,'(3(I4,2X))') MXRED,MXGRE,MXBLU
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
            REDSTR = 255./((MXRED-MINRED)*SIZE)
            GRESTR = 255./((MXGRE-MINGRED)*SIZE)
            BLUSTR = 255./((MXBLU-MINBLU)*SIZE)
        DO 25 I = 1, CLASES*STRETCH
           J = STRETCH
           IF (MOD(I,J) .EQ. 0) THEN
                MNRED(I) = (MNRED(I)-MINRED)*REDSTR
                MNGRE(I) = (MNGRE(I)-MINGRE)*GRESTR
                MNBLU(I) = (MNBLU(I)-MINBLU)*BLUSTR
                IF (MNRED(I) .LT. 0) MNRED(I) = 0
                IF (MNGRE(I) .LT. 0) MNGRE(I) = 0
                IF (MNBLU(I) .LT. 0) MNBLU(I) = 0
                IF (MNRED(I) .GT. 255) MNRED(I) = 255
                IF (MNGRE(I) .GT. 255) MNGRE(I) = 255
                IF (MNBLU(I) .GT. 255) MNBLU(I) = 255
           ELSE
                MNRED(I) = 0
                MNGRE(I) = 0
                MNBLU(I) = 0
           ENDIF
        CONTINUE
        DO 30 I= 0,CLASES*STRETCH
             TTAB(I+1)= MNRED(I)
             TTAB(BLU+I+1)= MNBLU(I)
             TTAB(GRE+I+1)= MNGRE(I)
             WRITE(CMES,'(4(I4,2X))') I,MNRED(I),MNGRE(I),MNBLU(I)
              CALL SDEST(CMES,0)
              CALL FDEST(LOGFIL,CMES)
        CONTINUE
          DO 40 I=0,14
             TTAB(GRED+I)=IRED(I+1)
             TTAB(GGRE+I)=IGREEN(I+1)
             TTAB(GBLU+I)=IBLUE(I+1)
          CONTINUE
    OPEN(UNIT=19,FILE=TABFIL,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
    WRITE(UNIT=19)   (TTAB(J),J=1,GBLU+I)
    CLOSE(UNIT=19)
    RETURN
    END



=================================================================*/
     MDM CLASSIFICATION ROUTINE
 This routine classifies a pixel, given its values in each band and
 its associated statistical data in global arrays

-----------------------------------------------------------------*/
    INTEGER*4 FUNCTION MDM(NSETS, ROW, COL, NBANDS, BUF, SMEAN, NULL)

     PARAMETER (MXBNDS=7)
     PARAMETER (MAXRC=3584)
     PARAMETER (MXCLAS=127)
     PARAMETER (YES=-1)
     PARAMETER (NO=0)
     INTEGER ROW, COL, NBANDS, NSETS, NULL, ZERO
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS)
      INTEGER*2 BUF(0:MAXRC,0:MXBNDS)
C     /* class to be returned     */
      INTEGER*2 OUTCLS
      INTEGER I, J, SET, BAND
C     /* distances to the mean of a set  */
      INTEGER D(MXBNDS)
      REAL*8 DISTSQ, MIN
C/*-----------------------------------------------
C  For NULL = ALL option:
      IF (NULL .EQ. 0) THEN
C       If pixel is zero in all elements, set class = 0, exit:
        ZERO = YES
        DO 5 BAND=0, NBANDS-1, 1
            IF (BUF(COL,BAND) .NE. 0) THEN
              ZERO = NO
            ENDIF
5       CONTINUE
        IF (ZERO .EQ. YES) THEN
          MDM = 0
          RETURN
        ENDIF
      ENDIF
C  For NULL = ANY option:
      IF (NULL .EQ. 1) THEN
C       If pixel is zero in any elements, set class = 0, exit:
        ZERO = NO
        DO 4 BAND=0, NBANDS-1, 1
            IF (BUF(COL,BAND) .EQ. 0) THEN
              ZERO = YES
            ENDIF
4       CONTINUE
        IF (ZERO .EQ. YES) THEN
          MDM = 0
          RETURN
        ENDIF
      ENDIF

C     /* Set initially unclassified */
      OUTCLS = 0
C     /* set initial minimum distance to something large */
      MIN = 1.0E10
      DO 10 SET=1, NSETS, 1
C       /* distsq is squared distance from mean of set to point */
        DISTSQ = 0
        BAND = 0
C       Simulated WHILE loop:
20      IF (BAND .GE. NBANDS) THEN
          GOTO 15
        ELSE
          D(BAND) = SMEAN(BAND,SET) - BUF(COL,BAND)
          IF (D(BAND)+DISTSQ .GT. MIN) THEN
            BAND = NBANDS
          ELSE
            DISTSQ = D(BAND)*D(BAND) + DISTSQ
            IF (DISTSQ .GT. MIN) THEN
                BAND = NBANDS
            ELSEIF (BAND .EQ. NBANDS-1) THEN
C               /* set new min distance to beat */
                MIN = DISTSQ
                OUTCLS = SET
            ENDIF
          ENDIF
          BAND = BAND + 1
        ENDIF
```

```
    GOTO 20
   CONTINUE
  CONTINUE
  MDM = OUTCLS
  RETURN
  END
```

```
/*-------------------------------------------------------------*/
/*              Function MDsigin                               */
/*      This routine reads data from McIDAS .SIG file.         */
/*        To be used with MDCLAS.PGM (McIDAS routine)          */
/*        The arrays are all indexed from 0 to n-1.            */
/*                                                             */
/* Read in Data:                                               */
/*   1) name of sig file                                       */
/*   2) number of classes                                      */
/*   3) number of bands                                        */
/*   4) blank (says "--Max data values--")                     */
/*   5) max-B1 max-B2 ... max-BN                               */
/*   6) blank (says "---BAND MEANS---")                        */
/*   7) blank (says "Class  Counts  " then bands)              */
/*   8) class# counts mean-B1 mean-B2 ... mean-BN              */
/*         C+1 of these...                                     */
/*   8+C+1) blank (says "Class covariance matrices")           */
/*   8+C+2) class#                                             */
/*   8+C+3) COVAR(0,0) COVAR(0,1) ... COVAR(0,N-1)             */
/*            N of these...                                    */
/*    C of these...                                            */
/*-----------------------------------------------             */
/*   Compile with: "fx mdsigin cli"                            */
/*-----------------------------------------------             */
/*  Written by Gerard Peltzer                                  */
/*  UW SSEC, 5/1/1992                                          */
/*-------------------------------------------------------------*/
#include <math.h>
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <malloc.h>
#define INPUTWIDTH 80       /* Number of chars in inputs.      */
#define MXCLAS    127
#define MAXSBD     16
#define MXBNDS      7
#define SUCCESS    -1
#define FAILURE     0
#define YES         1
#define NO          0
#define SBD         8
#define SIG         9
#define HISTBYTES 512*MXBNDS
#define COV       32*MXCLAS

typedef struct Sig{
            char signame[32];
            long scount;
            char blank[92];
            int minvector[MAXSBD];
            int maxvector[MAXSBD];
            int meanvector[MAXSBD];
            float covar[32];
            /*char histo[HISTBYTES];*/
                              } Signature;

typedef struct Sighead{
            char lanname[100];
            int classes;
            int bands;
            char blank[24];
                              } Sbdheader;
```

```
int sigin(char *infile,int *Clases, int *Nbands, int *Smean)
{
      Sbdheader *head, head2;
      Signature class[MXCLAS];
      int i,j,k;
      int clas, clases, nbands, band, eof, *meanptr;
      int max[MAXSBD], min[MAXSBD], smean[MXBNDS][MXCLAS];
      long count[MXCLAS];
      float fcount, fmean, cova[32];
      float *covarm;
      FILE *fpin;
      char *trlptr, nameline[32];
      char dataline[80];
      char firstline[100];
      char moreline[80];
      char line[70];

      char junkfil[8];
      head = &head2;
      if((fpin=fopen(infile,"rt")) == NULL)
      {  printf("\nError opening infile\n");
         return FAILURE;
      }
      fseek(fpin,0L,SEEK_SET);

      i = 0;
      eof = NO;
/* File search:  */
      while (eof == NO)
        {
   /* Header information:    */
          /*  First line  */
        for (i=0; i< 100 ; i++)  firstline[i] = 0;
        for (i=0; i< 100 ; i++)  (*head).lanname[i] = 0;
        if (fgets(firstline,100,fpin) == NULL) eof = YES;     /* 1  */
/*        printf("\nHeader of data file says: ");
        puts(firstline);
        printf("\n");*/
        if ((trlptr=strstr(firstline,".")) != NULL)
        { strcpy(trlptr,"~   "); }
        strcpy((*head).lanname, firstline);

           /*  Classes  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 2  */
        j = sscanf(dataline, "%d ",&clases);
        if  (j < 1 || j == EOF) eof = YES;
        (*head).classes = clases;
        *Clases = clases;

           /*  Bands  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 3  */
        j = sscanf(dataline, "%d ",&nbands);
        if  (j < 1 || j == EOF) eof = YES;
        (*head).bands = nbands;
        *Nbands = nbands;

        for (i=0; i< 24 ; i++)  (*head).blank[i] = 0;


   /* Develop structures for each signature:   */
```

```
    /*  Get Maximum Values  */
  if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 4  */
  for (i=0; i< 80 ; i++)  dataline[i] = 0;
  strcpy(dataline,"\0");
  if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 5  */
  for (i=0; i< MXBNDS ; i++)  max[i] = 0;
  j = sscanf(dataline, "%d %d %d %d %d %d %d",&max[0], &max[1],
    &max[2], &max[3], &max[4], &max[5], &max[6]);
  if  (j < 1 || j == EOF) eof = YES;

    /* 2blank lines */
  if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 6  */
  if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 7  */


    /*  Get Mean Values  */
  for (clas=0; clas<= clases ; clas++)
    {
    for (band=0; band< MXBNDS; band++) smean[band][clas] = 0;
    for (i=0; i< 80 ; i++)  dataline[i] = 0;
    if (fgets(dataline,80,fpin) == NULL) eof = YES;     /* 8>8+C */
    j = sscanf(dataline, "%d %f %d %d %d %d %d %d %d", &i,
        &fcount,&smean[0][clas],&smean[1][clas],
        &smean[2][clas],&smean[3][clas],&smean[4][clas],
        &smean[5][clas],&smean[6][clas]);
    count[clas] = (long)fcount;
    if  (j < 1 || j == EOF) eof = YES;
    }
meanptr = Smean;
    for (clas=0; clas<= clases ; clas++)
    {
    for (i=0; i< MXBNDS+1 ; i++)
      {
      *meanptr = smean[i][clas];
      meanptr++;
      }
    }

    /* 1 blank line */
  if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 8+C+1 */


    /*  Get Covariances  */
  for (clas=0; clas<= clases ; clas++)
    {
      /* 1 blank line */
    if (fgets(dataline,80,fpin) == NULL) eof = YES;     /* 8+C+2 */
    k = 0;
    for (band=0; band< nbands ; band++)
      {
      for (i=0; i< 80 ; i++)  moreline[i] = 0;
      strcpy(moreline,"\0");
      if (fgets(moreline,80,fpin) == NULL) eof = YES;  /* 8+C+3 */
      j = sscanf(moreline, "%f %f %f %f %f %f %f",&cova[0],
      &cova[1],&cova[2],&cova[3],&cova[4],&cova[5],&cova[6]);
      if  (j < 1 || j == EOF) eof = YES;
      if (k > 32)
        { printf("\nError in covar computation!");
          return FAILURE;
        }
      for (i=band; i< nbands ; i++)
        { /* covarm[k+clas*32] = cova[i];*/
          class[clas].covar[k] = cova[i];
          k++;
        }
          }
        }

      eof = YES;
      }

    for (clas=0; clas<= clases ; clas++)
      {
        /*  Name  */
      for (i=0; i< 32 ; i++)  nameline[i] = 0;
      for (i=0; i< 32 ; i++)  class[clas].signame[i] = 0;
      sprintf(nameline,"CLASS %d~",clas);
      strcpy(class[clas].signame,nameline);

        /*  Blank  */
      for (i=0; i< 92 ; i++) class[clas].blank[i] = 0;

        /*  Minimum Values  */
      for (i=0; i< 16 ; i++) class[clas].minvector[i] = 0;

        /*  Maximum Values  */
      for (i=0; i< nbands; i++) class[clas].maxvector[i] = max[i];
      for (i=nbands; i< 16 ; i++) class[clas].maxvector[i] = 0;

        /*  Mean Values  */
      for (i=0; i<nbands; i++)
       { fmean = 1.0*smean[i][clas];
         class[clas].meanvector[i]=fmean;
       }
      for (i=nbands; i< 16 ; i++) class[clas].meanvector[i] = 0;

        /*  Counts  */
      class[clas].scount = count[clas];

        /*  Covariances  */
      for (i=0; i< 32 ; i++)
        { /*class[clas].covar[i] = covarm[i+clas*32];*/
          /*class[clas].covar[i] = 1.;*/
        }

        /* histo */
/*      for (i=0; i<HISTBYTES; i++) class[clas].histo[i] = 0; */

      }


    fclose(fpin);

    return SUCCESS;
}
```

```
C-----------------------------------------------------------------
C ?   ISO.FOR:  Standard Routines for Cluster Splitting and Merging
C ?
C ?      Input parameters from main program are used as:
C ?                MERGE:  MERGING FACTOR, 0 TO 1,
C ?                        0 = NO MERGING
C ?                            MERGE= Q                DEFAULT IS 0.0
C ?                SPLIT:  SPLITTING FACTOR, 0 TO 10,
C ?                        0 = NO SPLITTING
C ?                            SPLIT= R                DEFAULT IS 0.0
C ?
C  Written by Gerard Peltzer
C  UW SSEC 3/6/1992
C-------------------------
C  Apply lumping (merging) and splitting of classes:
C  Variable names after Tou & Gonzalez, "Pattern Recognition Principles"
C  Some definitions:
C  LUMPF               The parameter for merging classes together.
C  SPLITF              The parameter for splitting classes apart.
C  STDIJ(BAND,CLASS)   Std deviation of each class, for each band.
C  STMAXJ(CLASS)       The maximum Std deviation for each class.
C  STMINJ(CLASS)       The minimum Std deviation for each class.
C  STDMAX              The maximum Std deviation for all classes.
C  STDMIN              The minimum Std deviation for all classes.
C  STDAVG              The average Std deviation for all classes.
C  DNETJ(BAND,CLASS)   The average distance of samples in each class from
C                      the class mean, for each band.
C  DBARJ(CLASS)        The average distance of samples from their means.
C  DBAR                Overall average distance of samples from their means.
C  SDIST(1,2)          Spectral distance between means of classes 1 and 2.
C  MINSD, MAXSD        The smallest and largest SDISTs.
C  MAXLMP              The maximum number of lumpings allowed (classes/7).
C  COVAR(CLASS,1,2)    Set of CLASS covariance matrices.
C  CORRE(CLASS,1,2)    Set of CLASS correlation matrices.
C-----------------------------------------------------------------

C ================================================================
C       SPLITR        Ratio Split
C
C       Function to split apart clusters as per the ISODATA
C       definition in  "Pattern Recognition Principles".
C
C       The threshold is essentially STDMAX/STDMIN>SPLITF for
C       bands in each class.  A SPLITF of 0 gives no splitting.
C       SPLITF should range from 1 to 10, with 1 splitting all
C       classes.  Note that only 1/3 of the classes will be split
C       at any iteration.
C
C-----------------------------------------------------------------
      SUBROUTINE SPLITR(CLASES,NBANDS,DSCLAS,ITER,SPLITF,SKIPF,
     C                  SMEAN,SCOUNT,STDIJ,STMAXJ,STMINJ,STDMAX,
     C                  STDMIN,STDAVG,DBARJ,DBAR)
        PARAMETER (MXBNDS=7)
        PARAMETER (MXCLAS=127)
        PARAMETER (MINPIX=64)
        PARAMETER (YES=-1)
        PARAMETER (NO=0)
       INTEGER  SMEAN(0:MXBNDS,0:MXCLAS), OLDCLS
       REAL*8   STDIJ(0:MXBNDS,0:MXCLAS), STMAXJ(0:MXCLAS)
       REAL*8   DBARJ(0:MXCLAS), SCOUNT(0:MXCLAS),STDAVG
       REAL*8   STDMAX, STDMIN, DBAR, SPLITF, STMINJ(0:MXCLAS)
       INTEGER  NBANDS,CLASES,DSCLAS,ITER,I,J,K,BAND,SKIPF,MAXSPL
       INTEGER  SPLIT,SMALL
       COMMON/TFILE/ LOGFIL
       CHARACTER*70 CMES

C   Exit if splitting operation is not enabled:
        IF (SPLITF .LT. 0.001) RETURN
C           MAXSPL is maximum number of cluster pairs which can be split.
            MAXSPL = CLASES/3
```

```
            OLDCLS = CLASES
            I = 1

1       CONTINUE
        SPLIT = NO
        SMALL = NO
C   Quit if we already have too many classes:
        IF ( CLASES-OLDCLS .GT. MAXSPL) GOTO 999

C   Split clusters no matter what if there are few classes:
C   Find the class with the largest STD and split it:
        IF ( CLASES .LE. DSCLAS/2 ) THEN
          SMAX = 0
          DO 10 J = 1, CLASES
            IF (STMAXJ(J) .GT. SMAX) THEN
              SMAX = STMAXJ(J)
              I = J
            ENDIF
10        CONTINUE
          SPLIT = YES
          SMALL = YES
        ELSE

C   Split clusters if this is an odd iteration:
          IF ( MOD(ITER,2) .NE. 0 .AND. CLASES .LT. 2*DSCLAS ) THEN
            IF (NBANDS .EQ. 1) STMINJ(I) = STDAVG
            WRITE(CMES,'(A20,1X,I3,1X,F9.3,F9.2)') 'Cluster: ',I,
     C            STMAXJ(I),STMINJ(I)
             CALL SDEST(CMES,0)
             CALL FDEST(LOGFIL,CMES)
            IF (STMINJ(I) .GT. 0 .AND. DBARJ(I) .GT. DBAR) THEN
              IF ( (STMAXJ(I)/STMINJ(I) .GT. SPLITF) .AND.
     C             (SCOUNT(I)*SKIPF**2 .GT. 10*MINPIX) ) THEN
                SPLIT = YES
                WRITE(CMES,'(A20,1X,I3,1X,F9.3,F9.2)') 'Split: ',I,
     C               SCOUNT(I)*SKIPF**2,10.*(MINPIX+1)
                CALL SDEST(CMES,0)
                CALL FDEST(LOGFIL,CMES)
                SPLIT = YES
              ENDIF
            ENDIF
          ENDIF
        ENDIF

        IF (SPLIT .EQ. NO) I = I + 1

        IF (SPLIT .EQ. YES) THEN
              CLASES = CLASES + 1
              WRITE(CMES,'(A20,1X,I3)') 'Splitting cluster: ',I
              CALL SDEST(CMES,0)
              CALL FDEST(LOGFIL,CMES)
              STMINJ(I) = 0
              STMAXJ(I) = 0
              DO 290 K= CLASES, I+1, -1
                SCOUNT(K) = SCOUNT(K-1)
                STMAXJ(K) = STMAXJ(K-1)
                STMINJ(K) = STMINJ(K-1)
                DBARJ(K) = DBARJ(K-1)
                DO 300 BAND=0, NBANDS-1, 1
                  STDIJ(BAND,K) = STDIJ(BAND,K-1)
                  SMEAN(BAND,K) = SMEAN(BAND,K-1)
300             CONTINUE
290           CONTINUE
              DO 310 BAND=0, NBANDS-1, 1
                  SMEAN(BAND,I+1) = SMEAN(BAND,I) + STDIJ(BAND,I)/1.5
                  SMEAN(BAND,I) = SMEAN(BAND,I) - STDIJ(BAND,I)/1.5
                  IF (SMEAN(BAND,I) .LT. 0) SMEAN(BAND,I) = 0
310           CONTINUE
              I = I + 2
        ENDIF
```

```
      IF (SMALL .EQ. YES) I = 1
      IF (I .LE. CLASES) GOTO 1

999   CONTINUE
      RETURN
      END

C=====================================================================
C       LUMP
C
C       Function to lump together clusters as per the ISODATA
C       definition in  "Pattern Recognition Principles".
C       The merging threshold is a percentage of the maximum
C       spectral distance found between cluster pairs.
C
C---------------------------------------------------------------------
      SUBROUTINE LUMP(CLASES,NBANDS,OLDCLS,ITER,LUMPF,SMEAN,
     C                SCOUNT,SDIST,STDIJ,STMAXJ,STDMAX,DBARJ,DBAR)
      PARAMETER (MXBNDS=7)
      PARAMETER (MXCLAS=127)
      PARAMETER (MINPIX=12)
      REAL*8  STDIJ(0:MXBNDS,0:MXCLAS), SDIST(0:MXCLAS,0:MXCLAS)
      REAL*8  DBARJ(0:MXCLAS), SCOUNT(0:MXCLAS), STMAXJ(0:MXCLAS)
      REAL*8  STDMAX,  DBAR, MINSD, MAXSD, LUMPF
      INTEGER SMEAN(0:MXBNDS,0:MXCLAS), ROW, PREI, PREJ, II, JJ
      INTEGER NBANDS,CLASES,OLDCLS,ITER,I,K,BAND
      INTEGER MINI(0:MXCLAS), MINJ(0:MXCLAS), MAXLMP
      COMMON/TFILE/ LOGFIL
      CHARACTER*70 CMES

C   Exit if lumping operation is not enabled:
      IF (LUMPF .EQ. 0) RETURN
C   Merging and splitting are not allowed together in same iteration:
      IF (CLASES .EQ. OLDCLS)  THEN
C       Sort, find lowest distances for merging:
        ROW = 0
        MAXSD = 0
C       MAXLMP is maximum number of cluster pairs which can be merged.
        MAXLMP = CLASES/3
380     CONTINUE
          MINSD = 1000000
          DO 360 I=1, CLASES-1, 1
            DO 370 J=I+1, CLASES, 1
              IF (ROW .EQ. 0 .AND. SDIST(I,J) .GT. MAXSD)
     C            MAXSD = SDIST(I,J)
              IF (SDIST(I,J) .LT. MINSD) THEN
                JJ = 0
                DO 400 II=0, ROW
                  IF (I .EQ. MINI(II) .OR. J .EQ. MINJ(II)) THEN
C                   We have already found this one, or one of these
C                   classes is to be merged somewhere else.
                    JJ = 1
                  ENDIF
400             CONTINUE
                IF (JJ .EQ. 0) THEN
                  PREI = I
                  PREJ = J
                  MINSD = SDIST(I,J)
                ENDIF
              ENDIF
370         CONTINUE
360       CONTINUE
C         If no distances are less than the minimum ,exit the loop!
          IF (ROW .EQ. 0) THEN
           WRITE(CMES,'(A31)') 'Distances between classes:'
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,'(A19,1X,F6.1)') 'Smallest = ',MINSD
            CALL SDEST(CMES,0)
```

```
            CALL FDEST(LOGFIL,CMES)
           WRITE(CMES,'(A19,1X,F6.1)') 'Largest  = ',MAXSD
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
          WRITE(CMES,'(A32,1X,F6.1)') 'Threshold for merging = '
     C                                    ,MAXSD*LUMPF
            CALL SDEST(CMES,0)
            CALL FDEST(LOGFIL,CMES)
          ENDIF
          MINI(ROW) = PREI
          MINJ(ROW) = PREJ
          IF (SDIST(MINI(0),MINJ(0)) .GT. MAXSD*LUMPF) GOTO 390
          IF (ROW .GE. 2*MAXLMP) GOTO 350
          ROW = ROW + 1
        GOTO 380
350     CONTINUE
        MINSD = SDIST(MINI(0),MINJ(0))
C       Write out the MAXLMP smallest distances:
        WRITE(CMES,'(I4,1X,A21)') MAXLMP,' Smallest Distances:'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        WRITE(CMES,'(A25)') 'Class1  Class2  Distance'
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        DO 435 II= 0, MAXLMP-1, 1
         WRITE(CMES,'(I4,4X,I4,4X,F6.1)')  MINI(II), MINJ(II),
     C                                SDIST(MINI(II),MINJ(II))
          CALL SDEST(CMES,0)
          CALL FDEST(LOGFIL,CMES)
435     CONTINUE
C     Do the lumping, replacing two classes with an average:
        DO 440 II= 0, MAXLMP-1, 1
410       CONTINUE
            IF (SDIST(MINI(II),MINJ(II)) .LE. MAXSD*LUMPF) THEN
C             Change the means of the lumped cluster:
              WRITE(CMES,'(A9,I3,1X,A1,1X,I3)') 'Merging: ',
     C                           MINI(II), '+', MINJ(II)
               CALL SDEST(CMES,0)
               CALL FDEST(LOGFIL,CMES)
              DO 420 BAND=0, NBANDS-1, 1
                SMEAN(BAND,MINI(II)) = ( SMEAN(BAND,MINI(II))*
     C               SCOUNT(MINI(II)) + SMEAN(BAND,MINJ(II))*
     C               SCOUNT(MINJ(II)) ) / (SCOUNT(MINI(II)) +
     C                                     SCOUNT(MINJ(II)) )
420           CONTINUE
C             Wipe out the old second cluster:
             SCOUNT(MINI(II))=SCOUNT(MINI(II))+SCOUNT(MINJ(II))
              DO 430 K= MINJ(II)+1, CLASES-1, 1
                SCOUNT(K) = SCOUNT(K+1)
                STMAXJ(K) = STMAXJ(K+1)
                DBARJ(K) = DBARJ(K+1)
                DO 425 BAND=0, NBANDS-1, 1
                  SMEAN(BAND,K) = SMEAN(BAND,K+1)
                  STDIJ(BAND,K) = STDIJ(BAND,K+1)
425             CONTINUE
430           CONTINUE
              CLASES = CLASES - 1
            ENDIF
440     CONTINUE
390     CONTINUE
        IF (OLDCLS .GT. CLASES) THEN
        WRITE(CMES,'(A20,I4,1X,I4)') 'Merging total: ',OLDCLS,CLASES
         CALL SDEST(CMES,0)
         CALL FDEST(LOGFIL,CMES)
        ENDIF
      ENDIF

      RETURN
      END
```

```
/*=================================================================*/
/*         ATOERD.C:     Converts McIDAS AREA files to ERDAS format.
                         Handles files from PC-McIDAS downloads and
                         McIDAS-AIX transfers.
                         Creates ERDAS .LAN and .GIS format files,
                         and will convert the .ET enhancement file
                         to a .TRL ERDAS trailer file if the output
                         file is specified as .GIS.

