

## N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM  
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT  
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED  
IN THE INTEREST OF MAKING AVAILABLE AS MUCH  
INFORMATION AS POSSIBLE

"Made available under NASA sponsorship  
in the interest of early and wide dis-  
semination of Earth Resources Survey  
Program information and without liability  
for any use made thereof."

E82-10210  
CR-168773

Registration of Heat Capacity Mapping Mission

Day and Night Images

by

Kenneth Watson, Susanne Hummer-Miller, and Don L. Sawatzky

(E82-10210) REGISTRATION OF HEAT CAPACITY  
MAPPING MISSION DAY AND NIGHT IMAGES  
(Geological Survey) 17 p HC A02/MF A01

N82-23583

CSCI 05B

Unclass

G3/43 00210

Original photography may be purchased  
from EROS Data Center  
Sioux Falls, SD 57198

Photogrammetric Engineering (in press)

# Registration of Heat Capacity Mapping Mission

## Day and Night Images

by

Kenneth Watson, Susanne Hummer-Miller, and Don L. Sawatzky

U.S. Geological Survey, Box 25046

Denver Federal Center, Denver, CO 80225

### Abstract

Registration of thermal images is complicated by distinctive differences in the appearance of day and night features needed as control in the registration process. These changes are unlike those that occur between Landsat scenes and pose unique constraints. Experimentation with several potentially promising techniques has led to selection of a fairly simple scheme for registration of data from the experimental thermal satellite HCMH using an affine transformation. Two registration examples are provided.

### Introduction

The technique of thermal-inertia mapping (Watson, 1971; Watson and others, 1972; Pohn and others, 1974