  A list of the important variables used:
        infile                    Names for the image input files.
        nbands                    Number of input areas, each a
                                  one band McIDAS area, to combine
                                  into an ERDAS image file.
        outfile                   Output ERDAS format image file
                                  with nbands bands.
        trlfile                   Output ERDAS .TRL trailer file.
                                  (for making ERDAS .GIS files.)
        etfile                    Input McIDAS enhancement file.

  Copyright Gerard Peltzer, 1992.
  Last modified 3/5/1992
/*-----------------------------------------------------------------*/
#include <stdio.h>
#include <string.h>
#include <dos.h>
#include <conio.h>
#include <stdlib.h>
#include <math.h>

#define FILECHARS 70          /* Max number of chars in filename. */
#define INPUTWIDTH 2          /* Number of chars in inputs.       */
#define MAXROWCOL 4000        /* Maximum # of rows or columns.    */
#define MAXBANDS 7            /* Most bands to put in Erdas file  */
#define SUCCESS -1
#define FAILURE 0
#define YES 1
#define NO 0
#define GIS 3
#define LAN 4

typedef unsigned char byte;

main()
{
      byte buf[MAXROWCOL], null[2000];
      long temp,head,head2,header[2000],*longspot;
      char infile[MAXBANDS][FILECHARS], outfile[FILECHARS];
      char lnbuf[80], c;
      int i, j, dx, row, col,length,reversal,*intspot;
      FILE  *fil[MAXBANDS], *fpout, *fpstuf;
      char *stuf = "header.txt";
      double dcol;

/* Enhancement table (GIS) variables:                              */
      FILE *etfil, *trlfil;
      char etfile[FILECHARS],trlfile[FILECHARS],*etptr,*trlptr;
      byte erdhed[128];
      long xstart,ystart;
      int maptyp,iautyp,nclass,clases;

/* Subroutines used:                                               */
      int Reverse4(long *word);
      int Reverse2(int *word);
      int maketrlfile(char etfile[FILECHARS],char trlfile[FILECHARS]);

/* Image specifications used:                                      */
/* Type long is really a long int (*4);                            */
      long ncols;          /* The number of columns in the input image  */
      long nrows;          /* The number of rows in the input image     */
```

```
        int imagetype;          /* Holds image type of input (GIS or LAN)     */
        int packtype;           /* The pack type of input image (4,8,16 bit) */
        int nbands;             /* The number of bands in the input image     */
        long prefix;            /* The line prefix before data                */
        int abands;
        int satellite;
        int packing;

        textbackground(1);
        textcolor(6);
        clrscr();
        window(1,1,80,15);
        gotoxy(10,1);
        printf("McIDAS (AREAxxxx) to ERDAS (.LAN or .GIS) file conversion\n");
        printf("For .GIS output, color table .ET file converted to .TRL.\n");
        window(1,17,80,25);
        gotoxy(5,19);
        clrscr();
        printf("Enter the number of image files (n <= 7) to put\n");
        printf("into a single ERDAS format image file with n bands:");
        window(1,1,80,15);
        gotoxy(1,6);
        clreol();
        printf("Number of areas (bands): ");
        clreol();
        gets(lnbuf);
        sscanf(lnbuf,"%d",&nbands);
        if(nbands < 1 || nbands > MAXBANDS)
          { printf("\nThis program uses 1 to %d bands!",
                   MAXBANDS);
            printf("\nTaking default of 1 band.");
            nbands =1;
          }
        for(i=0; i< nbands; i++)
          {
          strcpy(infile[i],"\0");
          while((fil[i]=fopen(infile[i],"rb")) == NULL)
            {
              window(1,17,80,25);
              gotoxy(5,19);
              clrscr();
              printf("File should be a single band McIDAS area\n");
              printf("This will become band %d in the ERDAS file\n",i+1);
              window(1,1,80,15);
              gotoxy(1,7);
              clreol();
              gotoxy(1,6);
              clreol();
              printf("Enter File Name for Channel %d: ",i+1);
              gets(infile[i]);
            }
/*  Read the header for each file, get parameters:                    */
          reversal = NO;
          head = 768;
          fread(header+1,1,head,fil[i]);
/*  Rows and columns   */
          nrows = header[9];
          ncols = header[10];
          head = header[34];
          clreol();
          if (nrows <= 1 || ncols <= 1 || (head < 256 || head > 1999) )
            {  printf("\n Header is not standard information...");
               printf("\nAttempting a reversed byte order. ");
               Reverse4(&header[4]);
               Reverse4(&header[9]);
               Reverse4(&header[10]);
               Reverse4(&header[34]);
               Reverse4(&header[35]);
               Reverse4(&header[3]);
               Reverse4(&header[11]);
```

```
            Reverse4(&header[14]);
            Reverse4(&header[63]);
            Reverse4(&header[49]);
            Reverse4(&header[50]);
            Reverse4(&header[51]);
            reversal = YES;
          }
          nrows = header[9];
          ncols = header[10];
          head = header[34];
          prefix = header[49]+header[50]+header[51];
        printf("\nLine Prefix = %ld ",prefix);
      if (prefix < 0 || prefix > 200)
        { printf("\nNo read of prefix size (%ld) - assuming 0."
                ,prefix);
          prefix = 0;
        }
      if (head < 256 || head > 1999)
        { printf("\nNo read of header size (%ld) - assuming 768 bytes."
                ,head);
          head = 768;
        }
      else
        {
          printf("\nHeader size = %ld ", head);
        }
      printf("\nEnter header size if different: ");
      clreol();
      gets(lnbuf);
      sscanf(lnbuf,"%ld",&head2);
      if (head2 <= 0 || head2 > 1999)
       { head2 = head; }
      else
       { head = head2;
         printf("\nAssumed header size: %ld",head);
       }

      printf("\nArea Date Read:  %ld",header[4]);
      printf("\nArea rows(lines): %ld   Area columns(elements): %ld"
              ,nrows,ncols);
        /*  only allow MAXROWCOL rows or cols  */
      if (nrows > MAXROWCOL || ncols > MAXROWCOL)
          {  printf("\n Too many rows or columns to handle!\n");
             printf("nrows: %ld ncols: %ld\n",nrows,ncols);
             exit(1);
          }
      if (nrows <= 1 || ncols <= 1)
        { printf("\n Problem reading header rows or columns!\n");
          printf("nrows: %ld ncols: %ld\n",nrows,ncols);
          exit(1);
        }

      satellite = header[3];
      packing = header[11];
      abands = header[14];
      clreol();
      printf("\nHeader size: %ld",head);
      printf("\nSatellite#: %d,  Bytes per pixel: %d,  bands in area: %d"
             ,satellite,packing,abands);

/* Option to print out header information to file 'header'  */
/*      fpstuf=fopen(stuf,"w");
      fprintf(fpstuf,"Word  Header(int) Header(long)\n");
      for(j=1;j<=head;j++)
        {  fprintf(fpstuf,"%d, %d  %ld\n",j,header[j],header[j]); }
       */
    }

/* Open output image file:                                  */
      window(1,17,80,25);
```

```
        gotoxy(5,19);
        clrscr();
        printf("\nEnter the new output file here\n");
        printf("Data will be saved to this file\n");
        printf("A .lan or .gis extension is recommended.\n");
        window(1,1,80,15);
        gotoxy(1,6);
        clreol();
        printf("Output File name: ");
        gets(outfile);
        while((fpout=fopen(outfile,"wb")) == NULL)
          { window(1,17,80,25);
            gotoxy(5,19);
            clrscr();
            printf("Error opening output ERDAS file \n");
            printf("Please try again: \n");
            window(1,1,80,15);
            gotoxy(1,6);
            clreol();
            printf("Enter Output File Name: ");
            gets(outfile);
          }
        window(1,1,80,25);
        clrscr();
        printf("succeeded opening %s\n",outfile);
        if (packing != 1 && packing != 2)
          { printf("\nData must be one or 2 bytes in size!");
            printf("\n Data packing = %d ",packing);
            exit(1);
          }
/*  Find if GIS or LAN file.  If GIS, search for trailer:                  */
        strcpy(trlfile,outfile);
        strupr(trlfile);
        if ((trlptr=strstr(trlfile,".GIS")) != NULL)
          {
          clases = 0;
          imagetype = GIS;
          if ((trlptr=strstr(infile,"REA")) != NULL)
            {
              strcpy(etfile,trlptr+3);  }
          else
            {
              strcpy(etfile,infile[0]); }
          strupr(etfile);
          strcat(etfile,".ET");
          printf("Searching for enhancement file: %s\n",etfile);
          if((etfil=fopen(etfile,"rb")) == NULL)
            {
            printf("McIDAS enhancement file %s not found. \n",etfile);
            printf("Enter enhancement table filename, if any: ");
            clreol();
            gets(etfile);
            printf("\n");
            if((etfil=fopen(etfile,"rb")) == NULL)
              printf("No enhancement table used \n");
            }
          if(etfil != NULL)
            {
            fclose(etfil);
            trlptr=strstr(trlfile,".GIS");
            sprintf(trlptr,".trl\0");
            if (maketrlfile(etfile,trlfile) == FAILURE )
              printf("Error making .TRL enhancement file! \n");
            else
              printf("Created .TRL enhancement file %s \n",trlfile);
            }
          }
        else imagetype = LAN;
/*    Set up ERDAS LAN and GIS file specs:                                 */
/*    ERDAS uses 128 byte header at the beginning of LAN and GIS files.    */
```

```
        if (packing == 1) packtype = 0;
        if (packing == 2) packtype = 2;
        xstart = 0;
        ystart = 0;
        maptyp = 0;
        iautyp = 0;
        if (imagetype == GIS) {nclass = clases;}
        if (imagetype == LAN) {nclass = 0;}
        for (i=0;i<128; i++);
          { erdhed[i] = 0; }
        sprintf(erdhed,"HEAD74");
        intspot = (int*)&erdhed[6];
        *intspot = packtype;
        intspot = (int*)&erdhed[8];
        *intspot = nbands;
        longspot = (long*)&erdhed[16];
        *longspot = ncols;
        longspot = (long*)&erdhed[20];
        *longspot = nrows;
        longspot = (long*)&erdhed[24];
        *longspot = xstart;
        longspot = (long*)&erdhed[28];
        *longspot = ystart;
        intspot = (int*)&erdhed[88];
        *intspot = maptyp;
        intspot = (int*)&erdhed[90];
        *intspot = nclass;
        intspot = (int*)&erdhed[107];
        *intspot = iautyp;


/*    Loop over rows and columns, convert input to output:                */
      printf("Header data for file %s:\n",outfile);
      printf("\n nrows: %ld ncols %ld \n",nrows,ncols);
       fseek(fpout,0l,SEEK_SET);
       fwrite(erdhed,1,128,fpout);
       fseek(fpout,1281,SEEK_SET);
    for ( i=0; i<nbands; i++)
      {
       fseek(fil[i],0l,SEEK_SET);
       length = fread(null,1,head,fil[i]);
      }
               gotoxy(1,22);
               clreol();
               printf("Processing row: ");
     for(row=0; row < nrows; row++)
       {
         for ( i=0; i<nbands; i++)
           {
              if (prefix > 0)
               { length = fread(buf,packing,prefix,fil[i]);
               }
              length = fread(buf,packing,ncols,fil[i]);
              j = 10*(row/10);
              dx = row - j;
              if (row > 0 && dx == 0)
                { gotoxy(17,22);
                  clreol();
                  printf("%d",row);
                }
              if (length != ncols)
                   { printf("\nA read error at row: %d",row);
                     printf(" ESC to exit, any key to continue");
                     if ((c=getc(stdin)) == 27)  exit(1);
                   }
              if (packing == 2)
                {
                  for(col=0; col<ncols; col++)
                   { dcol = col;
                     if (reversal == YES && fmod(dcol,2.0)==0)
```

```
                    { Reverse2(&buf[col]); }
                  /* compress data to 1 byte pixels */
                  buf[col] = buf[col]/255;
                }
              }
            /*  Write out data to outfile:       */
/*            outbufB = buf[i];
            fwrite(outbufB, 1, ncols, fpout);*/
            fwrite(buf, packing, ncols, fpout);
          }
        }

/* Print out parameters of interest:                                    */
/* Write out status to user:                                            */
      gotoxy(0,20);
      clreol();
      fclose(fpout);

      printf(" Ending... \n");
      return;
}


int Reverse4(long *word)
{
      typedef unsigned char byte;
      byte *pointl, *pointr, temp;
/*  Reverse the AIX 4 byte words:          */
      pointl = word;
      pointr = pointl+3;
      temp = *pointl;
      *pointl = *pointr;
      *pointr = temp;
      pointl++;
      pointr--;
      temp = *pointl;
      *pointl = *pointr;
      *pointr = temp;
      return SUCCESS;
}

int Reverse2(int *word)
{
      typedef unsigned char byte;
      byte *pointl, *pointr, temp;
/*  Reverse the AIX 4 byte words:          */
      pointl = word;
      pointr = pointl+1;
      temp = *pointl;
      *pointl = *pointr;
      *pointr = temp;
      return SUCCESS;
}


/*-----------------------------------------------------------------*/
/*                              Maketrlfile
        Function to save enhancement tables with means of sets from
        a McIDAS format .ET file in an ERDAS .TRL format trailer file.
        This file is used to define colors in ERDAS .GIS image
        classification files.

        Note that a stretch factor of 2 has been used throughout this
        program because of the 7 bit nature of the McIDAS color display.

        Written by Gerard Peltzer, UW SSEC 2/21/1991.
        For use on IBM PC, compiled with Borland C++.            */
/*-----------------------------------------------------------------*/
int maketrlfile(char etfile[FILECHARS],char trlfile[FILECHARS])
```

```
#include <stdio.h>
#include <string.h>
#include <dos.h>
#include <conio.h>
#include <stdlib.h>
#include <math.h>

#define MXBNDS 5
#define MXCLAS 256
#define STRETCH 2

{
    byte output[128];
    FILE *etfil, *trlfil;
    int BAND, SET, SIZE, NROWS, NCOLS, CLASES;
    int i,j, reverse;
    unsigned long longi,MNRED[MXCLAS],MNGRE[MXCLAS],MNBLU[MXCLAS];
    byte BMRED[MXCLAS],BMGRE[MXCLAS],BMBLU[MXCLAS];

/* Subroutines used:                                                    */
      int Reverse4(long *word);
      int Reverse2(int *word);

/*  Open the McIDAS format file, read information:   */
      while ((etfil = fopen(etfile,"rb")) == NULL)
       { printf("\n Error opening .ET file %s ",etfile);
         return FAILURE;
       }

/*  Read in color look-up tables:     */
        CLASES = MXCLAS/STRETCH;
        fseek(etfil,41,SEEK_SET);
        fread(MNRED,4,CLASES*STRETCH,etfil);
        fseek(etfil,41+4*2561,SEEK_SET);
        fread(MNGRE,4,CLASES*STRETCH,etfil);
        fseek(etfil,41+4*5121,SEEK_SET);
        fread(MNBLU,4,CLASES*STRETCH,etfil);

/*  Switch bytes, if bad values read in:    */
        reverse = NO;
        for(i=0;i<CLASES*STRETCH;i++)
          { if(MNRED[i] > 255 || MNRED[i] < 0)
            { reverse = YES; }
          }
        if (reverse == YES)
          {
            for(i=0;i<CLASES*STRETCH;i++)
            {  Reverse4(&MNRED[i]);
               Reverse4(&MNGRE[i]);
               Reverse4(&MNBLU[i]);
            }
          }
/*            for(i=0;i<CLASES*STRETCH;i++)
            { printf("r:%d g:%d b:%d \n",MNRED[i],MNGRE[i],MNBLU[i]);}*/

/*  Open the Erdas format file, write information:   */
      while ((trlfil = fopen(trlfile,"wb")) == NULL)
       { printf("\n Error opening .TRL output file %s ",trlfile);
         return FAILURE;
       }

/*  Clear output buffer, Write header:  */
       for (i = 0; i< 128; i++) { output[i]=0; }
       fseek(trlfil,0L,SEEK_SET);
       for (i = 0; i< 17; i++)
         {  fwrite(output,1,128,trlfil);
         }

       sprintf(output,"TRAIL74");
       sprintf(output+73,"McIDAS ISODATA IMAGE CLASSIFICATION~");
```

```
        fseek(trlfil,0L,0L);
        fwrite(output,1,128,trlfil);

/*  Write out class names, which are numbers:     */
/*        for (i = 0; i<= STRETCH*CLASES; i+=4)
          {
          for (j = 0; j< 128; j++) { sprintf(&output[j]," "); }
          for (j = 0; j<= 3; j++)
           {
            if (fmod((i+j),2) == 0)
             sprintf(output+32*j,"%3d~",(i+j)/2);
            else
             sprintf(output+32*j,"~");
           }
          fseek(trlfil,(128*(17+i/4)),SEEK_SET);
          fwrite(output,1,128,trlfil);
          }
*/
/*  Write out class means, integers changed to bytes:     */
       for (i = 0; i< MXCLAS; i++)
          {
          BMRED[i] = MNRED[i];
          BMGRE[i] = MNGRE[i];
          BMBLU[i] = MNBLU[i];
          }
         fseek(trlfil,1281,SEEK_SET);
         fwrite(BMGRE,1,CLASES*STRETCH,trlfil);
         fseek(trlfil,3841,SEEK_SET);
         fwrite(BMRED,1,CLASES*STRETCH,trlfil);
         fseek(trlfil,6401,SEEK_SET);
         fwrite(BMBLU,1,CLASES*STRETCH,trlfil);

       fclose(trlfil);
       fclose(etfil);
       return SUCCESS;

}

#
```

```
/*=====================================================================*/
/*          ERDTOA.C:   Converts ERDAS files to McIDAS area files.

       ERDAS format is band-sequential:
          Pixels 1 through x of line 1, band 1
          Pixels 1 through x of line 1, band 2 ...
          Pixels 1 through x of line 1, band n
          Pixels 1 through x of line 2, band 1 ...

       McIDAS format is band-interleaved:
          Element1: band1,band2,band3 Element2: band1,band2,band3 ...

         This program converts an n band ERDAS file to an n band
       McIDAS area.

         If the ERDAS file is a .GIS classification, then the
       corrosponding .TRL file will be converted to a McIDAS-X .ET
       color look-up table file.  To use the .ET file on PC McIDAS,
       a conversion program must be used to switch the byte positions
       in each 4-byte word.

         The areas and .ET files created by this program are ready to
       be sent to McIDAS-X machines via binary FTP.

       Copyright Gerard Peltzer, 1992.
       Last modified 5/28/1992
/*---------------------------------------------------------------------*/

#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <math.h>
#include <dos.h>
#include <conio.h>
#define INPUTWIDTH 2          /* Number of chars in inputs.      */
#define MAXROWCOL 3000        /* Maximum # of rows or columns.   */
#define MAXBANDS 7            /* Most bands from Erdas file */
#define SUCCESS -1
#define FAILURE 0
#define FILECHARS 70          /* Max number of chars in filename. */
#define INPUTWIDTH 2          /* Number of chars in inputs.       */
#define YES 1
#define NO 0
#define GIS 3
#define LAN 4
#define MAXELINT MAXROWCOL*MAXBANDS

typedef unsigned char byte;

void main(int argc, char *argv[])
{
      byte outbuf[21000];
      byte inbuf[MAXBANDS][MAXROWCOL];
      byte prefix[40];
      byte erdhed[128];
      long header[2000];
      byte color;
      char infile[FILECHARS], outfile[FILECHARS];
      char lnbuf[80], *c;
      FILE  *infil, *outfil;
      byte null[2000];
      long temp, head, head2, *longspot;
      int i, j, band, dx, row, col,length, reversal,*intspot;
      int headread, stretch;
      double dcol;

/* Enhancement table (GIS) variables:                                 */
      FILE *etfil, *trlfil;
      char etfile[FILECHARS],trlfile[FILECHARS],*etptr,*trlptr;
      long xstart,ystart;
```

```
      int maptyp,iautyp,clases;

/* Image specifications used:                                          */
/* Type long is really a long int (*4);                               */
      long ncols;          /* The number of columns in the input image  */
      long nrows;          /* The number of rows in the input image     */
      int imagetype;        /* Holds image type of input (GIS or LAN)    */
      int packtype;         /* The pack type of input image (4,8,16 bit) */
      int nbands;           /* The number of bands in the input image    */
      int nclass;           /* The number of classes (GIS)               */
      int abands;
      int satellite;
      int packing;

/* Subroutines used:                                                   */
      int Reverse4(long *word);
      int makeetfile(char etfile[FILECHARS],char trlfile[FILECHARS]);
      int Reverse2(int *word);


      textcolor(6);
      clrscr();
      window(1,1,80,15);
      gotoxy(10,2);

      printf("ERDAS .LAN to McIDAS AREA file conversion utility\n");


      window(1,17,80,25);
      gotoxy(5,17);
      clrscr();
      printf("Enter the ERDAS file to convert into a McIDAS area: ");
      window(1,1,80,15);
      gotoxy(1,6);
      clreol();
      printf("Enter ERDAS File Name: ");
      gets(infile);
      while((infil=fopen(infile,"rb")) == NULL)
        {
        clrscr();
        printf("File should be an ERDAS .LAN or .GIS file \n");
        clreol();
        printf("Enter Erdas input file name: ");
        gets(infile);
        }

/*  Stretch for McIDAS if file is a classification:  */
      strupr(infile);
      if ((trlptr=strstr(infile,".GIS")) != NULL)
        { stretch = 2; }
      else
        { stretch = 1; }

      fseek(infil,0l,SEEK_SET);
      length=fread(erdhed,128,1,infil);
      headread = 0;
      printf("Header data for file %s:\n",infile);
      while (headread != SUCCESS)
        {
        intspot = (int *)&erdhed[6];
        packtype = *intspot;
        intspot = (int *)&erdhed[8];
        nbands = *intspot;
        longspot = (int *)&erdhed[16];
        ncols = *longspot;
        longspot = (int *)&erdhed[20];
        nrows = *longspot;
        intspot = (int *)&erdhed[90];
        nclass = *intspot;
        printf("imagetype:%d packtype:%d nbands:%d",imagetype,packtype,nbands);
```

```
        printf("\n nrows: %ld ncols %ld \n",nrows,ncols);
/*  only allow MAXROWCOL rows or cols  */
        if(nrows > MAXROWCOL || ncols > MAXROWCOL || nrows<=0 || ncols<=0
           || nbands < 1 || nbands > MAXBANDS)
          {
          if (headread == 0) /* call reverse for PC to WS convert */
            {   printf("Now Attempting reversed byte order:\n");
            Reverse4(&erdhed[16]);
            Reverse4(&erdhed[20]);
            Reverse2(&erdhed[90]);
            Reverse2(&erdhed[6]);
            Reverse2(&erdhed[8]);
            headread++;
            }
          else
            { printf("\n Invalid parameters in data, exiting!\n");
            exit(1);
            }
          }
        else { headread=SUCCESS; }
        }
      printf("succeeded opening %s\n",infile);
      window(1,17,80,25);
      gotoxy(5,23);
      clrscr();
      printf("Enter the output McIDAS area, convention is AREAxxxx ");
      window(1,1,80,17);
      gotoxy(1,14);
      clreol();
      strcpy(outfile,"\0");
      printf("Enter McIDAS area file Name: ");
      gets(outfile);
      while((outfil=fopen(outfile,"wb")) == NULL)
        {
        window(1,17,80,25);
        gotoxy(5,23);
        clrscr();
        printf("File should be a new single band McIDAS area\n");
        window(1,1,80,15);
        gotoxy(1,14);
        clreol();
        printf("Enter McIDAS area file Name: ");
        gets(outfile);
        }
/*    If GIS file, search for trailer:                */
      strcpy(trlfile,infile);
      strupr(trlfile);
      strupr(outfile);
      if ((trlptr=strstr(trlfile,".GIS")) != NULL)
        {
        strcpy(trlptr,".TRL");
        if ((trlptr=strstr(outfile,"AREA")) != NULL)
          { strcpy(etfile,trlptr+4);
          strcat(etfile,".ET");
          strupr(etfile);
          }
        else
          { strcpy(etfile,outfile);
          strupr(etfile);
          if ((trlptr=strstr(etfile,".")) !=NULL) strcat(etfile,".ET");
          else strcat(etfile,".ET");
          }
        printf("Searching for ERDAS .TRL file: %s\n",trlfile);
        if((trlfil=fopen(trlfile,"rb")) == NULL)
          {
          printf("ERDAS enhancement file ->%s<- not found. \n",trlfile);
          printf("Enter trailer table filename, if any: ");
          clreol();
          gets(trlfile);
          printf("\n");
```

```
        if((trlfil=fopen(trlfile,"rb")) == NULL)
        printf("No color table used \n");
        if((etfil=fopen(etfile,"wb")) == NULL)
        printf("No color table used \n");
        }
      if(trlfil != NULL && etfil != NULL)
        {
        fclose(trlfil);
        fclose(etfil);
        if (makeetfile(etfile,trlfile) == FAILURE )
          printf("Error making .ET enhancement file! \n");
        else
          printf("Created .ET enhancement file %s \n",etfile);
        }
      }

/*  Set the header for McIDAS file, set parameters:                    */
      head = 768/sizeof(long);
      for (i=0;i<=head;i++) header[i] = 0;
      header[2] = 4;
      header[3] = 3;
      header[4] = 92000;
      header[8] = 1;
      header[9] = nrows;
      header[10] = ncols;
      header[3] = 0; /* satellite # */
      header[11] = 1; /* packing, in bytes */
      header[12] = 1; /* line resolution */
      header[13] = 1; /* element resolution */
      header[14]= nbands; /* # of bands */
      header[17] = 92000;
/*    Filter map-prefix (bit-for-band, right most bit is band 1) :    */
      header[19] = 1;
      if (nbands > 1)
        { for (i=2;i<=nbands;i++)
          { dcol = i-1;
          header[19]=header[19]+pow(2,dcol);
          }
        }
      header[34] = 768; /* area data offset */
      header[35]= 256;
      header[48] = 1; /* starting scan */
      if (nbands > 1)
        { header[51] = 8;
        header[15]=8;
        } /* LEV section of prefix */
      header[52] = 1381189974;
      header[53] = 1414091330;
      header[55] = 1;
      header[56] = 2;

/*  Debugging printouts:
      printf("visr= %d, %ld brit= %d, %ld\n",header[52],header[52],
        header[53],header[53]);
      for (i=1;i<65;i++) printf(" header[%d] = %ld\n",i,header[i]); */

/*    Line prefix setup:                                              */
      for (i=1;i<9;i++)
        { if (i <= nbands) prefix[i-1]=i;
        else prefix[i-1]=0;  }


/*    Loop over rows and columns, convert input to output:            */
      fseek(outfil,0l,SEEK_SET);
      fwrite(header+1,sizeof(long),head,outfil);
      fseek(infil,128l,SEEK_SET);
      gotoxy(1,22);
      clreol();
      printf("Processing row:   ");
      for(row=0; row < nrows; row++)
```

```
        {
        for(band=0; band<nbands; band++) fread(inbuf[band],1,ncols,infil);
        j = 10*(row/10);
        dx = row - j;
        if (row > 0 && dx == 0)
          { gotoxy(18,22);
          clreol();
          printf(" %d",row);
          }
        col = 0;
        j = 0;
        while(col < ncols)
          {
          for(band=0; band < nbands; band++)
            {
            outbuf[j] = inbuf[band][col]*stretch;
            j ++;
            }
          col++;
          }
/* Write out data to outimg,  ncols*nbands:     */
        if (nbands >1) {length = fwrite(prefix,1,8,outfil);}
        length = fwrite(outbuf,1,ncols*nbands,outfil);
        }
      fclose(infil);
      fclose(outfil);
      gotoxy(5,24);
      clreol();
      printf("\nFinished...Have a nice day. \n");
      exit(0);
}


/*  Reverse the AIX 4 byte words:           */
int Reverse4(long *word)
{
      typedef unsigned char byte;
      byte *pointl, *pointr, temp;
      pointl = (byte *)word;
      pointr = (byte *)pointl+3;
      temp = *pointl;
      *pointl = *pointr;
      *pointr = temp;
      pointl++;
      pointr--;
      temp = *pointl;
      *pointl = *pointr;
      *pointr = temp;
      return SUCCESS;
}


int Reverse2(int *word)
{
      typedef unsigned char byte;
      byte *pointl, *pointr, temp;
/*  Reverse the AIX 4 byte words:           */
      pointl = word;
      pointr = pointl+1;
      temp = *pointl;
      *pointl = *pointr;
      *pointr = temp;
      return SUCCESS;
}


/*-----------------------------------------------------------------*/
/*                       MakeETfile
      Function to save enhancement tables with means of sets from
    an ERDAS .TRL format trailer file.
```

```
     This file is used to define colors in ERDAS .GIS
     classification files.

       Note that a stretch factor of 2 has been used throughout this
     program because of the 7 bit nature of the McIDAS color display.

       Written by Gerard Peltzer
       UW SSEC 5/26/1992.
     For use on IBM PC, compiled with Borland C++.                    */
/*-----------------------------------------------------------------*/
int makeetfile(char etfile[FILECHARS],char trlfile[FILECHARS])

#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <math.h>

#define MXBNDS 5
#define MXCLAS 256
#define STRETCH 2

{
      FILE *etfil, *trlfil;
      int BAND, SET, SIZE, NROWS, NCOLS, CLASES;
      int i,j, reverse;
      unsigned long longi,MNRED[MXCLAS],MNGRE[MXCLAS],MNBLU[MXCLAS];
      byte BMRED[MXCLAS],BMGRE[MXCLAS],BMBLU[MXCLAS];

/* Subroutines used:                                                */
      int Reverse4(long *word);
      int Reverse2(int *word);

/*  Open the Erdas format file, read information:   */
      while ((trlfil = fopen(trlfile,"rb")) == NULL)
        { printf("\n Error opening .TRL input file %s ",trlfile);
        return FAILURE;
        }


/*  read in class means, integers changed to bytes:    */
      fseek(trlfil,128l,SEEK_SET);
      fread(BMGRE,1,MXCLAS,trlfil);
      fseek(trlfil,384l,SEEK_SET);
      fread(BMRED,1,MXCLAS,trlfil);
      fseek(trlfil,640l,SEEK_SET);
      fread(BMBLU,1,MXCLAS,trlfil);
      for (i = 0; i< MXCLAS/STRETCH; i=i+1)
        {
        j = i * STRETCH;
        MNRED[j] = BMRED[i];
        MNGRE[j] = BMGRE[i];
        MNBLU[j] = BMBLU[i];
        MNRED[j+1] = BMRED[i];
        MNGRE[j+1] = BMGRE[i];
        MNBLU[j+1] = BMBLU[i];
        }

/*  Debugging printouts:
      printf("LUT classes: %d",MXCLAS);
      for(i=0;i<MXCLAS;i++)
        printf("r:%d g:%d b:%d \n",MNRED[i],MNGRE[i],MNBLU[i]);*/

      reverse = YES;
      if (reverse == YES)
        {
        for(i=0;i<MXCLAS;i++)
          {  Reverse4(&MNRED[i]);
          Reverse4(&MNGRE[i]);
          Reverse4(&MNBLU[i]);
          }
```

```
        }
/*  Open the McIDAS format file:   */
      while ((etfil = fopen(etfile,"wb")) == NULL)
        { printf("\n Error opening .ET file %s ",etfile);
        return FAILURE;
        }
/*  WSrite out color look-up tables:     */
      fseek(etfil,4l,SEEK_SET);
      fwrite(MNRED,4,MXCLAS,etfil);
      fseek(etfil,4l+4*256l,SEEK_SET);
      fwrite(MNGRE,4,MXCLAS,etfil);
      fseek(etfil,4l+4*512l,SEEK_SET);
      fwrite(MNBLU,4,MXCLAS,etfil);
      fclose(trlfil);
      fclose(etfil);
      return SUCCESS;

}
```

```
/*=====================================================================*/
/*      SBDSIG.C

  This program converts ERDAS .SBD files to McIDAS .SIG files
  or vice-versa, depending on input.

  The program takes input parameters through a user
     friendly menu as well as through a command line of
     arguments.


  A list of the important variables used:
      infile                    Name for the .SIG or .SBD input file.
      outfile                   Name for the output file.

      Copyright Gerard Peltzer, 1992.
      Last modified: 4/29/1992                                      */
/*---------------------------------------------------------------------*/

#include <math.h>
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <malloc.h>
#define INPUTWIDTH 80       /* Number of chars in inputs.      */
#define MXCLAS    255
#define MAXSBD     16
#define MXBNDS     7
#define SUCCESS   -1
#define FAILURE    0
#define YES        1
#define NO         0
#define SBD        8
#define SIG        9
#define HISTBYTES 512*MXBNDS


typedef struct Sig{
              char signame[32];
              long scount;
              char blank[92];
              int minvector[MAXSBD];
              int maxvector[MAXSBD];
              float meanvector[MAXSBD];
              float covar[32];
              /*char histo[HISTBYTES];*/
                        } Signature;

typedef struct Sighead{
              char lanname[100];
              int classes;
              int bands;
              char blank[24];
                        } Sbdheader;


int main(int argc, char *argv[])
{
/* Declarations of the functions used in this program:              */
      Signature *class;
      Sbdheader head;
      void commandline(int argc, char *argv[], char *infile,
           char *outfile,int *type);
      int readsig(char *sigfile,Sbdheader *head, Signature *class);
      int writesig(char *sigfile,Sbdheader *head, Signature *class);
      int readsbd(char *sbdfile,Sbdheader *head,Signature *class);
      int writesbd(char *sbdfile,Sbdheader *head,Signature *class);
      int type, mean, lclass, hclass;
```

```
/* Variable declarations:   */
      char sigfile[INPUTWIDTH],sbdfile[INPUTWIDTH];
      char infile[INPUTWIDTH],outfile[INPUTWIDTH];

/* Allocate memory for class:  */
      if ((class = (Signature *) malloc(MXCLAS*sizeof(Signature)))
          == NULL)
        { printf("\nNot enough memory to allocate classes!\n");
          return(1); }


/* First take care of the input parameters:   */
      commandline( argc, argv, infile, outfile, &type);

/* Read in data from infile:   */
      if (type == SIG)
        {
        strcpy(sigfile,infile);
        strcpy(sbdfile,outfile);
        if ( readsig(sigfile, &head, class)  == FAILURE    )
          { printf("Quitting due to sig read errors... \n");
            return(1); }
        if ( writesbd(sbdfile,&head, class) == FAILURE    )
          { printf("Quitting due to sbd write errors... \n");
            return(1); }
        }
      if (type == SBD)
        {
        strcpy(sbdfile,infile);
        strcpy(sigfile,outfile);
        if ( readsbd(sbdfile,&head, class) == FAILURE    )
          { printf("Quitting due to sbd read errors... \n");
            return(1); }
        if ( writesig(sigfile, &head, class)  == FAILURE    )
          { printf("Quitting due to sig write errors... \n");
            return(1); }
        }



      printf("\n...Ending... \n");
      free(class);
      return(0);
}


/*=====================================================================*/
/*               Function Commandline
       This routine handles the command line inputs.

  A note on command line parameters:
     The command line parameters are passed in when the user calls up the
     program.  Thus, the 1st parameter is the name of the program name.
     The variables for comand line parameters are:
      argc                      The # of command line parameters read.
      argv[argc]                The char array of argc parameters
                                                          */
/*---------------------------------------------------------------------*/
void commandline(int argc, char *argv[], char *infile,
          char *outfile,int *type)
{
      char c[INPUTWIDTH], c2[INPUTWIDTH], namfile[INPUTWIDTH];
      char *trlptr;
      int check, j, band;
      FILE *fpin, *fpout;

/* If the user types in a ? after the program name, give him (or her)
   a list of the command line parameters:                            */
      if(((argc > 1) && (*argv[1] == '?')) || argc > 2)
      {
```

```
      printf("\nUse these easy command line parameters: \n");
      printf("<sbdsig> <Infile> <Outfile> ");
      exit(0);
     }
/*   Copy the command line parameters that were given into their
     respective variables.  Also clear any variables that were not
     given as command line parameters:                                  */
     if(argc >= 2) {strcpy(infile,argv[1]);}
      else         {strcpy(infile,"\0");}
/* In this case, the user gave all the parameters initially.      */
     if(argc >= 3) {strcpy(outfile,argv[2]);}
      else         {strcpy(outfile,"\0");}

     if(argc > 3)   {  printf("Maximum 3 input parameters!");
             printf("   Taking the first 3");       }
/*     clrscr();
     textbackground(0);
     textcolor(6);
     window(1,1,80,18);
     gotoxy(10,2); */
     printf("\nSignature File Transform\n------------------------\n");

     while((fpin=fopen(infile,"r")) == NULL)
     {
/*     window(1,20,80,25);
     gotoxy(5,20); */
     printf("\nEnter the input file here");
     printf("\n(Data should be .SIG or .SBD file)");
/*     window(1,1,80,18);
     gotoxy(1,3);
     clreol(); */
     printf("\nData File name: ");
     gets(infile);
     }
     fclose(fpin);

/* Find whether .SBD or .SIG file:  */
     strupr(infile);
     strcpy(namfile,infile);
     if ((trlptr=strstr(namfile,".SBD")) != NULL)
       { *type = SBD; }
     else
       {
       if ((trlptr=strstr(namfile,".SIG")) != NULL)
         { *type = SIG; }
       else
         { printf("\nNamefile type not specified - assuming SIG");
           *type = SIG;
         }
       }

/*  Check output file is viable: */
     strcpy(namfile,"\0");
     while((fpout=fopen(outfile,"w")) == NULL)
       {
       strcpy(namfile,infile);
       if ((trlptr=strstr(namfile,".")) != NULL)
         { if (*type==SIG) strcpy(trlptr,".SBD");
           if (*type==SBD) strcpy(trlptr,".SIG");
         }
/*       window(1,20,80,25);
       gotoxy(5,20); */
       if (*type==SIG) printf("\nEnter the output .SBD file here");
       if (*type==SBD) printf("\nEnter the output .SIG file here");
       printf("\n(Default name is %s)",namfile);
/*       window(1,1,80,18);
       gotoxy(1,3);
       clreol(); */
       printf("\nOutput File name: ");
           gets(outfile);
```

```
        if (strcmp(outfile,"\0")==0)   strcpy(outfile,namfile);
        }
/*      window(1,20,80,25);
      clrscr();
      window(1,1,80,18);
      clrscr();
      gotoxy(1,10); */
      fclose(fpout);

      return;
}

/*=============================================================*/
/*               Function Readsig                              */
/*       This routine reads data from McIDAS .SIG file.        */
/*                                                             */
/*       The arrays are all indexed from 0 to n-1.             */
/*                                                             */
/* Read in Data:                                               */
/*   1) name of sig file                                       */
/*   2) number of classes                                      */
/*   3) number of bands                                        */
/*   4) blank (says "--Max data values--")                     */
/*   5) max-B1 max-B2 ... max-BN                               */
/*   6) blank (says "---BAND MEANS---")                        */
/*   7) blank (says "Class  Counts  " then bands)              */
/*   8) class# counts mean-B1 mean-B2 ... mean-BN              */
/*         C+1 of these...                                     */
/*   8+C+1) blank (says "Class covariance matrices")           */
/*   8+C+2) class#                                             */
/*   8+C+3) COVAR(0,0) COVAR(0,1) ... COVAR(0,N-1)             */
/*            N of these...                                    */
/*    C of these...                                            */
/*-------------------------------------------------------------*/
      int readsig(char *infile,Sbdheader *head, Signature class[])
#define COV 32*MXCLAS
{
      int i,j,k;
      int clas, band, clases, nbands, eof;
      int max[MAXSBD], min[MAXSBD], smean[MAXSBD][MXCLAS];
      long count[MXCLAS];
      float fcount, fmean, cova[32];
/*      float covarm[COV];*/
      float *covarm;
      FILE *fpin;
      char *trlptr, nameline[32];
      char dataline[80];
      char firstline[100];
      char moreline[80];

/* Allocate memory for covarm:  */
/*      if ((covarm = (float *) malloc(COV*sizeof(float)))
          == NULL)
        { printf("\nNot enough memory to allocate covariance!\n");
          return(1);
        }*/

      if((fpin=fopen(infile,"rt")) == NULL)
      {  printf("\nError opening infile\n");
      return FAILURE;
      }
      fseek(fpin,0L,SEEK_SET);

      i = 0;
      eof = NO;
/* File search:  */
      while (eof == NO)
        {
   /* Header information:    */
         /*  First line  */
```

```
        for (i=0; i< 100 ; i++)  firstline[i] = 0;
        for (i=0; i< 100 ; i++)  (*head).lanname[i] = 0;
        if (fgets(firstline,100,fpin) == NULL) eof = YES;     /* 1  */
        printf("\nHeader of data file says: ");
        puts(firstline);
        printf("\n");
        if ((trlptr=strstr(firstline,".")) != NULL)
        { strcpy(trlptr,"~   "); }
        strcpy((*head).lanname, firstline);

           /*  Classes  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 2  */
        j = sscanf(dataline, "%d ",&clases);
        if  (j < 1 || j == EOF) eof = YES;
        (*head).classes = clases;

           /*  Bands  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 3  */
        j = sscanf(dataline, "%d ",&nbands);
        if  (j < 1 || j == EOF) eof = YES;
        (*head).bands = nbands;

        for (i=0; i< 24 ; i++)  (*head).blank[i] = 0;


/* Develop structures for each signature:   */

           /*  Get Maximum Values  */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 4  */
        for (i=0; i< 80 ; i++)  dataline[i] = 0;
        strcpy(dataline,"\0");
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 5  */
        for (i=0; i< MXBNDS ; i++)  max[i] = 0;
        j = sscanf(dataline, "%d %d %d %d %d %d %d",&max[0], &max[1],
          &max[2], &max[3], &max[4], &max[5], &max[6]);
        if  (j < 1 || j == EOF) eof = YES;

           /* 2blank lines */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 6  */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 7  */


           /*  Get Mean Values  */
        for (clas=0; clas<= clases ; clas++)
          {
          for (band=0; band< MXBNDS; band++) smean[band][clas] = 0;
          for (i=0; i< 80 ; i++)  dataline[i] = 0;
          if (fgets(dataline,80,fpin) == NULL) eof = YES;     /* 8>8+C */
          j = sscanf(dataline, "%d %f %d %d %d %d %d %d %d", &i,
              &fcount,&smean[0][clas],&smean[1][clas],
              &smean[2][clas],&smean[3][clas],&smean[4][clas],
              &smean[5][clas],&smean[6][clas]);
          count[clas] = (long)fcount;
          if  (j < 1 || j == EOF) eof = YES;
          }

           /* 1 blank line */
        if (fgets(dataline,80,fpin) == NULL) eof = YES;       /* 8+C+1 */


           /*  Get Covariances  */
        for (clas=0; clas<= clases ; clas++)
          {
            /* 1 blank line */
          if (fgets(dataline,80,fpin) == NULL) eof = YES;     /* 8+C+2 */
          k = 0;
```

```
        for (band=0; band< nbands ; band++)
          {
          for (i=0; i< 80 ; i++)  moreline[i] = 0;
          strcpy(moreline,"\0");
          if (fgets(moreline,80,fpin) == NULL) eof = YES;  /* 8+C+3 */
          j = sscanf(moreline, "%f %f %f %f %f %f %f",&cova[0],
          &cova[1],&cova[2],&cova[3],&cova[4],&cova[5],&cova[6]);
          if  (j < 1 || j == EOF) eof = YES;
          if (k > 32)
            { printf("\nError in covar computation!");
              return FAILURE;
            }
          for (i=band; i< nbands ; i++)
            { /* covarm[k+clas*32] = cova[i];*/
              class[clas].covar[k] = cova[i];
              k++;
            }
          }
        }

      eof = YES;
      }

    for (clas=0; clas<= clases ; clas++)
      {
          /*  Name  */
        for (i=0; i< 32 ; i++)  nameline[i] = 0;
        for (i=0; i< 32 ; i++)  class[clas].signame[i] = 0;
        sprintf(nameline,"CLASS %d~",clas);
        strcpy(class[clas].signame,nameline);

          /*  Blank  */
        for (i=0; i< 92 ; i++) class[clas].blank[i] = 0;

          /*  Minimum Values  */
        for (i=0; i< 16 ; i++) class[clas].minvector[i] = 0;

          /*  Maximum Values  */
        for (i=0; i< nbands; i++) class[clas].maxvector[i] = max[i];
        for (i=nbands; i< 16 ; i++) class[clas].maxvector[i] = 0;

          /*  Mean Values  */
        for (i=0; i<nbands; i++)
         { fmean = 1.0*smean[i][clas];
           class[clas].meanvector[i]=fmean;
         }
        for (i=nbands; i< 16 ; i++) class[clas].meanvector[i] = 0;

          /*  Counts  */
        class[clas].scount = count[clas];

          /*  Covariances  */
        for (i=0; i< 32 ; i++)
          { /*class[clas].covar[i] = covarm[i+clas*32];*/
            /*class[clas].covar[i] = 1.;*/
          }

          /* histo */
/*        for (i=0; i<HISTBYTES; i++) class[clas].histo[i] = 0; */

      }


    fclose(fpin);

    return SUCCESS;
}

/*============================================================*/
```

```
/*              Function Writesig                                    */
/*       This routine writes data to McIDAS .SIG file.               */
/*                                                                   */
/*       The arrays are all indexed from 0 to n-1.                   */
/*                                                                   */
/* Sig Data:                                                         */
/*   1) name of sig file                                             */
/*   2) number of classes                                            */
/*   3) number of bands                                              */
/*   4) blank (says "--Max data values--")                           */
/*   5) max-B1 max-B2 ... max-BN                                     */
/*   6) blank (says "---BAND MEANS---")                              */
/*   7) blank (says "Class  Counts  " then bands)                    */
/*   8) class# counts mean-B1 mean-B2 ... mean-BN                    */
/*        C+1 of these...                                            */
/*   8+C+1) blank (says "Class covariance matrices")                 */
/*   8+C+2) class#                                                   */
/*   8+C+3) COVAR(0,0) COVAR(0,1) ... COVAR(0,N-1)                   */
/*            N of these...                                          */
/*    C of these...                                                  */
/*-------------------------------------------------------------------*/
      int writesig(char *outfile,Sbdheader *head, Signature class[])
#define COV 32*MXCLAS
{
      int i,j,k;
      int clas, band, clases, nbands, eof, maxes[MXCLAS];
      int max[MAXSBD], min[MAXSBD], smean[MAXSBD][MXCLAS];
      long count[MXCLAS];
      float fcount, fmean, cova[32];
      float covar[MXBNDS][MXBNDS];
      float *covarm;
      FILE *fpin;
      char *trlptr, nameline[32];
      char dataline[70];
      char firstline[100];
      char moreline[80];

      if((fpin=fopen(outfile,"wt")) == NULL)
      {  printf("\nError opening outfile\n");
      return FAILURE;
      }
      fseek(fpin,0L,SEEK_SET);

      nbands = (*head).bands;
      clases = (*head).classes;
      i = 0;
      eof = NO;
      for (i=0; i< 70 ; i++)  dataline[i] = 0;
/* File search:  */
      while (eof == NO)
        {
   /* Header information:    */
           /*  First line  */
        strcpy(dataline,(*head).lanname);
        if (fputs(dataline,fpin) == NULL) eof = YES;     /* 1  */

           /*  Classes  */
        j = sprintf(dataline,"\n%d Classes",(*head).classes);
        if (fputs(dataline,fpin) == NULL) eof = YES;       /* 2  */
        if  (j < 1 || j == EOF) eof = YES;

           /*  Bands  */
        j = sprintf(dataline,"\n%d Bands",(*head).bands);
        if (fputs(dataline,fpin) == NULL) eof = YES;       /* 3  */
        if  (j < 1 || j == EOF) eof = YES;

        j = sprintf(dataline,"\n--Max data values--");
        if (fputs(dataline,fpin) == NULL) eof = YES;       /* 4  */

   /* Develop structures for each signature:   */
```

```
      /*  Get Maximum Values  */

    for (i=0; i<clases ; i++) maxes[i]=0;
    for (i=0; i<clases ; i++)
      { for (j=0; j<nbands; j++)
        { if(maxes[j] < class[i].maxvector[j])
          maxes[j]=class[i].maxvector[j];
        }
      }

    for (i=0; i< 70 ; i++)  dataline[i] = 0;
    j = sprintf(dataline,"\n");
    for (i=0; i< nbands ; i++)
     {
     j=sprintf(dataline+1+i*6,"%5d ",maxes[i]);
     }
    if  (j < 1 || j == EOF) eof = YES;
    if (fputs(dataline,fpin) == NULL) eof = YES;       /* 5  */

      /* 2 info lines */
    j=sprintf(dataline,"\n         ---BAND MEANS---");
    if (fputs(dataline,fpin) == NULL) eof = YES;       /* 6  */
    j=sprintf(dataline,"\nClass  Counts     Band Means\n");
    if (fputs(dataline,fpin) == NULL) eof = YES;       /* 7  */

/*  Write Mean Values  */
     for (clas=0; clas< clases ; clas++)
       {
       fcount = (float)class[clas].scount;
       j=sprintf(dataline,"%3d %7.1f ",clas,fcount);
       for (i=0; i< nbands ; i++)
        {
        j=sprintf(dataline+12+i*6,"%5d ",
                  (int)class[clas].meanvector[i]);
        }
       if  (j < 1 || j == EOF) eof = YES;
       if (fputs(dataline,fpin) == NULL) eof = YES;    /* 8>8+C */
       if (fputs("\n",fpin) == NULL) eof = YES;
       }

      /* Covariance line */
    j = sprintf(dataline,"Class covariance matrices");
    if (fputs(dataline,fpin) == NULL) eof = YES;       /* 8+C+1 */

      /*  Write Covariances  */
           for (clas=0; clas< clases ; clas++)
     {
     /* 1 Number line */
     if (fputs("\n",fpin) == NULL) eof = YES;
     strcpy(dataline,class[clas].signame);
     if (fputs(dataline,fpin) == NULL) eof = YES;    /* 8+C+2 */

     /* Unfold covariance */
     k = 0;
     for (band=0; band< nbands ; band++)
       {
       if (k > 32)
         { printf("\nError in covar computation!");
           return FAILURE; }
       for (i=band; i< nbands ; i++)
         { covar[band][i] = class[clas].covar[k];
           covar[i][band] = covar[band][i];
           k++; }
       }
     for (band=0; band< nbands ; band++)
       {
       if (fputs("\n",fpin) == NULL) eof = YES;
       for (i=0; i< nbands; i++)
        {
```

```
            j=sprintf(dataline+i*9,"%8.2f ",covar[band][i]);
            }
          if  (j < 1 || j == EOF) eof = YES;
          if (fputs(dataline,fpin) == NULL) eof = YES;
          }

        }

      eof = YES;
      }


    fclose(fpin);

    return SUCCESS;
}



/*=============================================================*/
/*                Function Readsbd                             */
/*       This routine reads data from ERDAS .SBD file.         */
/*                                                             */
/*       The arrays are all indexed from 0 to n-1.             */
/*                                                             */
/* Read in Data:                                               */
/*-------------------------------------------------------------*/
    int readsbd(char *sbdfile,Sbdheader *head,
      Signature class[])
{
    int i,j,k, clas, band, clases, nbands;
    unsigned char zero;
    FILE *fpsbd, *namout;
    char namfile[INPUTWIDTH],classname[32];
    char *trlptr;



/*  Read in .SBD file:  */
    if((fpsbd=fopen(sbdfile,"rb")) == NULL)
      { printf("Error opening sbdfile\n");
        return FAILURE;
      }
    fseek(fpsbd,0L,SEEK_SET);

    /* Read in Sbdheader:  */
      j = fread((*head).lanname,sizeof(char),100,fpsbd);
      j = fread(&(*head).classes,sizeof(int),1,fpsbd);
      j = fread(&(*head).bands,sizeof(int),1,fpsbd);
      j = fread((*head).blank,sizeof(char),24,fpsbd);

    nbands = (*head).bands;
    clases = (*head).classes;
    /* Read in Signatures: */
    zero = 0;
    if (nbands <= 0 || nbands > MXBNDS || clases > MXCLAS)
      { printf("Error reading signatures from sbd file\n");
        return FAILURE;
      }

    for (i=0; i<=clases; i++)
      {
        j = fread(class[i].signame,sizeof(char),32,fpsbd);
        j = fread(&class[i].scount,sizeof(long),1,fpsbd);
        j = fread(class[i].blank,sizeof(char),92,fpsbd);
        j = fread(&class[i].minvector[0],sizeof(int),MAXSBD,fpsbd);
        j = fread(&class[i].maxvector[0],sizeof(int),MAXSBD,fpsbd);
        j = fread(&class[i].meanvector[0],sizeof(float),MAXSBD,fpsbd);
        /* Handle ERDAS bugs: */
```

```
        if (nbands == 4)
          {
             k = fread(&class[i].covar[0],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[1],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[4],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[2],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[5],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[7],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[3],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[6],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[8],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[9],sizeof(float),1,fpsbd);
             for (j=10; j<32; j++)
              {k = fread(&class[i].covar[j],sizeof(float),1,fpsbd);}
          }
        if (nbands == 3)
          {
             k = fread(&class[i].covar[0],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[1],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[3],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[2],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[4],sizeof(float),1,fpsbd);
             k = fread(&class[i].covar[5],sizeof(float),1,fpsbd);
             for (j=6; j<32; j++)
              {k = fread(&class[i].covar[j],sizeof(float),1,fpsbd);}
          }
        if (nbands != 3 && nbands != 4)
            { for (j=0; j<32; j++)
              { k = fread(&class[i].covar[j],sizeof(float),1,fpsbd);}
            }

        for (k=0; k<nbands*512; k++) j = fread(&zero,1,1,fpsbd);
      }

    fclose(fpsbd);


    return SUCCESS;
}


/*=============================================================*/
/*               Function Writesbd                             */
/*       This routine writes data to ERDAS .SBD file.          */
/*                                                             */
/*       The arrays are all indexed from 0 to n-1.             */
/*                                                             */
/* Read in Data:                                               */
/*   1) name of sig file                                       */
/*   2) number of classes                                      */
/*   3) number of bands                                        */
/*   4) blank (says "--Max data values--")                     */
/*   5) max-B1 max-B2 ... max-BN                               */
/*   6) blank (says "---BAND MEANS---")                        */
/*   7) blank (says "Class  Counts  " then bands)              */
/*   8) class# mean-B1 mean-B2 ... mean-BN                     */
/*         C+1 of these...                                     */
/*   8+C+1) blank (says "Class covariance matrices")           */
/*   8+C+2) class#                                             */
/*   8+C+3) COVAR(0,0) COVAR(0,1) ... COVAR(0,N-1)             */
/*            N of these...                                    */
/*    C of these...                                            */
/*-------------------------------------------------------------*/
    int writesbd(char *outfile,Sbdheader *head,
      Signature class[])
{
    int i,j,k, clas, band, clases, nbands;
    unsigned char zero;
    FILE *fpout, *namout;
    char outnamfile[INPUTWIDTH],classname[32];
```

```
        char *trlptr;

        nbands = (*head).bands;
        clases = (*head).classes;


/*  Open .NAM file and write class names: */
        strcpy(outnamfile,outfile);
        if ((trlptr=strstr(outnamfile,".")) != NULL)
          { strcpy(trlptr,".NAM");  }
        if((namout=fopen(outnamfile,"wb")) == NULL)
          { printf("Error opening namefile\n");
            return FAILURE;
          }
        fseek(namout,0L,SEEK_SET);
        for (i=0; i<=clases; i++)
          { strcpy(classname,class[i].signame);
            fprintf(namout,"%s\n",classname);
          }
        fclose(namout);


/*  Write out .SBD file:  */
        if((fpout=fopen(outfile,"wb")) == NULL)
          { printf("Error opening outfile\n");
            return FAILURE;
          }
        fseek(fpout,0L,SEEK_SET);

        /* Write out Sbdheader:  */
          j = fwrite(&(*head).lanname,sizeof(char),100,fpout);
          j = fwrite(&(*head).classes,sizeof(int),1,fpout);
          j = fwrite(&(*head).bands,sizeof(int),1,fpout);
          (*head).blank[2]=1;    /* Histogram=yes */
          j = fwrite(&(*head).blank,sizeof(char),24,fpout);



        /* Write out Signatures: */
        zero = 0;
        if (nbands <= 0 || nbands > MXBNDS || clases > MXCLAS)
          { printf("Error writing signatures\n");
            return FAILURE;
          }

        for (i=0; i<=clases; i++)
          {
            j = fwrite(&class[i].signame,sizeof(char),32,fpout);
            j = fwrite(&class[i].scount,sizeof(long),1,fpout);
            class[i].blank[2]=1;    /* Histogram=yes */
            j = fwrite(&class[i].blank,sizeof(char),92,fpout);
            j = fwrite(&class[i].minvector[0],sizeof(int),MAXSBD,fpout);
            j = fwrite(&class[i].maxvector[0],sizeof(int),MAXSBD,fpout);
            j = fwrite(&class[i].meanvector[0],sizeof(float),MAXSBD,fpout);
            /* Handle ERDAS bugs: */
            if (nbands == 4)
              {
                 k = fwrite(&class[i].covar[0],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[1],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[4],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[2],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[5],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[7],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[3],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[6],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[8],sizeof(float),1,fpout);
                 k = fwrite(&class[i].covar[9],sizeof(float),1,fpout);
                 for (j=10; j<32; j++)
                  {k = fwrite(&class[i].covar[j],sizeof(float),1,fpout);}
              }
```

```
        else
          { for (j=0; j<32; j++)
            { k = fwrite(&class[i].covar[j],sizeof(float),1,fpout); }
          }
        for (k=0; k<nbands*512; k++) j = fwrite(&zero,1,1,fpout);
      }

    fclose(fpout);



    return SUCCESS;

}
#
```

2. A Comprehensive Unsupervised Clustering Technique for the Classification of Remotely Sensed Data.

A COMPREHENSIVE UNSUPERVISED CLUSTERING TECHNIQUE FOR THE CLASSIFICATION OF REMOTELY SENSED DATA

by

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A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

(Civil and Environmental Engineering)

at the

UNIVERSITY OF WISCONSIN-MADISON

1992

APPROVED:

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Date: Aug. 11, 1992

ABSTRACT

An original procedure to classify multispectral images into spectrally similar categories in an automatic, or unsupervised, manner has been developed at the Space Science and Engineering Center of the University of Wisconsin - Madison. This procedure has been integrated into an existing image processing package which provides an accurate, adjustable, and easy to use process for the extraction of thematic information from multispectral data.

The package presented consists of routines for image classification and analysis of classification output. It also includes routines which aid in comparing output with that of other classification methods.

The classification algorithm is recursive and processes an image repeatedly, using a changing set of spectral clusters which evolve to represent the statistical classes present in the data. Throughout the classification, oversized clusters are split using a method analogous to analyzing mass moments of inertia. Poorly separated clusters are merged using Transformed Divergence as a decision function for class separability. The final number of classes produced is a function of the degree of class separation and the class shape desired by the user.

Tests of the classifier show results to be better defined than for a commercially available package and a popular unsupervised routine. In addition, outputs of the classification have good accuracy in test images with ground truth. Additional tests of the classifier show many possible future applications.

ACKNOWLEDGEMENTS

I wish to express my thanks and gratitude to Professor Frank L. Scarpace, my Advisor, whose insight and support are greatly appreciated. I would like to thank Dr. Sanjay S. Limaye of the Space Science and Engineering Center, whose support, patience, and exceptional scientific knowledge are also greatly appreciated. In addition, sincere thanks are extended to the other members of my committee, Professors Thomas M. Lillesand and Ralph W. Kiefer.

This work was supported in part through NASA Contract NAS5-31347: "A Planetary Version of PC-McIDAS." McIDAS is the host package for the algorithms developed for this thesis.

I would like to thank the people at SSEC for their assistance and for a job well done in the development of the McIDAS-X system. David Santek provided McIDAS system programming assistance. Patrick Fry provided programming assistance and X-Windows graphing routines which were very effective and easy to use.

I would like to thank Philip Polzer for providing his data and image classifications for use in testing. Thanks also to Professor Roland Chin, whose courses in Digital Image Processing and Pattern Recognition provided me with a solid background.

I especially wish to express my gratitude to my family and friends for their encouragement and support. I wish to thank my father, Robert G. Peltzer, for providing me with much of the information and software I needed to write this document. I would like to thank Christine A. Wu for her help in editing and formatting, and for the all the support she has given me.

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1.0 INTRODUCTION

In recent years, the concurrent development of digital imaging systems and powerful, inexpensive computers has resulted in the development of the field of digital image classification. Image classification is a form of pattern recognition where the ultimate objective is to be able to represent an image by a set of classes or themes which describe all of the features present. Classifications are thus, in essence, maps of image features, and can contain spatial, spectral, or temporal information about data in image form.

The majority of image classifications are spectrally based, and are performed on multispectral images (Lillesand and Kiefer, 1987). These images contain recorded intensities of different wavelengths of light at each image element or pixel. The rationale behind spectral classification is that feature types exhibit unique spectral reflectance combinations, or signatures, which are contained in their data values in multispectral images.

The classification methods discussed in this paper are based on this spectral concept, and make use of multispectral data. This does not preclude the use of other types of data as long as they can be presented in the form of multiple data values, or bands, for each image element. For example, a temporal classification could be performed with bands containing data obtained at different times. Also, a spatial element could be introduced with the addition of bands containing ancillary geographic data (Northcutt, 1991). Once again, the rationale is that different feature types will show unique signatures in their multi-band data values.

Image classification can be performed in a supervised or unsupervised manner. In a supervised procedure, sample areas or "training sets", of known feature type are developed by the user and used to describe the spectral signatures of features. Each image element is then classified to the class it most

nearly matches. In unsupervised, or automatic classification, clusters are found which are statistical groupings of similar signatures, and then each element is classified to the most similar cluster. The main advantage of this method over supervised classification methods is that no training sets of known data need to be taken, giving the user a much easier procedure to follow. However, in an unsupervised process the user is left to define the relationship between clusters and feature types after classification. Unsupervised classification is also very useful in gaining insight into the nature or structure of the data, especially in the discovery of distinct new subclasses and departures from expected characteristics (Duda and Hart, 1973).

A wide variety of unsupervised clustering algorithms have been developed for applications in the field of statistical pattern recognition, many of which include heuristic procedures developed as a result of experience gained through experimentation (for some descriptions see Tou and Gonzalez, 1974, Duda and Hart, 1973). One of the most widely used of these procedures in image classification is the "Iterative Self-Organizing Data Analysis Technique" or ISODATA (Tou and Gonzalez, 1974). The advantages of ISODATA are that it is not spatially biased to any edge of the data file, and that it produces better results than other methods for data that are not normally distributed (ERDAS, 1990). The disadvantages include the narrow range of input parameters which lead to convergence, a simplistic, data dependent criteria for cluster splitting and merging, and a lack of control over the distribution and shape of output clusters.

1.1 Hypothesis

The thesis hypothesis is that an unsupervised classifier can be developed which is accurate, easy to use, and gives the user control of the distribution and shape of output clusters according to an absolute index of separability. This

classifier would be based on the ISODATA method, with an improved cluster splitting criterion analogous to mass moments of inertia, and a merging criterion using Transformed Divergence as a decision function to improve accuracy and ease of use.

1.2 Format of Document

In this thesis, the development and testing of an unsupervised classification procedure is illustrated. In Chapter Two, methodologies for multispectral image classification are reviewed, and the types of variables used and terms describing them are defined. The ISODATA method is developed in detail at the end of Chapter Two. In Chapter Three, the strengths and weaknesses of ISODATA and other classifiers are discussed, and procedures for a new classifier are derived in detail. In Chapter Four, the implementation of this new classifier is presented, including additional routines which aid in analysis of the classification output. In Chapter Five, classifiers are applied to several test images, and the accuracy and usefulness of the new classifier is assessed.

2.0 BACKGROUND AND LITERATURE REVIEW

Multispectral classification can be described as using pattern recognition to transform an image into a map of information classes, so any discussion of the subject needs to start with a description of the field of statistical pattern recognition. In pattern recognition, the question to be dealt with is: how does one specify a procedure for partitioning data? Whether separating apples from oranges or specifying land cover classes, the principal function of a pattern recognition system is to provide decisions to the user concerning the class membership of the patterns in the data encountered (Tou and Gonzalez, 1974).

2.1 Symbolic Definitions

Before moving further, a mathematical notation will be developed which can be used to describe the subjects covered in this paper. In general, bold face characters are used to denote vectors, and capitals are used to denote matrices. The matrix transpose is denoted by T, and vectors used will often be presented in their transposed format for convenience.

The mathematics of pattern recognition often involves use of a multi-dimensional geometrical pattern space. This pattern space is used to describe multispectral data, and is a geometrical construct consisting of a separate dimension for each type of data measurement. For example, in an n band multispectral image classification there will be n dimensions, one for each spectral band of data. For visualization, data is often presented in a scatter plot format, with multiple 2-dimensional scatter plots shown for data with more than two dimensions in pattern space.

Multispectral data values can be described as pattern vectors: $\boldsymbol{x} = (x1\ x2\ x3\ \ldots)T$. Here $\boldsymbol{x}$ represents all the data for one image picture element; each xi is the value of the ith band of data.

The mean vector of a class k is described as: $m_k = (m1\ m2\ m3\ ...)T$ Here m represents the vector of means for a class of data; each mi is the value of the mean of the class in the ith band of data. The terms 'class' and 'cluster' will often be used together, and have essentially the same meaning here.

It is often reasonable to assume that classes are sets of data containing multivariate Gaussian distributions. In this case, a measure of the joint variation of two variables about their common mean can be developed (Jensen, 1986). This measure is called the covariance and is defined as: $cij = E\{[x-mi][x-mj]\}$. Here E denotes the expected value of a function and cij represents the covariance between dimensions i and j. Computationally, the covariance is usually represented as a matrix for a given set of data. The covariance matrix of a class k is represented as:

$$K_k = \begin{bmatrix} c11 & c12 & ...c1n \\ c12 & c22 & ...c2n \\ c1n... & & cnn \end{bmatrix}$$

Note that the covariance matrix is symmetrical; $cij = cji$ always.

The diagonal elements of the covariance matrix, cii, are actually the variances of the data set in each band. The square root of these variances gives the standard deviation vector for the class, which is defined as: $\sigma_k = (\sigma1\ \sigma2\ \sigma3\ ...)T$.

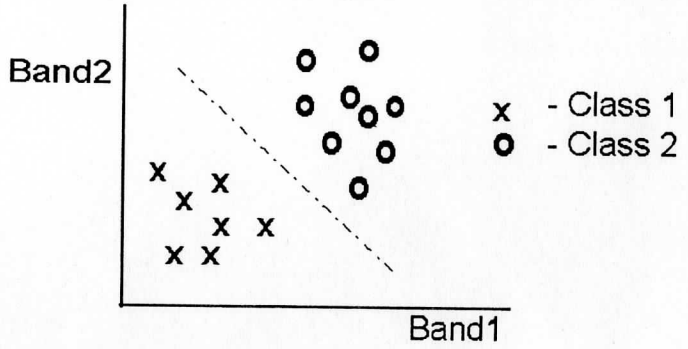
The covariance matrix contains information about the similarity and relationships between different bands in the data, but at first glance is difficult to interpret. Another way to interpret this information is with the correlation matrix, which is easily derived from the covariance. The correlation matrix contains elements which give a correlation for data values in one band versus another; each element is computed as: $cij/(\sigma i*\sigma j)$ (Jensen, 1986). For example, the

correlation between bands 1 and 2 is $c12/(\sigma 1 * \sigma 2)$. Correlations run from -1 to 1, with 1 indicating band i's data varies in exactly the same way as band j, -1 being a perfect negative relationship between the two, and 0 being no correlation whatsoever.

2.2 Decision Functions

The question of how to partition data in a classification actually involves two separate issues: how should one measure the similarity between samples, and how should one evaluate a partitioning of a set of samples into clusters. (Duda and Hart, 1973) The traditional approach to these problems is to use a distance function to develop a set of decision functions in a multi-dimensional pattern space. Decision functions are mathematical boundaries separating one class of data from another, and a set of decision functions for all possible class pairs is all that is needed to classify a data set. As an example, in an image with two dimensions of data, a decision function between two classes would simply be a line or curve delineating the border between classes (see Figure 1). For data of three dimensions, a decision function becomes a plane or surface, and in more dimensions decision functions are referred to as hyperplanes or hyperspace surfaces (Tou and Gonzalez, 1974).

Fig. 1. Decision function for two classes:



2.3 Distance Functions

An important approach to finding the similarity between samples is the use of distance functions in pattern space. Distance functions can be expressed as decision functions, and are a measure of a data point's similarity to a class. The relationship is essentially the smaller the distance, the greater the similarity. As an example, in Figure 1, an unknown data point could be classified as either class 1 or class 2 based on the shortest Euclidean distance to the mean vector of each class. This type of distance function is called Minimum Distance to Mean, or MDM, and can be described as $d = ||x - m||$. Here $||x - m||$ represents the Euclidean distance $\sqrt{(x1 - m1)^2 + (x2 - m2)^2 + \ldots (xn - mn)^2}$. Considering all possible values of x, the MDM function produces a linear decision function between two classes. In two dimensions, the decision boundary between class 1 and class 2 is a line normal to the vector from the first class mean to the second.

There are other meaningful distance functions which are sometimes useful in classification. The Mahalanobis distance, for example, is a useful measure of similarity when statistical properties of clusters are known. This distance is given as $d = (x - m)TK^{-1}(x - m)$, and is derived from the probability density function of a multivariate Gaussian distribution (Tou and Gonzalez, 1974). The Mahalanobis distance function produces a parabolic decision function between two classes where the focus in each dimension is the class mean with the smallest variance.

2.4 Clustering

Once a certain form of distance function is decided upon, the problem of classification becomes one of determining the best parameters. Theoretically,

applying standard parametric classifiers such as the maximum likelihood or Bayesian approach would be useful, but unfortunately these approaches do not yield analytically simple results (Duda and Hart, 1973). With these approaches, exact solutions have computational requirements that grow exponentially with the number of samples, making all but the simplest examples unmanageable. There is another set of classifiers, however, which are not subject to this limitation. These classifiers use a process called clustering, and there are many varieties of clustering routines. Duda and Hart (1973) present an excellent literature review of the history of the methods used in unsupervised clustering. Some of the earliest work in clustering was done in the field of numerical taxonomy, and Sokal and Sneath (1963) present references to this work. The remainder of this chapter will focus on the methodologies leading to the development of the ISODATA algorithm, which was first presented by Ball and Hall (1967) and described in detail in Tou and Gonzalez (1974).

To pursue the problem of clustering, some assumptions must first be made about the nature of image data. From a geometrical perspective, multispectral data can be viewed as clouds of points in an n-dimensional space. By assuming these clouds are normal distributions, a compact statistical description of the data can be developed. But what if the actual information classes in the image are not normally distributed and their probability distributions are unknown? In this case the normal assumption is still useful because the clustering procedure can approximate complex density functions with a mixture of normal distributions (Duda and Hart, 1973). The algorithm is not concerned with which combinations of normal distributions produce information classes; that task is left to the operator.

2.5 Criterion Functions

One way to determine parameters and develop a well-defined clustering routine is to define a criterion function that measures the clustering quality of any partition of the data (Duda and Hart, 1973). Criterion functions are designed to be minimized when the criterion for the best possible clustering according to the function is met. Some examples of criterion functions include the average squared distances between samples in each cluster, the scatter matrix criterion, and the trace and determinant criteria. Numerous other performance indices used in pattern recognition are useful in clustering.

2.5.1 Minimum Variance Criterion

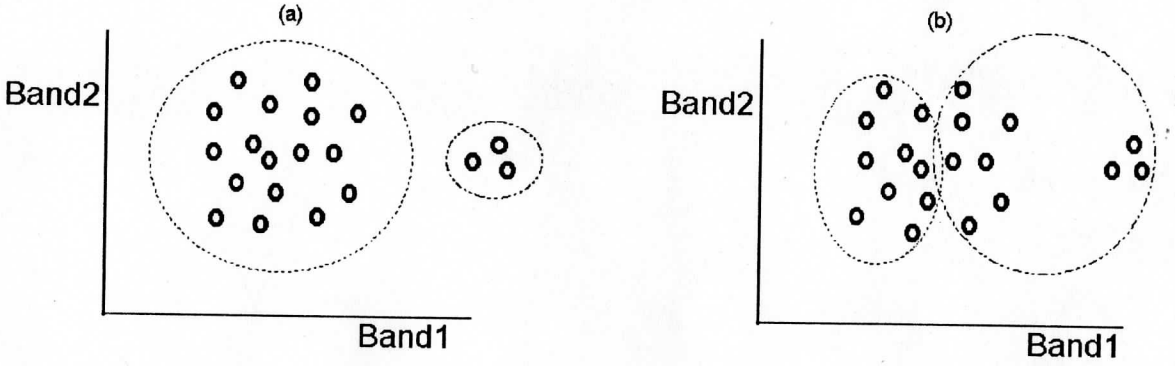
One of the most useful and widely used criterion functions is the sum of squared errors function. This function is also known as the minimum variance criterion (Murtagh, 1990), and is defined as: $J = \sum_{i=1}^{Nc} \sum_{\boldsymbol{x} \in Ci} ||\boldsymbol{x} - \boldsymbol{m}_i||^2$.

Here, J is the sum of squared error criterion, Nc is the number of clusters, and Ci is cluster i. The sum of squared error is the sum of the single class error criteria over all the clusters being analyzed. Each single class criterion is the sum of the distance from the mean squared for every data vector contained in the cluster. What J really represents is the total squared error incurred in representing the n samples ($\boldsymbol{x}$) by the Nc cluster means ($\boldsymbol{m}_i$) (Duda and Hart, 1973). This criterion is similar to a least mean square error (LMSE) algorithm, where the summation of errors to be minimized is proportional to an average or mean value (Tou and Gonzalez, 1974).

As with all criterion functions, the minimum variance criterion has its advantages and disadvantages. When the data forms clusters of compact, well-separated clouds it performs well, but, as can be expected, difficulties arise with

clusters that are not clearly defined. A less obvious problem arises when there are large differences in the number of samples in adjacent clusters (Duda and Hart, 1973). In this case, the larger cluster is partitioned poorly because a small reduction in the squared distance is multiplied by a large number of data points. This is shown in Figure 2, where the sum of the squared error is lower for the poorly defined partition of (b). This problem can be dealt with by the addition of other secondary criterion functions, which will be described later in this paper.

Fig. 2. The problem of classifying large clusters:



The sum of the squared error is larger for (a) than for (b).
(From Duda and Hart, 1973).

2.6 Decision Directed Approaches

Now the question at hand is how to implement the above criterion, decision, and distance functions into a useful unsupervised clustering routine. Duda and Hart (1973) concisely describe the best way to proceed as the decision directed approach, which is "to use the a priori information to design a classifier and to use the decisions of this classifier to label the samples." What this infers is that the classifier should use the knowledge accumulated from processed samples to alter the decision functions of the classifier. If these alterations are made to optimize a criterion function, a fairly robust classification scheme can be developed. An algorithm can follow this procedure by

processing the data set in a one-pass manner, or it can be designed to repetitively process the entire data set in a process of iterative optimization. The main advantage of one-pass methods is their speed, but they cannot compete with fully repetitive methods in thorough processing of data. Some of the more popular variations of one-pass methods include sequential clustering (ERDAS, 1990), and maximum-minimum distance algorithms (Tou and Gonzalez, 1974).

There are many varieties of iterative optimization procedures which follow the decision directed approach and make decision function alterations according to a criterion function. One of the most powerful classifiers developed recently is the AUTOCLASS algorithm, developed at the NASA Ames Research Center for analysis of Infrared Astronomical Satellite data (Denning, 1989). The AUTOCLASS program applies Bayesian inference to determine the most probable classification of the data, assuming normal distributions for classes. Construction of a set of all possible hypothesis would far exceed the capacity of any existing supercomputer, so AUTOCLASS constructs a locally most-likely hypothesis iteratively, using posterior probability as a criterion (Denning, 1989). Although very effective, AUTOCLASS is computationally intensive, requiring approximately 36 hours on a Symbolics mainframe to classify a star field of 5425 objects with 94 spectral bands of data each (Denning, 1989).

2.7 The ISODATA Classifier

The minimum variance criterion can also be used in an iterative optimization approach to image classification. This class of algorithm is generally named after the ISODATA method, an acronym for Iterative Self-Organizing Data Analysis Technique. Several versions of the ISODATA algorithm have been developed, starting with the basic iterative optimization and moving on to include secondary criteria and heuristic procedures.

The basic procedure for the ISODATA classifier is as follows. Initially choose a set of k cluster means. For the first iteration, classify each sample to the nearest cluster mean: $\boldsymbol{x} \in C_i$ if $||\boldsymbol{x} - \boldsymbol{m}_i(1)|| < ||\boldsymbol{x} - \boldsymbol{m}_j(1)||$, for all classes j. Next, find the new cluster centers which minimize the sum of squared distances from all points in each cluster C_i to a new mean for iteration 2, $\boldsymbol{m}_i(2)$. The beauty of this criterion is that the new set of $\boldsymbol{m}$ vectors which fulfill this requirement is simply the sample mean of all the elements classed in C_i (Tou and Gonzales, 1974, Duda and Hart, 1973). So each cluster i is assigned a new mean given by $\boldsymbol{m}_i(2) = \frac{1}{n_i} \sum_{\boldsymbol{x} \in Cj} \boldsymbol{x}$. The data is then re-classified using the new cluster means, and the means are once again updated to minimize the sum of squared distance. The process is repeated until the cluster means cease to vary significantly from one iteration to the next. When this convergence is reached, the user is presented with a set of classes which describe the locations of the local maxima in the data. This basic ISODATA routine is also known as the K-means algorithm for its function of allowing the analyst to specify the number of clusters (k) to be found in the data (Lillesand and Kiefer, 1987).

The basic ISODATA routine can be expected to yield good results when the data are arranged in clusters which are relatively far apart, and when the number of clusters in the data is known. For most practical applications, experimenting with the number of clusters and the initial cluster placement is required to obtain a good classification of data. This can be a time-consuming process considering that the image is processed repetitively for each classification, and multiple classifications must be performed to get good results.

To improve on the theme of the basic ISODATA, various secondary criteria can be added to the iterative optimization. Some of these procedures

are heuristic in nature, having been developed through experimentation with what 'looks good'. A definitive example of the standard full ISODATA routine is described in Tou and Gonzalez (1974); its routines for cluster splitting and merging will be discussed here.

One improvement is to optimize the initial placement of cluster means in the pattern space of the data set. A technique shown experimentally to be a good method is to spread the initial cluster means linearly and evenly from the minimum data value in each band to the maximum value in each band (ERDAS, 1990). In addition, deleting clusters which contain few or no pixels after each iteration can be used to rid the output of classes with no useful information.

2.7.1 Splitting Clusters

The two most important secondary criteria used in the full ISODATA routine are cluster splitting and merging. Cluster splitting involves breaking up clusters which are physically too large, dimensionally too elongated, or whose distribution is too far from a normal distribution. In the standard ISODATA, a splitting criterion is applied to all clusters on every even iteration. This criterion is applied by taking the standard deviation vector for each cluster j, $\sigma_j = (\sigma_{1j}, \sigma_{2j}, \ldots \sigma_{nj})$, and finding the maximum component σ_{jmax}. In addition, the average distance of samples from the cluster mean vector in each class j is computed: $\overline{D}_j = \frac{1}{Nj} \sum_{x \in Cj} \| x - m_j \|$, with Nj being the number of samples in cluster j. From this, an overall average distance is obtained by: $\overline{D} = \frac{1}{N} \sum_{Cj} Nj \overline{D}_j$, where N is the total number of data elements in the image. Finally, the criterion is: if, for a class j, $\overline{D}_j > \overline{D}$ and $\sigma_{jmax} > \Phi$, then split cluster j into two new clusters. Φ is the split factor, input by the user. Thus the cluster is split if its

greatest variance in any band is larger than a maximum allowable value and if it is of larger than average size. The two new clusters are assigned the mean vector of the original cluster, then an amount equal to a fraction of σ_{jmax} is added to the mean vector of the first and subtracted from the mean vector of the second. This amount should be large enough to make a detectable difference, yet not so large as to cause the new means to interfere with other clusters.

2.7.2 Merging Clusters

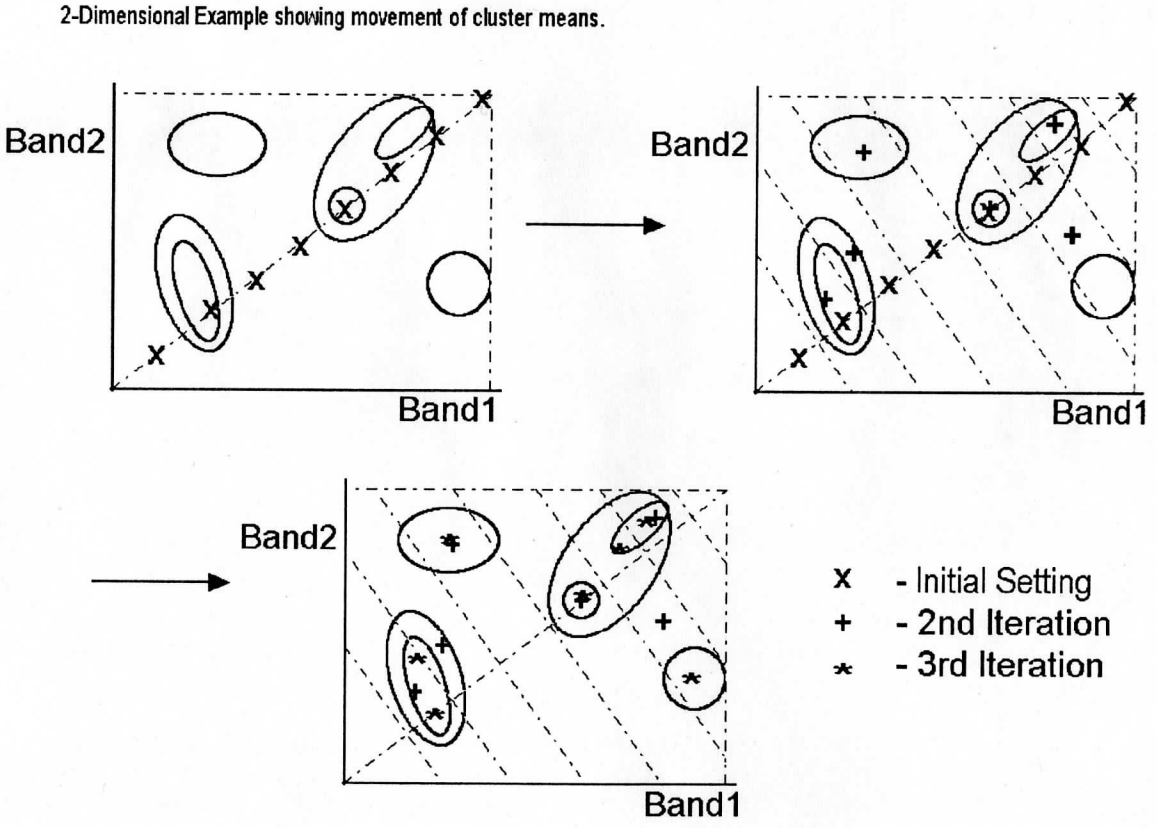
Cluster merging in the ISODATA routine involves combining clusters whose characteristics are too similar according to some criterion. In the standard ISODATA, clusters are merged simply if their means are too close together. Functionally, cluster merging takes place on even iterations, or when no cluster splitting occurred. The pairwise distances between cluster centers are first computed: $D_{ij} = \| \boldsymbol{m}_i - \boldsymbol{m}_j \|$, for every combination of classes i and j. The L smallest pairs with distances that are less than a distance of Θ apart are merged. Here L is the maximum number of mergings and Θ is the merging factor; both are input by the user. The new merged cluster mean is a weighted average of the previous means: $\boldsymbol{m}^* = \frac{1}{N_1 + N_2}(N_1 \boldsymbol{m}_1 + N_2 \boldsymbol{m}_2)$, where N_1 and N_2 are the number of pixels in the two original clusters.

2.7.3 ISODATA Illustrated

The standard ISODATA procedure is illustrated in Figure 3. In this two-dimensional example, a scatterplot of a hypothetical data set is shown. Initially, the cluster means are distributed equally from the minimum to maximum values of the data in both bands, and are shown as 'x's. At the end of the first iteration, the means migrate to new positions (shown as '+'s), with the two clusters at the extreme ends being removed as empty clusters. Note that the clusters are moving toward the maxima of the data set, with the exception of the cluster

located between two maxima in the upper right. This cluster is split as its variance in band 2 is quite large relative to the other clusters. By the third iteration (shown as '*'s), the split has produced two clusters which are much closer to peaks in the data. In the upper right corner, there are two clusters which are relatively close to one another. These two would be merged if the merging parameter is greater than their pairwise distance.

Fig 3. ISODATA Procedure:



3.0 METHODOLOGY

The standard ISODATA routine is an effective means for classifying images in an unsupervised manner. However, there are several major drawbacks to the routine which make it difficult to apply and limit its effectiveness. The goal of this chapter is to describe these limitations and how they can best be overcome to produce a better classifier.

Before going into the specific strengths and weaknesses of the ISODATA routine, one central weakness of all iterative optimization routines needs to be addressed. Ideally, any clustering routine applied to an image would either find all the classes inherent in the data, or would have misclassifications if it were not comprehensive enough. Unfortunately, in the real world there is a significant problem with this, for in an unsupervised setting, there is no definitive right answer; the true number of classes may be impossible to define in a realistic scene with gradually changing features. To compound this problem, the nature of iterative optimization routines is that different initial conditions will lead to different results. Iterative routines such as ISODATA can be unstable with respect to initial conditions, and a small change in input parameters can result in a large change in output results. This is because the convergence criterion has no memory and only works to minimize its error from the current conditions. It is extremely difficult to produce an unsupervised classifier which will always converge to a single 'right' answer, but it is possible to design a classifier which responds to input parameter changes in a predictable manner. Such a classifier would be very useful, providing a highly adjustable process which could be customized for different uses.

3.1 Problems with ISODATA

Although a good unsupervised classifier, the standard ISODATA routine has some significant weaknesses. The most significant problem with ISODATA involves the input parameters given by the user. As mentioned previously, ISODATA can be unstable with respect to changes in initial values. To compound the problem, the routine requires the user to provide values for these numerous initial parameters, some of which are data dependent. This has the result of forcing the operator to perform classifications repeatedly in a search for good results. In the standard ISODATA, there are essentially 5 input parameters: the initial number of classes, the separate splitting and merging factors, a maximum number of pairs to be merged, and a convergence threshold. Anderberg (1973) describes a version of the ISODATA method which requires 7 initial parameters.

One solution to this problem of too many parameters is to fix some of the variables to values which generally provide useful results for a range of input images. This can be done by defining each parameter to be a certain fraction of a maximum value encountered in the data set. Although certainly making the routine easier to use, this approach reduces its adaptability. A general rule in unsupervised clustering is that, as in the field of high-performance aircraft, more maneuverability means less stability and the need for a more highly qualified operator.

The best solution to this dilemma of clustering parameters however, is to reduce the number of required parameters and define them in terms of an absolute index. In the best possible classifier, all of the new parameters would be data independent, would have reliable default settings, and would produce output changes predictably. To build such a classifier, the ISODATA routine must be stripped down and rebuilt using a better set of secondary criteria.

3.2 Splitting Clusters

The first secondary criterion to deal with is the splitting criterion. The effect of cluster splitting on the overall classification should be relatively small, yet tests of the standard ISODATA implemented by the author have shown it to destabilize the routine, forcing more iterations before convergence. In addition to occasionally leading to a lack of convergence, this tends to make the routine's output unstable with respect to the splitting parameter Φ.

3.2.1 Standard Splitting Problems

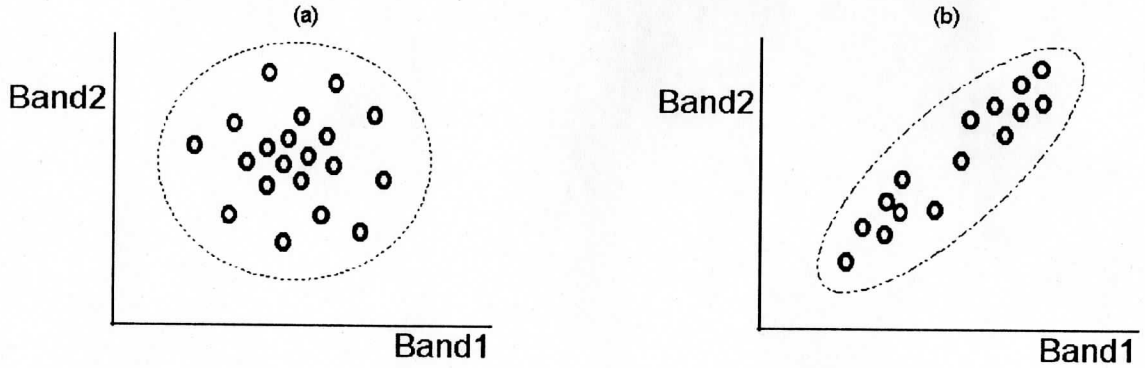
The standard ISODATA routine splits clusters when the greatest variation of sample data in one band is large. Here the user defines what is considered large by selecting the value of Φ. As a parameter, Φ can be input as a straight value, a percentage of the largest variance in the data, or a ratio of the largest variance over the smallest variance present in the data. All of these methods have been implemented in routines written by the author, and the ratio method has been found to produce the most reasonable working values. Regardless of the method used however, the splitting criterion still remains a simplistic method for splitting clusters.

There are three fundamental weaknesses with splitting routines that lead to poor judgment in cluster splitting and output instability when changing values of Φ. The first is that splitting is not determined (especially in the percentage approach) solely on one cluster's attributes, but from a relative index which changes with every iteration. The second problem is that there is only one splitting factor which must work for all image bands used in the classification. This can cause problems because if the variances are consistently larger in one band of the data, then that band will always determine cluster splitting. This common problem occurs when classifying data from scanners such as the

Landsat Thematic Mapper, where the thermal infra-red channel is statistically quite different from the other channels.

A third important weakness of the ISODATA splitting criterion (especially in the ratio approach) is that it analyzes the separability only along the axes of the bands in the pattern space of the classification. Splitting may not occur where it should because the data may have its maximum variance along axes not aligned along spectral channels. Figure 4 illustrates this condition by showing two clusters that are equally likely to be split according to the standard splitting criterion. Of the two, It is obvious that (b) should be the cluster to be split, but the variances in each band do not provide enough information to come to that conclusion.

Fig. 4. The problem of the ISODATA splitting criterion.



With equal variances along each band, both clusters have an equal potential for splitting.

So how can a better criterion for cluster splitting decisions be developed? To find the answer, it is necessary to discuss the factors leading to a decision to split a cluster into separate classes. The first thing to keep in mind is the MDM nature of the classification. Because of this, clusters with a normal distribution of similar proportions in all dimensions are to be desired. In looking at (b) of Figure 4, two things seem important in determining that it is the preferable

cluster to split. First, the ratio of the longest dimension of the cluster to the shortest dimension is a good indicator of how far the cluster is from a uniform normal distribution. Second, the distribution of samples (e.g. in clusters or smoothly distributed) is an indication of whether the cluster data is distributed normally or bimodally.

3.2.2 Mass Moments of Inertia

There is a way to incorporate these observations into a useful splitting criterion. This criterion uses a method which is based on the concept of mass moments of inertia from the field of mechanics. A moment of inertia is essentially a measure of the resistance of a body to angular acceleration about an axis of rotation (Hibbeler, 1986). What the method of moments of inertia can provide in terms of cluster splitting is an indication of the mass distribution of the contents of a cluster, and a means of measuring this distribution along the longest axis of the cluster.

The moment of inertia of an object about any axis is given by the parallel axis theorem: $I = Iobj + md^2$, where $Iobj$ is the moment of inertia of the object, m is the mass, and d is the normal distance to the axis. For a point mass, $Iobj$ is zero and m is equal to 1. For any normal three-dimensional object, there are three different moments of inertia and three products of inertia which describe the object's inertia about all possible axes. For an object filling a volume v with uniform density, the moments of inertia about the x, y, and z orthogonal axes are respectively:

$$I_{xx} = \int_v (y^2 + z^2)\,dv, \quad I_{yy} = \int_v (x^2 + z^2)\,dv, \quad I_{zz} = \int_v (x^2 + y^2)\,dv.$$

The products of inertia are respectively:

$$I_{xy} = -\int_{v}(xy)dv, \quad I_{xz} = -\int_{v}(xz)dv, \quad I_{yz} = -\int_{v}(yz)dv.$$

These expressions can be derived discretely for an object consisting of separate point masses (such as a cluster in the ISODATA routine). In this case, the integral is replaced by a summation. $I_{jj} = \sum_{x}^{data} \sum_{i \neq j}^{axes} (x_i - m_i)^2$ represents the moment about an axis j. The mean vectors have been included here to find the moment for an origin at the object's mean vector while using the general pattern space coordinate system. The product of inertia can be expressed as $I_{ij} = -\sum_{x}^{data}(x_i - m_i)(x_j - m_j)$ for the product involving axes i and j.

The inertial and product moments can be combined into a matrix called the inertial matrix (Greenwood, 1988). This 3 by 3 matrix contains all the information needed to know an object's mass distribution about any axis, and is given by

$$\boldsymbol{I} = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & Iyz \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix}.$$

To better develop a feeling for an object's mass distribution about an axis, the concept of a radius of gyration can be defined. It can be seen that a moment of inertia about an axis is the integral of all the mass elements making up the object, multiplied by the square of the distance from that axis. The effective (or root mean square) value of this distance for an object is known as the radius of gyration for the given axis (Greenwood, 1988). This radius is defined as

$k_i = \sqrt{\frac{I_{ii}}{m}}$ for an object mass m and axis i in the pattern space of the classification. The radius of gyration is an extremely useful concept in cluster splitting, giving an indication of how far, on average, samples are located from any axis passing through the mean vector of the cluster.

Another useful concept related to the inertial matrix is that of principal axes. For any given object, there always exists a set of axes for which the products of inertia are all equal to zero, and the inertial matrix is diagonal. In this special case, the axes are called the principal axes, and the corresponding moments are the principal moments of inertia. Specifically, the principal moments are found from the eigenvalues of the inertial matrix; the corresponding eigenvectors give the principal axes. The key to the principal moments of inertia is that they, as eigenvalues, contain the largest and smallest possible values for the system. This translates into knowing the largest and smallest radii of gyration, and the longest and shortest axes of an object.

3.2.3 An Improved Splitting Procedure

At this point, a new criterion for cluster splitting can be developed from the above concepts - a criterion where each cluster is judged individually and there is no comparison between clusters. The procedure starts by finding the inertial matrix for the cluster to be considered. The principal axes and moments of inertia are found, and the ratio of the longest to shortest dimensions of the cluster in terms of radius of inertia is computed. This length to width value is then compared to the splitting parameter, which now represents an absolute measure of the 'roundness' of the cluster. For example, a split factor of three would split any cluster whose longest dimension is greater than three times its smallest. If the cluster is split, the two new means are moved apart by one radius of gyration in the direction of the longest axis of the cluster. This criterion

is not prevented from using more than three bands of data, as the mathematics remain valid for multidimensional inertial matrix operations.

After some consideration, it may seem that the actions of the inertial and covariance matrices are similar, and that this splitting procedure could be related to the covariance matrix of the data. This is indeed the case, and the principal axes can be found through a principal components analysis of the covariance matrix. Alternatively, a simple relationship between the inertial and covariance matrices can be derived. Each diagonal element of the covariance matrix (relating to the variance) can be expressed as: $Cii = \frac{1}{(n-1)} \sum_{x}^{data} (x_i - m_i)^2$, where n is the data count of the cluster. The diagonal elements of the inertial matrix can then be expressed as: $I_{ii} = (n-1) \sum_{j \neq i}^{bands} Cjj$. Similarly, the non-diagonal elements, $Cij = \frac{1}{(n-1)} \sum_{x}^{data} (x_i - m_i)(x_j - m_j)$, can be used to make $I_{ij} = -(n-1)Cij$. The inertial matrix can now be written from components of the covariance matrix as:

$$\boldsymbol{I} = \begin{bmatrix} I_{12} & I_{12} & I_{1n} \\ I_{12} & I_{22} & I_{2n} \\ I_{1n} & I_{2n} & I_{nn} \end{bmatrix} = (n-1) \begin{bmatrix} (c22+...cnn) & -c12 & ...c1n \\ -c12 & (c11+cnn) & ...-c2n \\ -c1n & -c2n... & (c11+c22...) \end{bmatrix}$$

3.3 Merging Clusters

In the ISODATA routine, the most important secondary criterion is that of cluster merging. In most applications of the standard ISODATA, cluster splitting and merging compete to produce a final number of output classes. The merging

parameter must walk a fine line, merging similar clusters without producing an elongated cluster that will be split on the next iteration (leading to an endless cycle with no convergence).

3.3.1 Standard Merging Problems

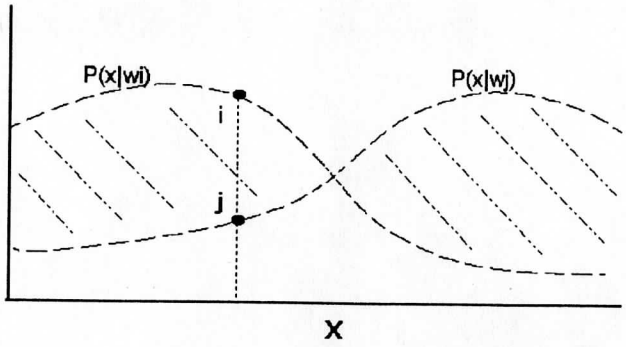
The standard merging criterion has problems because it works solely with cluster mean vectors and not with information about cluster distributions. It also suffers from the same problem of the standard splitting routine: it uses a relative merging parameter Θ which changes every iteration. It should be noted here that in the standard merging routine, Θ is best input as a fraction of the maximum distance found between cluster pairs. Any other method, such as direct distance, has been found in tests by the author to be too unwieldy for normal use.

3.3.2 Divergence

It now becomes obvious that to design a better merging routine, a criterion needs to be developed which can quantify the similarity between two clusters while taking into account their sample distributions. In the field of pattern recognition, there exists just such a measure, known as divergence. Divergence is a measure of the statistical dissimilarity between two classes, and can be used to evaluate the effectiveness of classification decisions.

The concept of divergence can be developed from the laws of conditional probability (Tou and Gonzalez, 1974). If the probability of having a data sample x, given that it belongs to cluster wi is $P(x|wi)$, then a likelihood ratio can be developed between the two classes wi and wj as $Uij = ln\frac{P(x|wi)}{P(x|wj)}$. This ratio can be better understood through Figure 5, where it is apparent that the ratio is a measure of the likelihood of finding x in class wi versus finding it in class wj.

Fig. 5. Conditional probabilities:



The expected value of the likelihood ratio for the class wi is $E\{Uij\,|wi\} = \int_{x} P(x|wi)\, ln\frac{P(x|wi)}{P(x|wj)}dx$. There is also the expected value of the class wj's likelihood ratio, which is $E\{Uji\,|wj\} = \int_{x} P(x|wj)\, ln\frac{P(x|wj)}{P(x|wi)}dx$. Uij is equal to $-Uji$, so this can be expressed as $E\{Uji\,|wj\} = \int_{x} -P(x|wj)\, ln\frac{P(x|wi)}{P(x|wj)}dx$. The divergence between wi and wj is given as $Div_{ij} = E\{Uij\,|wj\} + E\{Uji\,|wi\}$, and can be re-written as $Div_{ij} = \int_{x} [P(x|wi) - P(x|wj)]\, ln\frac{P(x|wi)}{P(x|wj)}dx$. What this essentially means is that the divergence is proportional to the shaded areas of Figure 5 showing dissimilarity between classes. As the two classes become more distinct, this area increases along with the divergence.

An equation for the divergence in multidimensional situations can be derived as long as the conditional probability $P(x|wi)$ is known. For multivariate normal distributions, the conditional probability can be defined as $P(x|wi) = \frac{1}{2\pi^{n/2}|\mathbf{K}_i|^{1/2}} exp[-\frac{1}{2}(x-m_i)^T \mathbf{K}_i^{-1}(x-m_i)]$, where $|\mathbf{K}_i|$ is the determinant of the covariance matrix $\mathbf{K}_i$. The divergence can then be derived

as

$$Div_{ij} = \tfrac{1}{2} tr[(\mathbf{K}_i - \mathbf{K}_j)(\mathbf{K}_i^{-1} - \mathbf{K}_j^{-1})] + \tfrac{1}{2} tr[(\mathbf{K}_i^{-1} + \mathbf{K}_j^{-1})(\mathbf{m}_i - \mathbf{m}_j)(\mathbf{m}_i - \mathbf{m}_j)^T]$$

, where *tr* is the trace, or sum of the diagonal elements, of a matrix (Tou and Gonzalez, 1974).

When the divergence between two clusters is calculated, the resulting value can be difficult to interpret. To convert to a scale which is more easily understandable, the concept of transformed divergence has been developed (Kumar and Silva, 1977). The transformed divergence gives an exponentially decreasing value for the separability of a pair of classes and is expressed as $TDiv_{ij} = 2000(1 - exp\frac{-Div_{ij}}{8})$. A transformed divergence of 2000 indicates total separation of the classes while 1700 or less is poor according to Jensen (1986).

3.3.3 An Improved Merging Procedure

A good procedure for cluster merging can now be put together with the use of a criterion based on divergence. This criterion ensures that an absolute index of class separability is used and that merging should not interfere with cluster splitting when parameters are set to reasonable values. In this procedure, the transformed divergence is first calculated for every combination of cluster pairs. Next, any clusters with a transformed divergence less than the merging parameter Θ are merged. Θ is now a transformed divergence threshold; the output classification is guaranteed to have clusters with a transformed divergence greater than the minimum selected by the user.

3.4 An Improved Classifier

The ISODATA routine can now be rebuilt with these improved procedures for cluster splitting and merging. Theoretically, the process is straightforward,

but producing a working classification system is challenging and requires a whole host of additional procedures. In the practical development of the algorithm, there are more ways in which the standard ISODATA can be improved upon. The next chapter will describe a working example of a complete unsupervised classification system based on the improved ISODATA classifier.

4.0 IMPLEMENTATION

The development of this thesis came about partly as a result of a perceived need for a good unsupervised classification system to augment available image processing packages. The basic requirements for a useful classification system would consist of one or more classification routines, a means of display and printout, and a way to edit output classifications and easily examine their class statistics.

4.1 Software and Hardware Packages Used

Currently, two major software packages are available for users of remotely sensed data at the University of Wisconsin - Madison. The first package is the Environmental Remote Sensing Data Analysis System, or ERDAS, and is used at the University's Environmental Remote Sensing Center. The second package is the Man-Computer Interactive Data Access System, or McIDAS, developed by the University of Wisconsin Space Science and Engineering Center (SSEC). The idea to develop an unsupervised classification system for McIDAS came about because there was no available classification routine for the McIDAS system, and the ERDAS ISODATA routine previously produced such poor results as to be practically useless. The ERDAS corporation has recently rewritten its version of the ISODATA routine, which now produces good results and provides a benchmark for testing classification routines.

4.1.1 McIDAS

McIDAS is a very powerful data analysis system used in meteorology, remote sensing, and planetary science. It is unique in that it has the capability to ingest real-time data from geostationary and polar orbiting satellites (McIDAS Applications Guide, 1985). It also has the ability to process large amounts of data rapidly and display time sequences of images in a motion-picture fashion.

McIDAS is an open system and has the advantage of allowing the user to integrate additional routines into the main body of code through a custom compiler. It is currently available on several types of computers, including IBM PS/2 compatibles and IBM RISC workstations. The classification system was developed on the UNIX version of McIDAS, McIDAS-X, because of the speed of the workstation and its UNIX operating system which allows multitasking and integration of FORTRAN and C languages. In the time span of this project, McIDAS-X has gone from beta test to full release versions, and has proven to be an excellent host system for image classification.

McIDAS-X runs in an X-Windows environment and consists of a window for command input, an image window, and one or more output windows. An example of how McIDAS and its classification system appear to the user is shown in Image 1. The image window contains a number of frames, each of which may contain an image or graph. Only one of these frames may be displayed at a time, but the user can switch the display between frames rapidly. This feature can be very useful in viewing subtle changes in similar images or image classifications. Commands in McIDAS-X are entered through the command window, where they are processed in a background mode. The advantage of this is that the user is able to work on other projects while large, time consuming processes are running. Because of the mainframe origin of McIDAS, programs generally are not run in an interactive manner and all the information the program needs is given in advance.

4.1.2 ERDAS

The PC-ERDAS software package is a large conglomeration of image processing programs running on IBM PC compatible computers. PC-ERDAS contains several routines for multispectral image classification, including a version of the ISODATA routine, two one-pass methods for image classification,

and several routines for performing supervised image classification. The exact nature of the ERDAS ISODATA classifier is not described in the manuals, but can be inferred by watching it at work.

The ERDAS ISODATA routine requires initial parameters for the number of classes, the maximum number of iterations, and a skip factor. The skip factor works to speed up the routine by analyzing data only at pixels every nth row and column apart, where n is the skip factor. This can drastically reduce the time required, as a skip factor of four can make the classifier finish in one-sixteenth the time of a full classification. Increasing the skip factor could be expected to reduce the final number of output classes because the actual amount of data analyzed decreases. This is the case for the standard ISODATA classifier, but changing the skip factor in the ERDAS ISODATA classifier causes unpredictable changes in the classification output. This is because of a key characteristic of the ERDAS routine; the ERDAS ISODATA is a k-means classifier whose output number of classes is the same as that input. As with all k-means methods, this has the advantage of producing exactly the number of classes desired, but is insensitive to the actual number of clusters in the data. It is unknown whether ERDAS incorporates any cluster splitting or merging with its k-means approach. However, plots of cluster signatures suggest that a length-to-width means for cluster splitting is not used.

4.1.3 File Translation

To transfer files between ERDAS and McIDAS, a set of file translation programs were written early in the project. These programs allow the user to move images between systems and compare classification results in one system versus the other. Specifically, they translate image files between the ERDAS *.LAN* image format and the McIDAS area format, and translate classifications between the ERDAS *.GIS* format and McIDAS classification areas. ERDAS

image classifications are composed of three files: *.GIS* files, *.TRL* files, and *.SBD* files. The *.TRL* files contain enhancement tables relating the display color to the class number, while the *.SBD* files contain statistical signature information about spectral classes. In McIDAS, the equivalent to the enhancement table file is the standard *.ET* file and the equivalent signature file is the *.SIG* file, a format developed for this project. There are 3 main programs which are listed in Appendix B: ATOERD.C, ERDTOA.C, and SBDSIG.C. ATOERD converts from McIDAS to ERDAS while ERDTOA converts from ERDAS to McIDAS and SBDSIG converts between *.SIG* and *.SBD* formats.

4.2 The McIDAS Classifier

The McIDAS classification system developed by the author consists of a set of original routines and existing functions that allow the user to classify and analyze multispectral images within the McIDAS system. In this new system, there are essentially three classification routines and a routine for visualizing the output classes of a classification. In addition, the McIDAS system provides routines for displaying classifications and changing the output enhancement table in order to highlight or merge classes.

The first two classification routines in the system consist of an implementation of the standard ISODATA and an MDM classification routine. The MDM routine reads in class signatures from *.SIG* files and is designed to classify additional images from clusters derived in an ERDAS ISODATA or McIDAS classification. The standard ISODATA routine uses a ratio based splitting parameter which is the largest allowable ratio of maximum to minimum standard deviations. The standard ISODATA subroutines for cluster splitting and merging are included in ISO.FOR in Appendix B

The most important routine of the package is the improved ISODATA classifier, named USCLAS. USCLAS embodies all of the criteria proposed in

this thesis, including cluster splitting using moments of inertia and cluster merging using transformed divergence. The full USCLAS program is included in Appendix B.

4.2.1 USCLAS

USCLAS is run as a command in the McIDAS system, with parameters entered through the command line. The only required parameters are for the input and output areas, though a number of adjustable parameters may be entered. The default parameter settings are given in the help menu for the program. When first viewing the USCLAS help menu, the assortment of parameters might seem confusing. This should not be disconcerting, as the program is designed for ease of use and should produce good classification results using defaults. The additional parameters, however, can be very useful in gaining added control over the output of the classifier. The program parameters will now be discussed with an emphasis on their relation to the performance of the classifier.

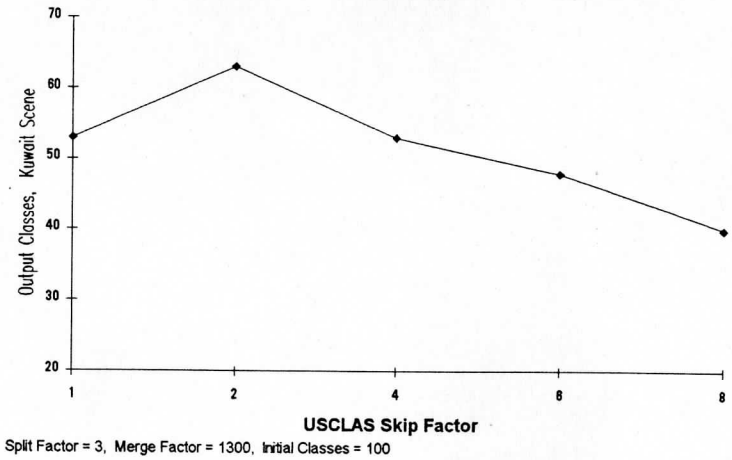
The first optional parameter is *nbands*, the number of bands. This parameter allows the user to run a classification using either all of the bands of an image, or only selected bands. The maximum number of bands is currently set at seven.

The next parameter, *clases*, allows the user to choose the initial number of classes for the classifier to work with. The initial number of classes has an important and predictable effect on the classification output. Increasing the number of initial classes in USCLAS generally produces a larger number of output classes that meet all the other requirements of the classification. This effect is one of diminishing returns, however, and increasing the initial number of classes beyond a certain threshold ceases to change the output classification. A high value of around 200 initial classes has been found to be most effective for

finding as many distinct classes as possible in the data; however, values greater than 100 generally work well.

The *skip* parameter sets the classifier to analyze data only at every *n*th row and column. This speeds up the clustering by a factor of n^2, but at a cost of a poorer classification. Unlike the ERDAS approach, the skip factor in USCLAS is used until convergence is reached, at which point the whole image (*skip* set at 1) is classified. A good approach to getting to a desired type of output quickly is to run USCLAS classifications with a large skip factor until the most useful program settings are found, then run USCLAS on the whole image to produce the final output. The effects of varying the skip factor on a test image are illustrated in Figure 6. In these classifications of an AVHRR scene with 4 bands, increasing the skip factor generally produces fewer output classes. (The AVHRR and the scene used are described in Chapter 5.)

Fig. 6. Output classes as a function of skip factor.



The parameter *iter*, the maximum number of iterations allowed, has a default of 35. This should be enough in most cases, except for data where the image bands are not registered well to each other. In general, changing the other parameters in USCLAS makes the classifier either more or less demanding, which is reflected in an increase or decrease in the required

iterations. If USCLAS goes to the maximum number of iterations, it terminates and classifies the image using the last set of classes.

The *merge* and *split* parameters work as described earlier in the text. For merging, a transformed divergence value is entered. This value is the minimum transformed divergence allowed between cluster pairs. Although values of 1700 or greater are considered good theoretically (Jensen, 1986), practical values of around 1400 seem to show better results. The ERDAS ISODATA seems to agree with this value, as its output classifications often contain cluster pairs with transformed divergences of less than 1500.

For cluster splitting, a value for the ratio of the largest to smallest cluster dimensions is entered. The default ratio of three allows clusters to be essentially up to three times as long as they are wide. For cluster splitting as well as merging, an input of zero disables the routine.

The *null* parameter tells the MDM classifier how to handle data in which there are areas of no data for some or all of the bands. In the case where some bands are zero, USCLAS is generally forced to develop an entirely new set of classes for that area which have a zero mean in the empty bands. As this can be good or bad depending on the application, the null parameter can be set to classify pixels as zero if any one of the bands contains drop-outs, or only if all bands are empty. The classifier reserves the special class of zero for data drop out.

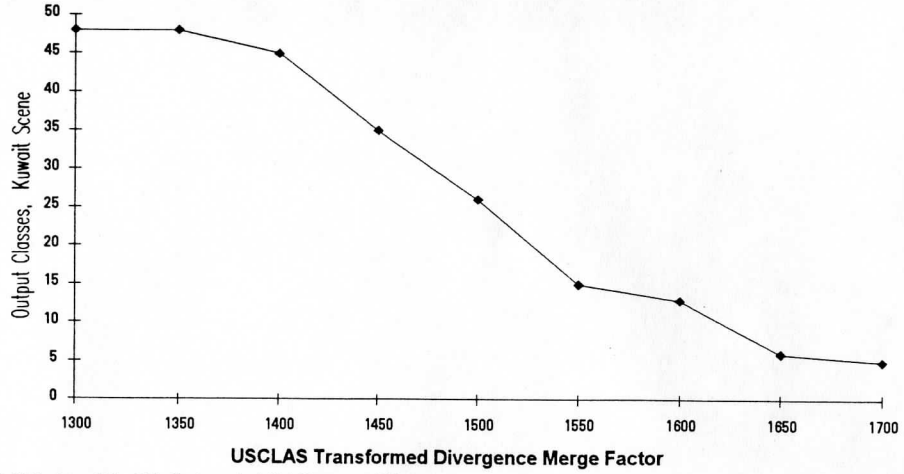
The *minpix* parameter is the key in defining the minimum number of pixels allowed in each cluster. In USCLAS, a cluster is defined as empty and is removed if there are fewer than the minimum number of pixels in that cluster. As many images contain noise pixels, setting the minimum number of pixels to a value greater than zero reduces the presence of small noise classes. Setting

this parameter to a value too high can eliminate small classes of useful information, however.

The *stretch* parameter in USCLAS allows the user to change the output appearance of the classification. In USCLAS, the output classes are given colors (described in the classification's enhancement table file) which try to match the 'colors' of the class mean vectors in the first three bands of the data. To make a more pleasing display, the colors are obtained from a histogram stretch of the mean vectors. The *stretch* parameter defines the type of stretch used: either linear or histogram equalization may be used.

One measure of the success of USCLAS as the practical implementation of the improved ISODATA classifier is in its response to the modified parameters. When changing the merging parameter, the classifier responds in a stable manner, as shown in Figure 7. Increasing the minimum transformed divergence in USCLAS makes for a more demanding classifier which reduces the output number of classes and increases the iterations required. At the extreme values of the merging parameter (no merging or no allowed cluster overlap), the classifier tends to an output equilibrium. Because of the predictable nature of this criterion, adjusting the merging parameter is the best way to fine-tune the number and characteristics of the output classes desired.

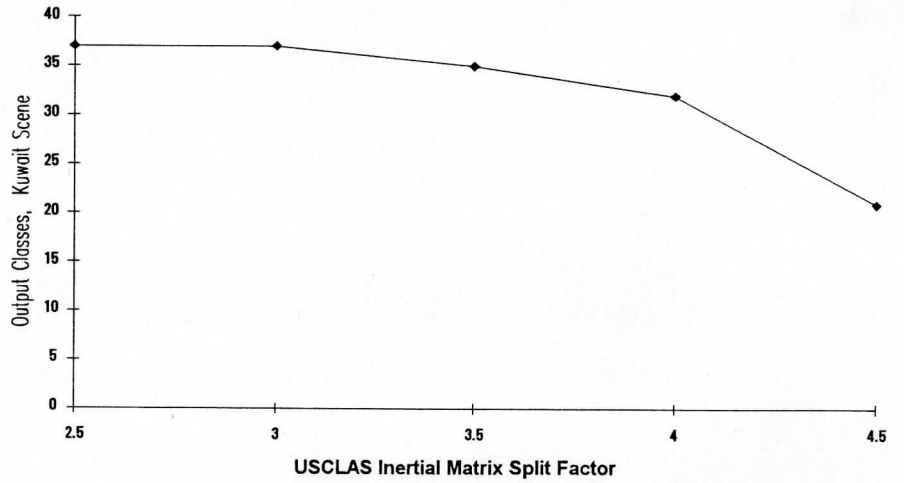
Fig. 7. Output classes as a function of merge factor.



Split Factor = 3.5, Skip Factor = 4, Initial Classes = 100

Cluster splitting also responds predictably to changes in the splitting factor for most images, as is shown in Figure 8. Due to the nature of the criterion however, the splitting factor is not recommended as a means to adjust the number of output classes, but rather as a check to ensure that class sizes are well behaved.

Fig. 8. Output classes as a function of split factor.



Merge Factor = 1450, Skip Factor = 4, Initial Classes = 100

The speed of USCLAS on an IBM RISC workstation is very fast relative to an ISODATA routine running on a PC-compatible computer, but still requires a significant amount of time. As an example of the time required, a USCLAS

classification of a 512 by 512 image containing six bands takes from twenty to forty minutes to classify, depending on the number of iterations required. The same scene processed through the ERDAS ISODATA on a 33MHz 80486 based PC-compatible computer can require over five hours to complete. The large difference in speed is due mainly to the differences in processing power and disk access time between the two computers, but there are also some speed enhancements incorporated into USCLAS. The standard ISODATA routine is slowed considerably by its need to access the disk repeatedly. For every iteration, it must read in the image, read in the old classification for comparison, then write out the new classification. This heavy disk access creates a scenario where the classifier works at the speed of the disk drive, no matter how fast the processor. In USCLAS, the output classification is kept entirely in memory until the final write, thus reducing the three disk operations to only one disk read each iteration.

4.2.2 Cluster Visualization

The USCLAS program produces four separate output files which contain the information from the classification. The display part of the output consists of a McIDAS area containing classified values for the image classified and an *.ET* enhancement table to provide colors for these classes. The other two files are *.SIG* and *.LOG* files which contain the statistics of the classification. The *.LOG* file is a log of the classification's operations through every iteration, including detailed descriptions of changing cluster means and statistics.

The *.SIG* file may be used to visualize the positions of the output classes in the pattern space of the classification through the use of the cluster visualization program named ELLIPS. ELLIPS is so named because it plots elliptical plots of the statistical distribution of the data in each cluster. This program also plots only the locations of the mean vectors of the data if

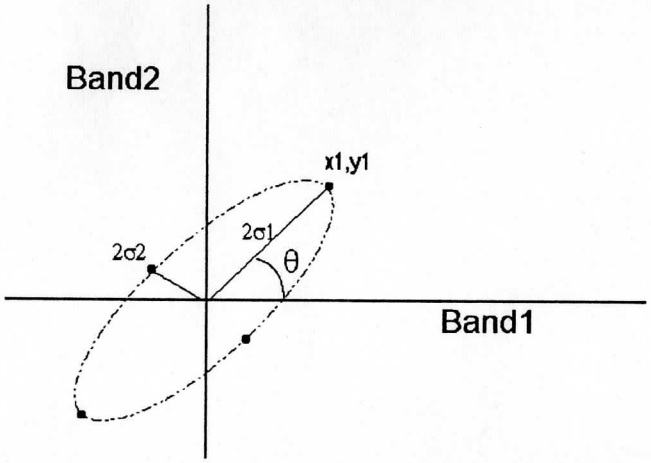
requested, but the elliptical plots give a much better indication of the spread and overlap of classes.

ELLIPS draws a series of elliptical plots, going through all the possible combinations of axes two at a time. An example of an ELLIPS plot can be seen in Image 1, where the ellipses of the displayed classification are drawn for bands two and three. To follow the process ELLIPS goes through, a two-dimensional covariance matrix can be analyzed:

$$\boldsymbol{K}_k = \begin{bmatrix} c11\ c12 \\ c12\ c22 \end{bmatrix} = \begin{bmatrix} \sigma_1^2\ c12 \\ c12\ \sigma_2^2 \end{bmatrix}.$$

A plot of a class distribution for a value of two standard deviations out from the mean vector would appear similar to Figure 9.

Fig. 9. Elliptical distribution plots.



In the ELLIPS program, a plot connecting the four points along the principal axes of the ellipse is performed for every class in the output. To obtain these points, the value of θ is first computed as $\theta = tan^{-1}[\frac{\sigma_2}{\sigma_1}]$. Coordinates for ellipse axes points are simply computed in the manner of

$x_1 = m_1 + 2\sigma_1 cos\theta$ and $y_1 = m_1 + 2\sigma_1 sin\theta$. ELLIPS uses two standard deviations as a default value, but will also accept any other value as an input parameter.

4.3 Performing a Classification

Now that the components of the classification have been described in detail, the classification procedure will be described to help clarify the way the system works.

To begin an image classification, a multi-band McIDAS area must be first obtained. (USCLAS will classify a single-band image, but this amounts to performing a level slicing operation.) If the image is in the form of several single-band areas, then the user must first run the McIDAS COMBIN routine, which was developed by the author to make a multi-band image from single-band components.

The next step is to run USCLAS. A help menu for the program can be obtained through the *HELP USCLAS* command. When running this or any other classification routine, the best approach is to switch to a separate output window, start the classifier, then switch back to the first output window. The USCLAS output, which includes progress updates every iteration, can then be monitored separately while other McIDAS routines are run.

Once USCLAS has finished running, the user may display the output area in the image window, using the command *EU REST nnnn* to color the classification image. *nnnn* is the output area number; all the USCLAS output files are written as this number plus an extension. Class colors may be modified with the *EU* command. Classes may also be merged by making component clusters of an information class the same color.

To aid in the analysis of output classes, the ELLIPS program may be called to create a window containing a plot of statistical ellipses or class means.

Several ELLIPS plots may be run at once; the only limitation is with available screen area for viewing.

After processing, the classification output may also be used as input for other McIDAS programs. The MDCLAS program, for example, can classify later images in a time series with the classes obtained from the first image of the series.

5.0 APPLICATIONS AND TESTS

In the course of its development, the USCLAS classification program has been used to classify a wide variety of test images. Classifications have been run on images from the Landsat Thematic Mapper (TM), SPOT High Resolution Visible (HRV) scanner, NOAA Advanced Very High Resolution Radiometer (AVHRR), Voyager spacecraft, and digitized aerial photography. All of these classifications have produced results that are appealing and useful to the user, so it could be argued that USCLAS is successful at producing good unsupervised classifications on a wide variety of data. It is important, however, to define just how good the classifier is in comparison with other classification methods.

To investigate the usefulness of the USCLAS program, three test images have been selected to provide working comparisons. These images consist of an AVHRR image of Kuwait and the Persian Gulf during the Gulf War, a Landsat TM image of agriculture in central Wisconsin, and a planetary mosaic of Jupiter created from Voyager spacecraft images. The three images were chosen specifically to allow USCLAS to be compared to as many other methods as possible. The Kuwait image provides a difficult scene for unsupervised classifiers due to the presence of gradually changing smoke features. The Wisconsin image, on the other hand, provides an easily classified scene for which a supervised classification made with ground truth is available. The Jupiter image used for the third scene is useful for comparison with published results of an unsupervised classification on a similar image.

5.1 A Challenging AVHRR Scene

The first scene to be analyzed is the Kuwait image: a NOAA-10 AVHRR image obtained on February 23, 1991. The AVHRR scanner has a resolution of approximately 1km per pixel, with four spectral bands of data. There is one band each for red visible light at .58-.68μm, near-Infrared (IR) at .7-1.1μm, mid-IR at 3.5-3.9μm (the spectral region of equal solar reflectance and thermal emission), and thermal IR at 10.5-11.3μm.

The Kuwait image is a complex scene with many interesting features, as can be seen from the visible and mid-IR bands displayed in Images 2 and 3. The most significant feature is the oil-fire smoke that drifts over the desert and the Persian Gulf. Smoke presents a challenge in classification because of its gradually changing density and spectral signature. It affects the signatures of the features it covers by lowering their effective albedo, and is very hard to differentiate over water. Another image feature which complicates classification comes in the form of sun-glint over the southern Persian Gulf. This saturates the mid-IR and thermal IR channels and is difficult to distinguish from the oil fires present in the image.

With these difficulties in mind, a series of classifications were performed to attempt a mapping of image features and smoke densities. First, the ERDAS ISODATA classifier was used to produce two classifications, one with 26 output classes and one with 40. Initial parameters for the ERDAS classifier were a skip factor of 1 and the same convergence criteria (96% of pixels unchanged) as that used in USCLAS. Next, USCLAS classified the image with two different merging parameter settings (transformed divergences of 1400 and 1450) to produce classifications with 44 and 24 classes, respectively. The USCLAS classifications used initial parameters of 200 initial classes, a skip factor of 1, and a splitting factor of 3. The 44-class USCLAS classification is shown in Image 4 along with

ellipse plots of the least correlated bands. The 40-class ERDAS classification is printed out in a similar manner in Image 5.

There are several dissimilarities between the two classifications which show the strengths and weaknesses of each. The first thing to be noticed about the two classifications is the difference in class colors. This comes from the use of a histogram equalization stretch in USCLAS; which creates more vivid colors at the cost of a less "natural" looking output. It is also evident that the ERDAS classification contains more classes in the general area of smoke-free desert. Although these classes might be useful for analysis, their transformed divergences are small and their shapes are subject to change with slight differences in initial parameters. A test of USCLAS using a transformed divergence merging parameter of 1350 brought out more land classes to make the output look similar to that of the ERDAS classification.

The most significant difference in the two classifiers is in the classification of the actual oil fires. In Images 6 and 7, the two classifications are shown in closer detail with water and fire classes highlighted for visibility. Here the advantage of the USCLAS splitting criteria over that of the ERDAS ISODATA routine can be clearly seen. For in the ERDAS classification, the oil fires are not composed of separate classes as in the USCLAS output, but are misclassified into several water classes. Increasing the number of classes in the ERDAS classifier does not solve this problem, as it persists for a wide range of input class numbers. In contrast, USCLAS finds several unique smoke classes throughout a wide range of input parameters when a reasonable splitting parameter is used.

The differences in classifications can also be seen in the ellipse plots of Images 4 and 5. In the ERDAS classification, the area of pattern space corresponding to smoke-free desert is crowded with a host of classes which

overlap in all band combinations. In contrast, the same area of the USCLAS output contains fewer classes in a quilted pattern with little overlap. The USCLAS output also contains many more classes in the spectral region of the snow covered areas of Iran (in the northeast corner of the image). These classes are most visible in the upper-right region of the ellipse plot for bands 1 and 3, and contain significant information that has been missed in the ERDAS classification.

The results of classifying this image and other similar scenes of the Kuwaiti oil fires show that the USCLAS classifier is the better approach to the problem of mapping oil fires and smoke densities in multispectral images.

5.2 Landsat Scene of Central Wisconsin

A Landsat TM scene of agricultural areas around Rush Lake (near Oshkosh, Wisconsin) is the next scene to be analyzed. This image, dated May 7, 1990, is one of a series of scenes for which supervised classifications with ground truth have been performed (Polzer, 1992). In the supervised classification of this scene, 174 initial training sets were taken and classified using the IR bands 3, 4, 5, and 7 of the Thematic Mapper. The results were then merged to make a classification with 42 output classes and a final display classification with a further reduction to 24 information classes. The final display classification was made with a majority smoothing filter and was not used in this comparison.

To test the USCLAS and ERDAS ISODATA classifiers against the supervised classification, a 600 by 600 pixel subset of the scene containing a large density of training sets was selected. This subset provides a test image of manageable size for repeated classifications. Although not reflecting the true diversity of the full scene, the subset image still contains most of its spectral

variation. For this reason, it is not unfair to compare classifications derived from this image with the supervised full scene classification.

To obtain results comparable to the supervised classification, the scene subset was classified by USCLAS using a skip factor of 1, a splitting factor of 3, and a merging factor of 1375, with 200 initial classes. This produced an output classification containing 36 classes. The image was also classified with the ERDAS ISODATA routine with the number of classes set at 42. These two classifications were then compared with a subset of the supervised classification.

The results of the classifiers can be seen in Images 8, 9, and 10, where a portion of the subset has been displayed for the USCLAS, ERDAS ISODATA, and supervised classifications, respectively. The darkest classes in the USCLAS and ERDAS images have been enhanced for greater visibility, and are shown in shades of blue. Also included in Images 8 and 9 are ellipse plots of the two band combinations with the least correlation. In these plots, band 2 represents the .76-.90μm TM band 4, band 3 represents the 1.55-1.75μm TM band 5, and band 4 represents the 2.08-2.35μm TM band 7.

It can be seen that the USCLAS and ERDAS results are similar for this scene with only a few differences. As in the Kuwait image, the ellipse plots show that the USCLAS output classes are more distinct and better distributed than the ERDAS ISODATA classes. The USCLAS classification also contains several more water-edge classes, including classes containing only a few pixels at the edge of Rush Lake. These classes are statistically unique, and may or may not be useful to the operator depending on the application. The *minpix* parameter of USCLAS can be very useful for this type of situation by allowing the user to eliminate these small classes if desired.

In comparison with the unsupervised classifications, the supervised output is much more difficult to interpret. Initially, the dissimilarity between color enhancement tables might lead the interpreter to consider the supervised results to be inferior, but a more careful analysis should be performed. Such an analysis requires an intimate knowledge of the scene and classification methods used, and is beyond the scope of this paper. However, some useful observations can still be made in comparing classifications. In general, the supervised classification appears less homogenous than the unsupervised results, and areas used as training sets often contain more than one class. In contrast, these training set areas in USCLAS are more homogenous and contain better separated classes. The accuracy of the USCLAS output based on training areas would likely be higher than that of the supervised classification because of this. A credit to the supervised classification comes in its separate class for roads (not shown in the image), which are only detectable as changes in class type in the unsupervised classifications.

5.3 Voyager Planetary Image

The final image to be analyzed is a mosaic of the planet Jupiter derived from images taken by the Voyager 1 spacecraft. It serves as an example of the application of unsupervised classification techniques to the analysis of cloud motions and cloud compositions. What makes this image useful as a test is that it may be compared with published work on a statistical clustering analysis performed on similar data (Thompson, 1990).

The image used is essentially a rectified map of the surface features of the planet Jupiter, and is one of a series of planetary mosaics made from images taken during the spacecraft's flyby of Jupiter in 1979. The images in this series cover 360 degrees of longitude with 9 pixels per degree for a total of 3240 image

elements. In latitude, they cover areas from 60 degrees north latitude to 60 degrees south latitude with 8 pixels per degree for a total of 960 image lines. Images using the .345μm ultra-violet (UV) filter, the .481μm blue filter, the .561μm green filter, and the .589μm orange filter were combined to make the four band image used for classification. Some problems with this type of image that make classification difficult include areas of data drop-out in one or more bands, areas of blurry imaging in the UV band, and poor geometrical registration between bands mainly in areas of high latitudes.

USCLAS was used to classify the Jupiter mosaic image with several different sets of input parameters in order to develop a feeling for how classifications of this type of image would turn out. Because of the registration problems, the USCLAS mosaic classifications exhibit a steep curve for the number of output classes as a function of the merging factor. Two classifications with good results were used for analysis: one in the middle range of output classes and one near the upper equilibrium number (where increasing the merging factor further ceases to affect the output). The first classification resulted in 26 output classes for parameters of 200 initial classes, split factor of 3, skip of 4, and merging factor of 1375. The second classification produced 38 classes with the merging factor at 1350. Image 11 shows the first classification with two accompanying ellipse plots of the least correlated bands of the data. The classes are seen to be well-behaved, except for classes 3, 6 and 14 which represent areas of poor (but not zero valued) data in band 4 (orange). For this classification the *null* parameter was used in the *null=any* setting to classify data as zero when any band contains a dropout. For the mosaic images, this helps to produce a neater classification.

The differences in output between the first and second classifications may be seen in Images 12 and 13. These cover a portion of the image in greater

detail, showing cloud structure around the Great Red Spot. The 38 class classification obviously contains more gradations in cloud types; whether this is an advantage or not is dependant on the application. In both cases, the classifications differentiate the separate cloud features well.

The USCLAS classifications of these Jovian mosaics have proven to be useful in current work on the cloud structure and mean zonal flows of Jupiter, but there remains the question of what the best number of output classes to work with is. Thompson, 1990, helps to answer this in his classification of similar composite images from Voyager 1 and Voyager 2. Thompson perfomed unsupervised classifications on Jovian mosaics using four bands composed of the green and orange filters along with the clear and narrowband Methane filters. Because the UV filter was not used, the images used were better in general than those classified by USCLAS and contained no drop-outs. In addition to the classification, a statistical package was used to determine the number of clusters which could be considered statistically significant. The results of this analysis showed there to be approximately 40 significant clusters, with 25 being of sufficient size to merit keeping. Thompson's results suggest that the USCLAS classifier is adept at finding the significant clusters in mosaic data, but the input merging parameter should be varied through a few classification runs in order to produce the best results for the application at hand.

6.0 SUMMARY

The goal of this thesis has been to present an unsupervised classification system which is accurate, easy to use, and more discriminating than other available methods. To reach this goal, a solid analysis of the most popular unsupervised classification methods was first presented, concentrating on the relative strengths and weaknesses of different methods. Next, the minimum variance criterion and the ISODATA method were shown to make a good basic framework for a new unsupervised classification routine. Additional criteria were then added to improve the classifier and provide more control over the nature of the output. Finally, a useful classification system was presented which integrates the new USCLAS classifier and a cluster visualization technique into an existing image processing package.

The new classification system was tested on a wide variety of images until the author was satisfied that its results are at least as useful as those from other available methods. In practice, the USCLAS classifier has performed as predicted, and has shown to be easily adjustable for optimizing the output to the application at hand. Additional comparisons of USCLAS to supervised classifiers in future projects would be useful in better defining the relative strengths and weaknesses of both approaches. The author encourages researchers to try this classification system along with traditional methods when working on detailed classification projects.

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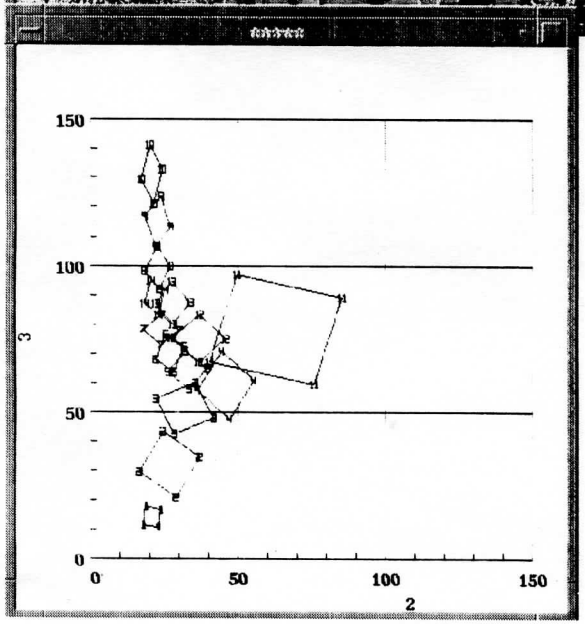
APPENDIX A - IMAGES


```
** MIRANDA **

SUMMARY FILE      3901.log
USCLAS UNSUPERVISED CLASSIFICATION
 INPUT AREA: 3900

    IMAGE CONTENTS
    ROWS:      600
    COLUMNS:   800
    BANDS IN AREA:     3
 BANDS TO CLASSIFY:     3
  MAX SKIP TO BE USED =     6
 DATA DROPOUT HANDLING USED = ALL
 MINIMUM PIXELS IN A CLUSTER =      47
 OUTPUT STRETCH USED = HIST

 OUTPUT AREA: 3901
```



McIDAS1 [T=4]

McIDAS0 [T=4]

```
USCLAS -- SPECTRALLY CLASSIFY A MULTI-BAND IMAGE
   --- UNSUPERVISED MULTISPECTRAL IMAGE CLASSIFICATION ---

            USCLAS INAREA OUTAREA
PARAMETERS:
          INAREA  - AREA TO BE CLASSIFIED
          OUTAREA - FINAL CLASSIFIED AREA WITH  M CLASSES.

KEYWORDS:
          BANDS   NUMBER OF AREA BANDS TO CLASSIFY,
                  DEFAULT IS ALL BANDS IN AREA.
                  USER DEFINES THE BANDS TO USE:
                      BANDS= BAND1 BAND2 ... BANDN
          CLASES: INITIAL # OF CLASSES PRESENTED.
                      CLASES= M                DEFAULT IS 100
          SKIP    SKIP FACTOR FOR ITERATIVE
                  CLASSIFICATION.  NUMBER OF ROWS
                  AND COLUMNS SKIPPED, MUST BE < 8.
                      SKIP= N                  DEFAULT IS 1
```

Loop	Bounds	Frame	Host	Image	Day	Time
off	random	4	no	on	92184	04:59

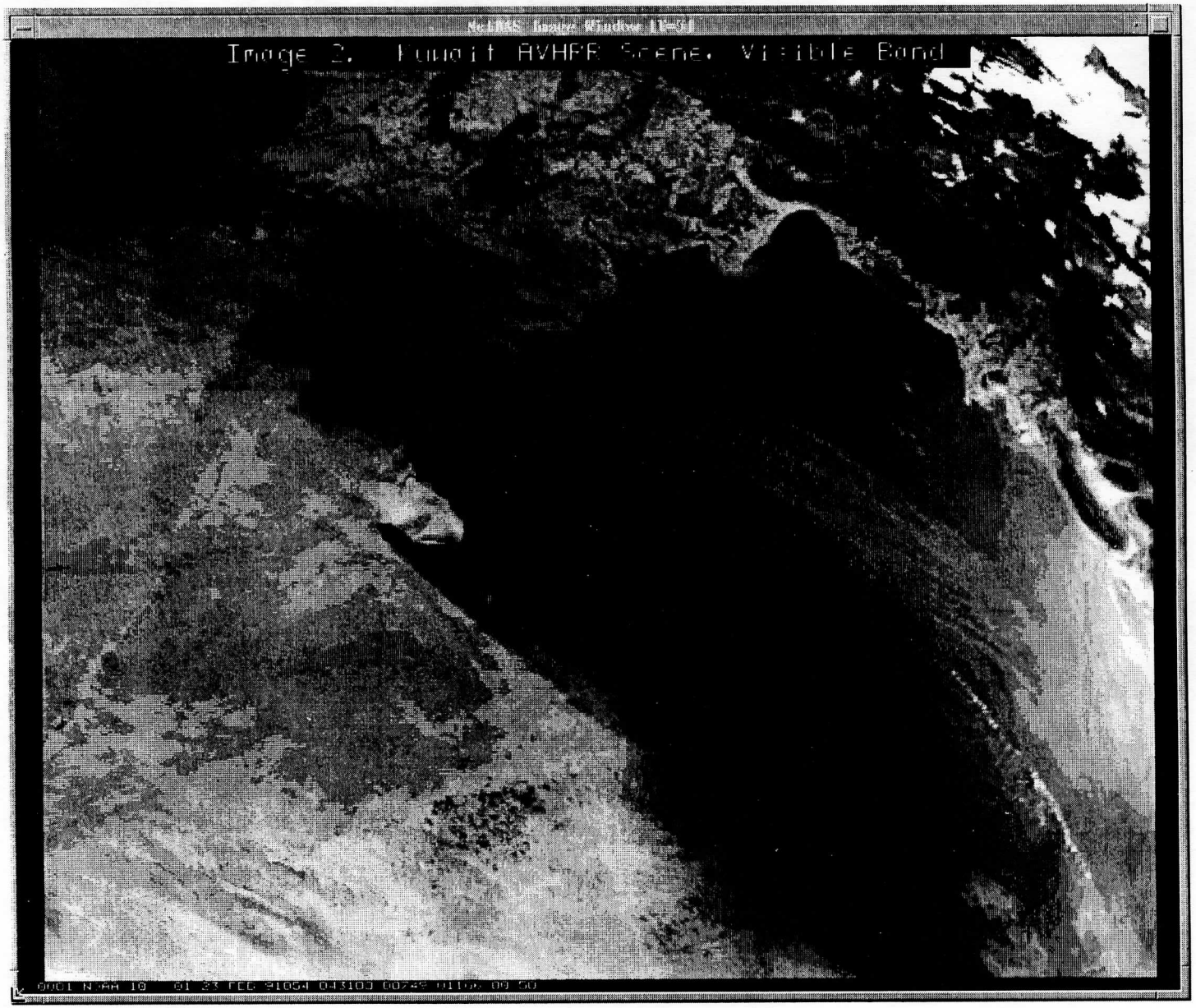


Image 2. Kuwait AVHRR Scene, Visible Band

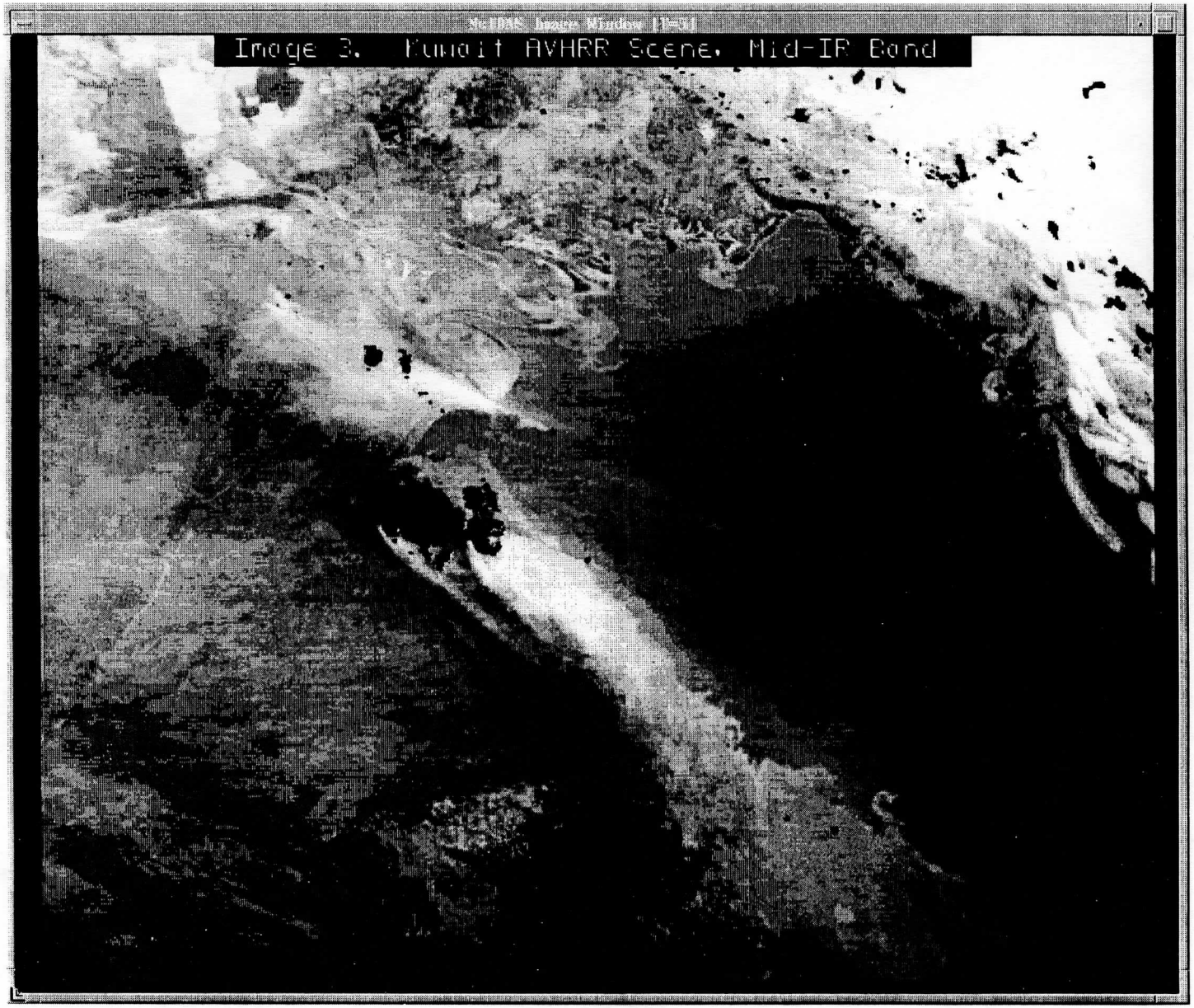


Image 3. Kuwait AVHRR Scene, Mid-IR Band

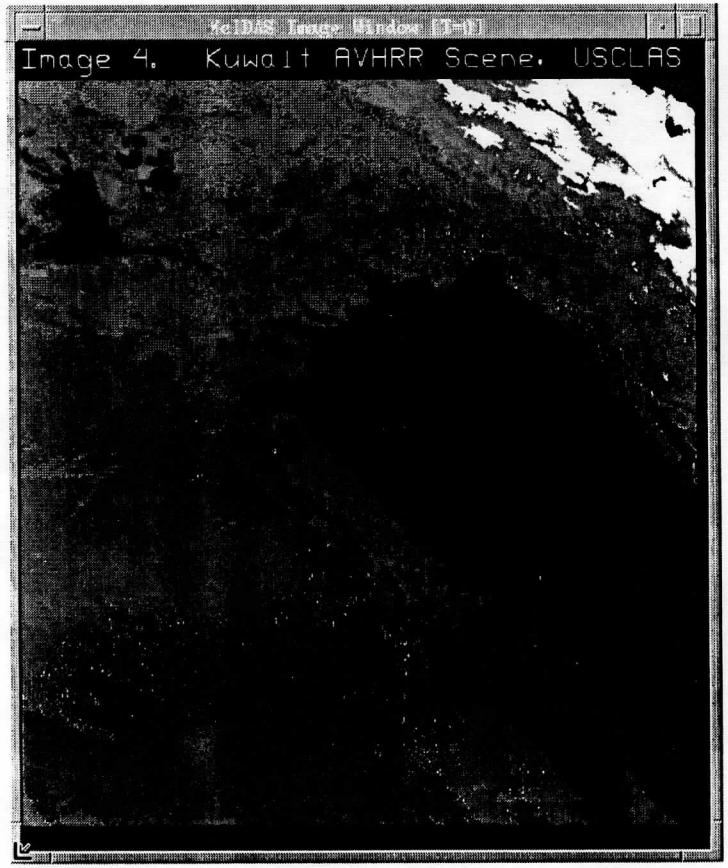
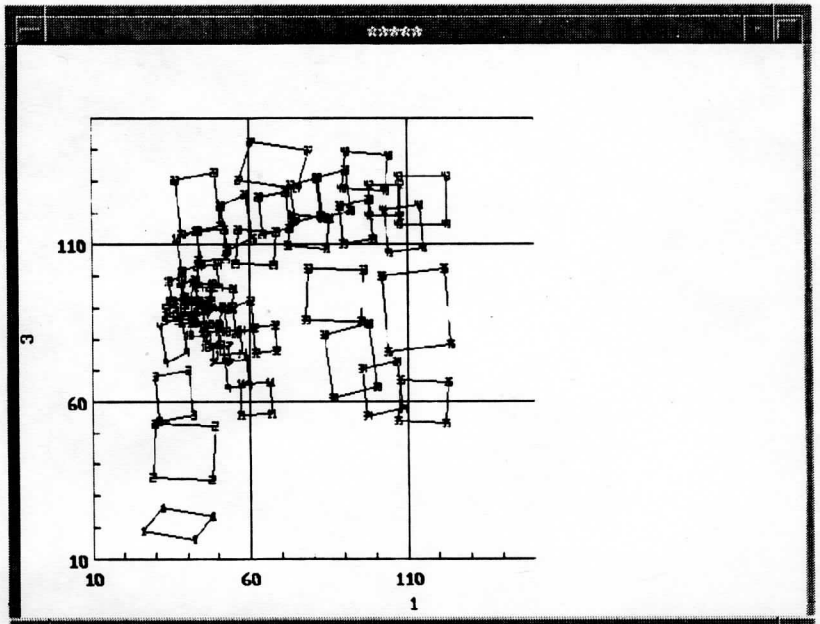


Image 4. Kuwait AVHRR Scene. USCLAS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110
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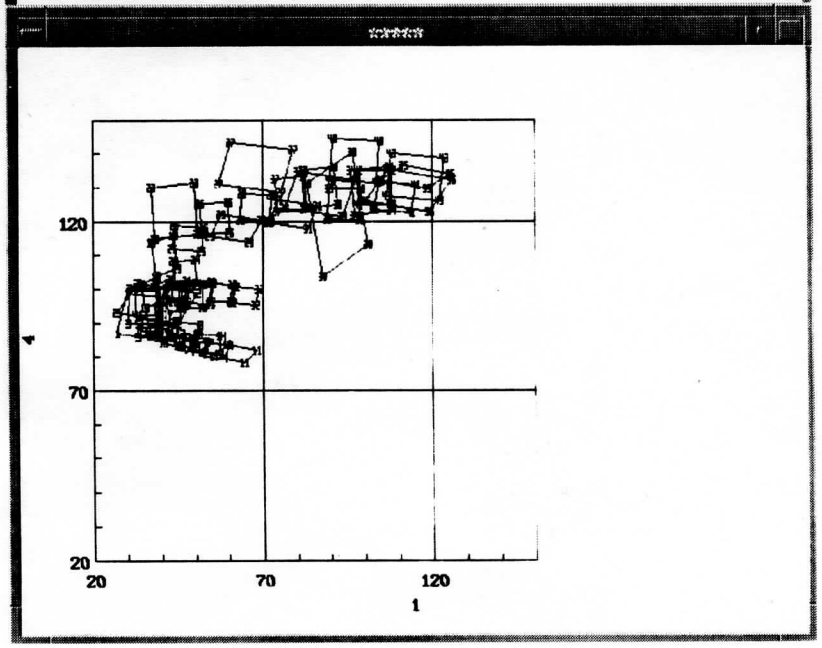
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4
20
70
120
1

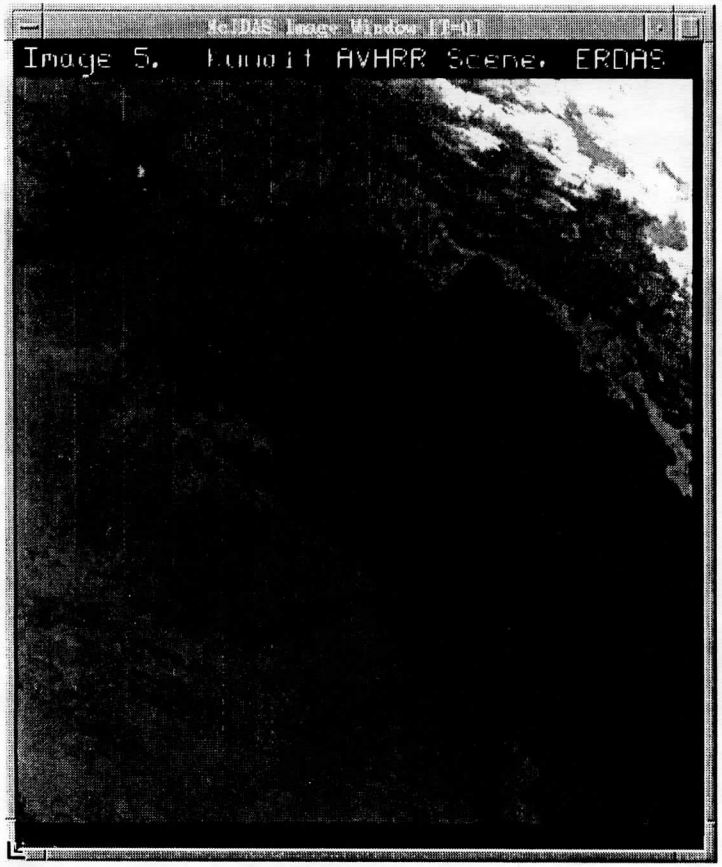
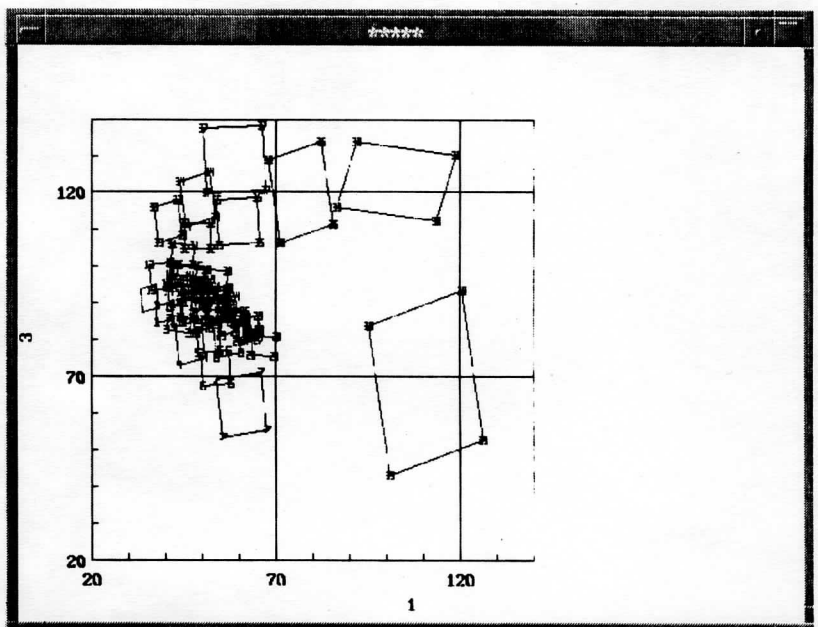


Image 5. Kuwait AVHRR Scene. ERDAS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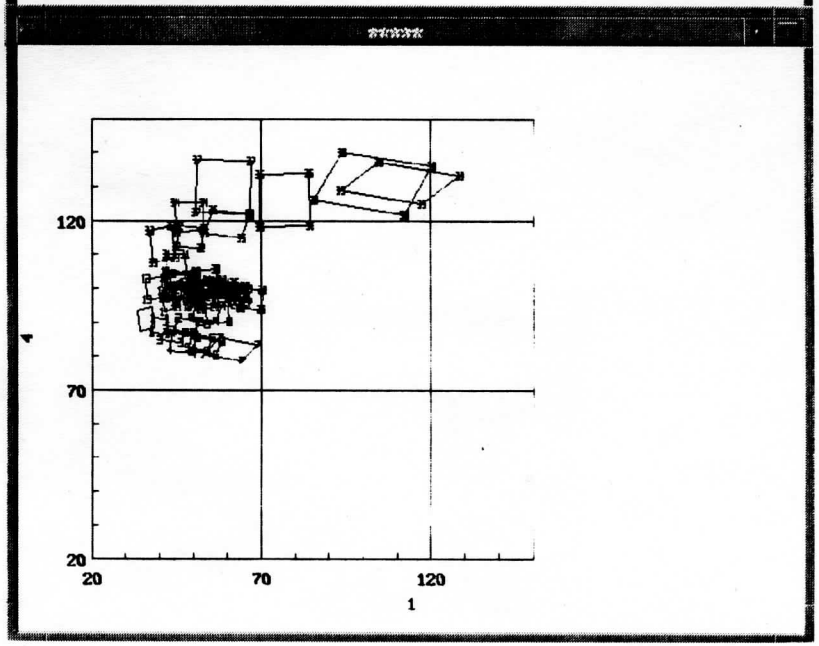
20
3
20
70
120
1


*****
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70
20
4
20
70
120
1

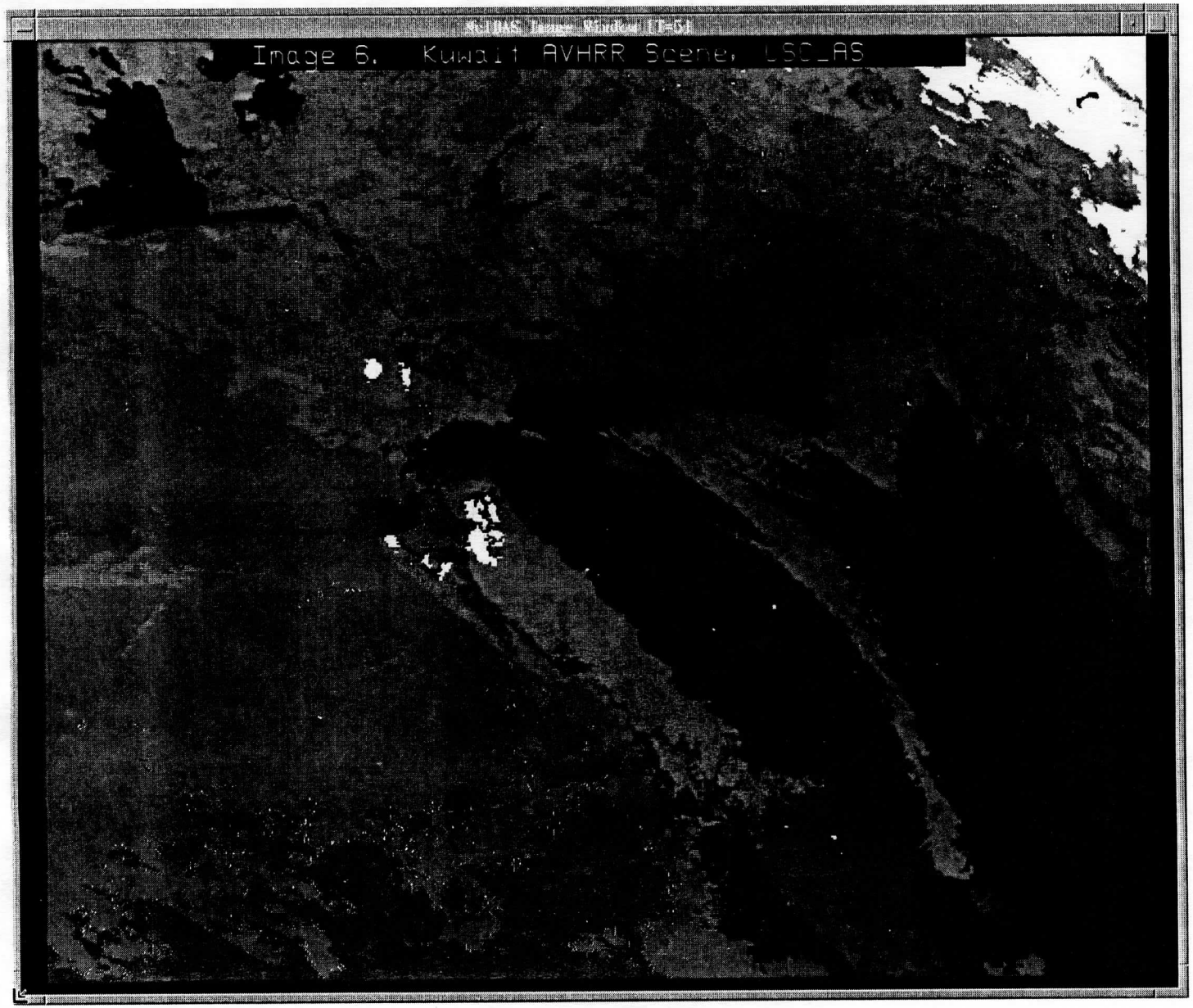


Image 6. Kuwait AVHRR Scene, LSC_AS

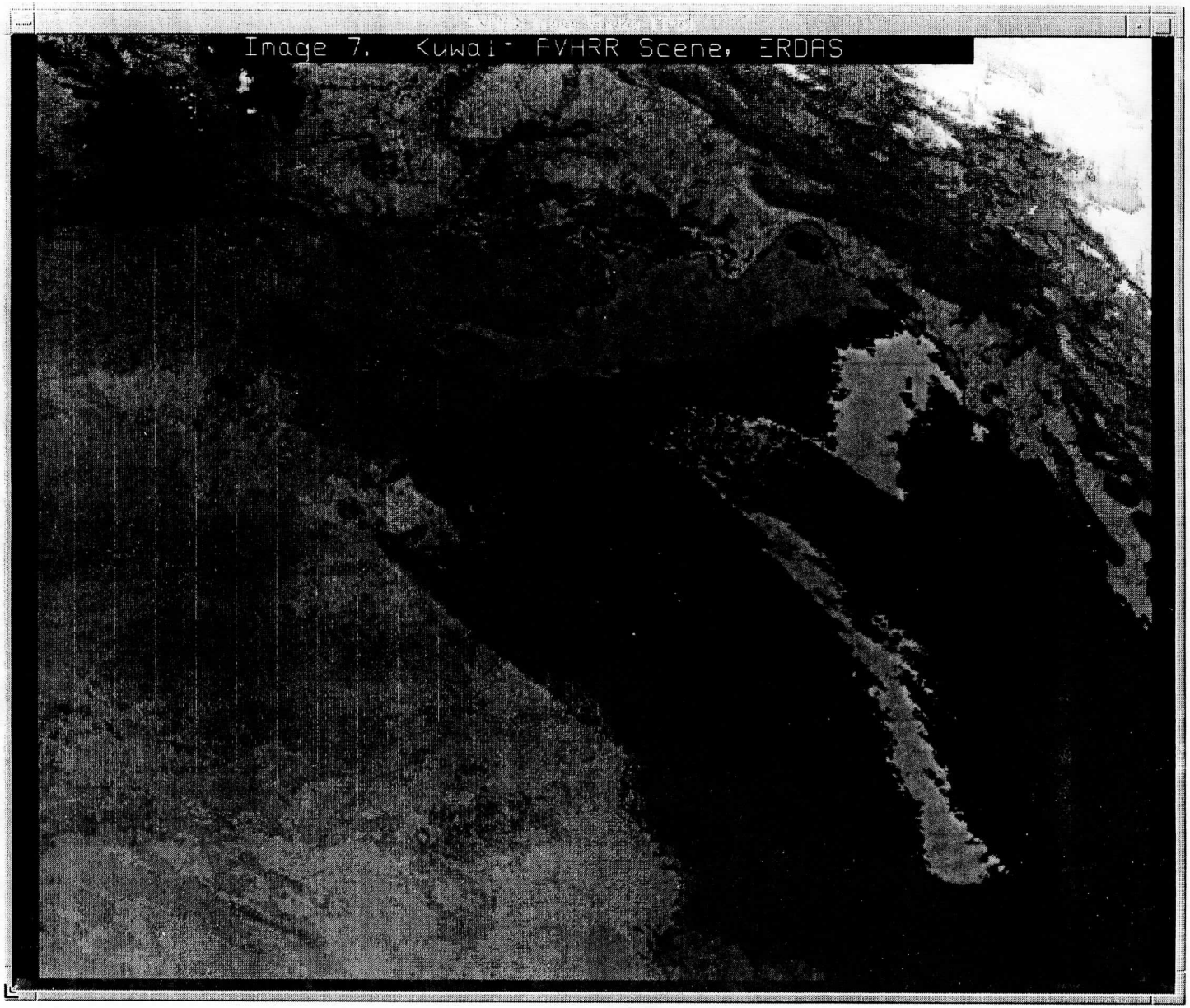
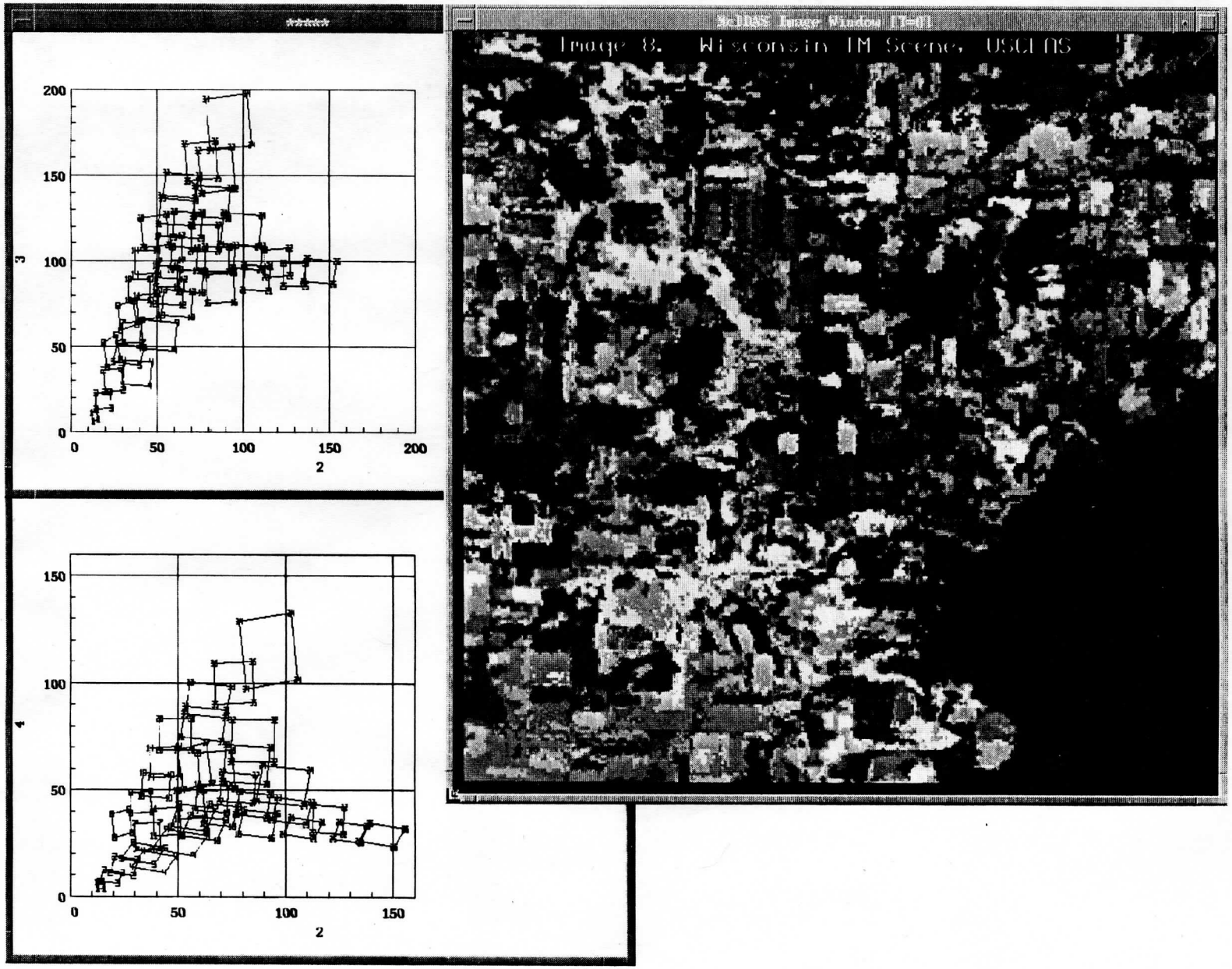


Image 7. Kuwait AVHRR Scene, ERDAS


******
200
150
100
50
0
3
0
50
100
150
200
2
150
100
50
0
4
0
50
100
150
2
Image 8. Wisconsin TM Scene, USGLAS

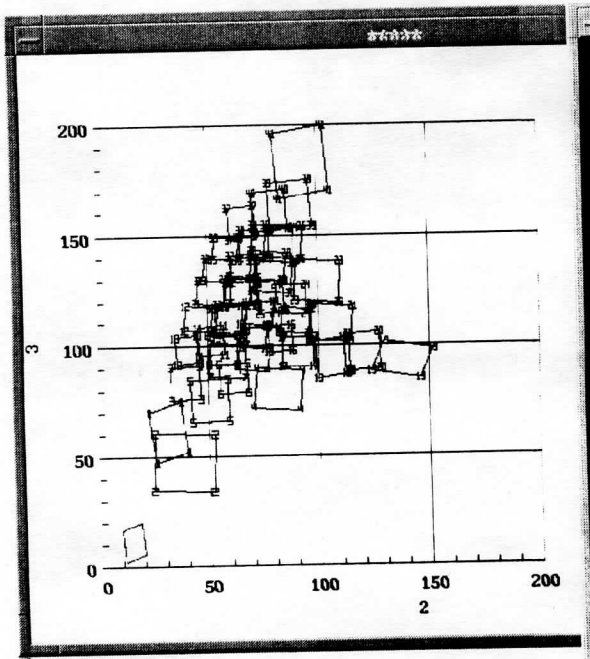

200
150
100
50
0
3
0
50
100
150
200
2


Image 9. Wisconsin TM Scene, LRDMS

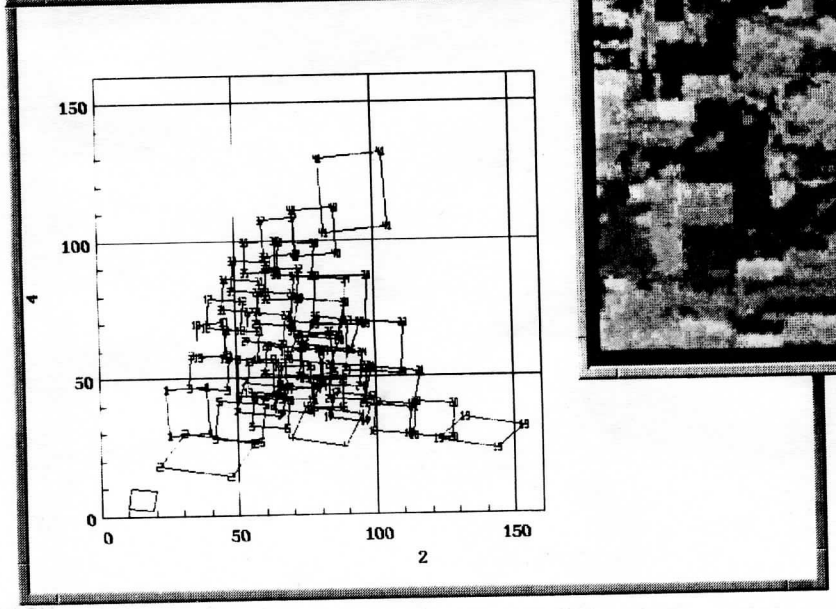

150
100
50
0
4
0
50
100
150
2


Image 10. Wisconsin TM Scene, Supervised

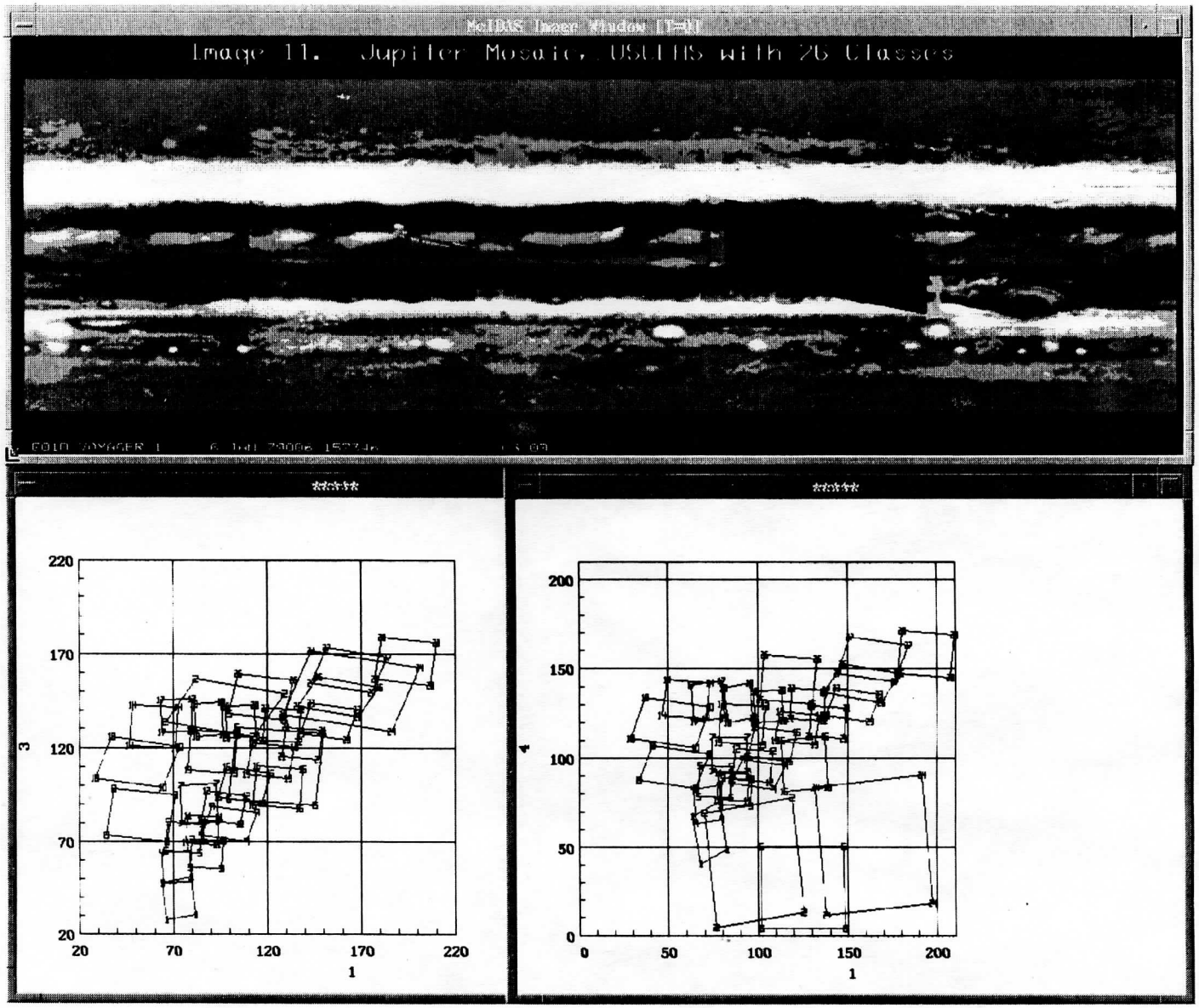
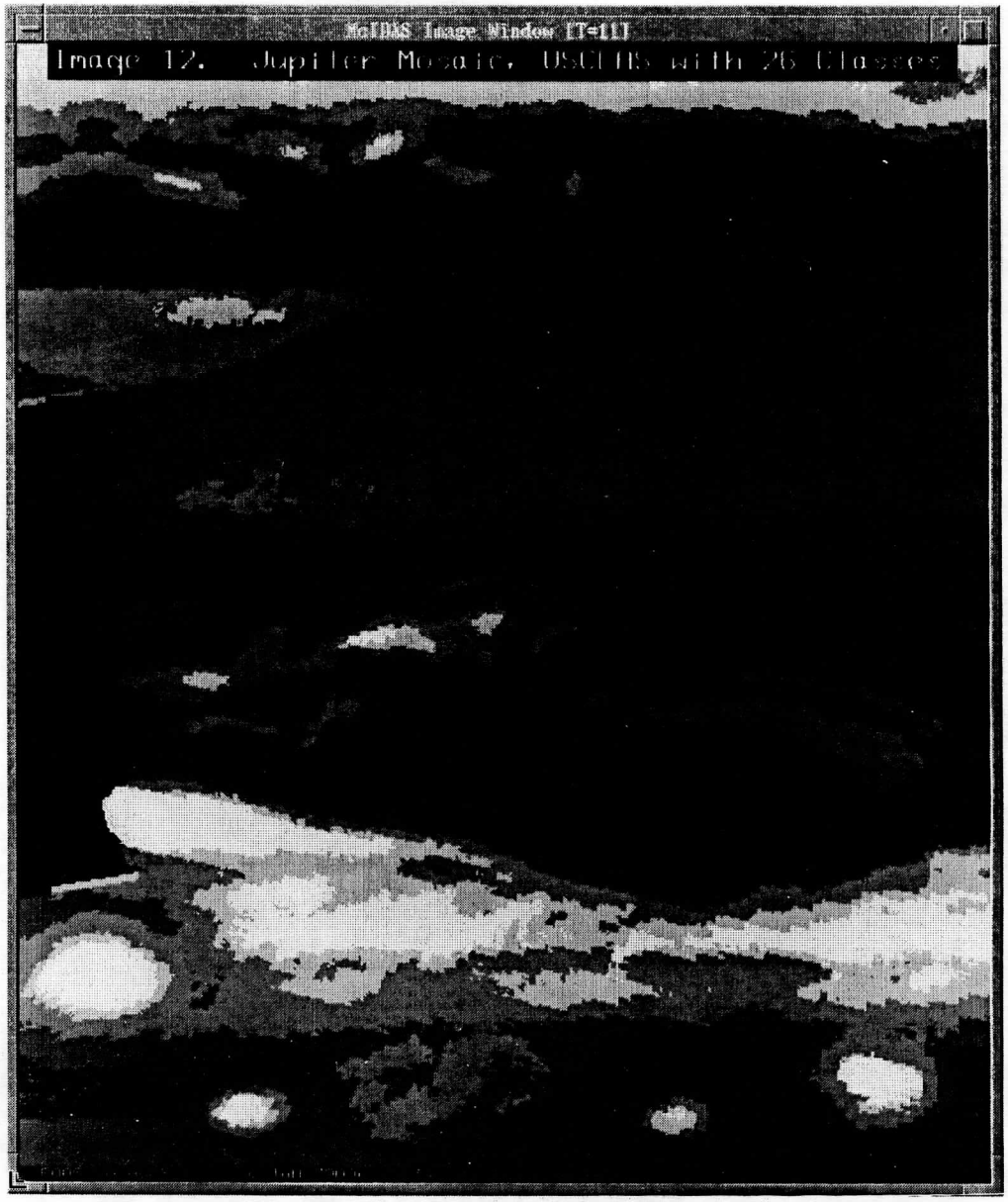


Image 11. Jupiter Mosaic, USGIHS with 26 Classes
*****
220
170
120
70
20
3
20
70
120
170
220
1
*****
200
150
100
50
0
4
0
50
100
150
200
1


MaIDAS Image Window [T=11]
Image 12. Jupiter Mosaic, USGIIS with 26 Classes

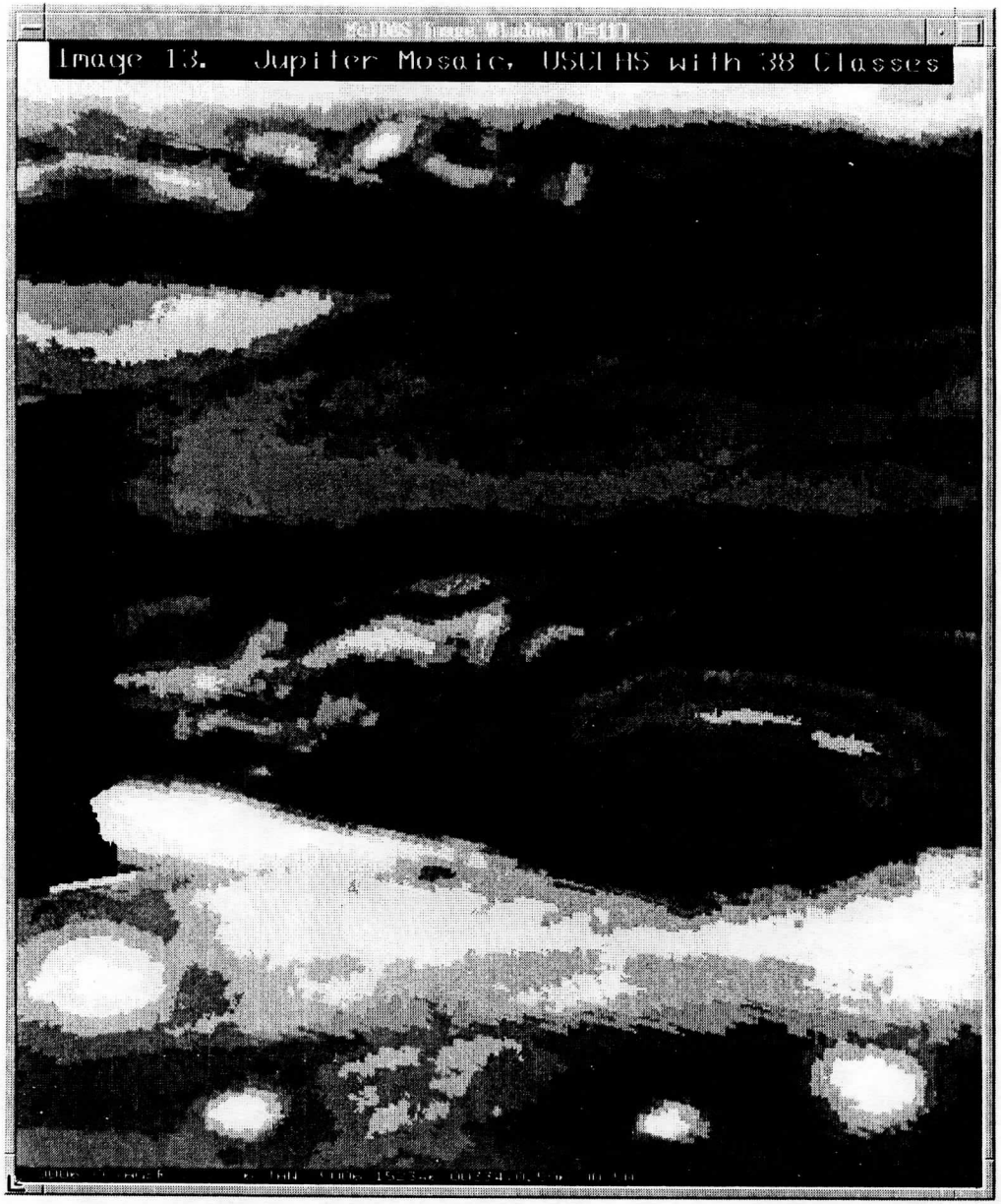


Image 13. Jupiter Mosaic, USGIHS with 38 Classes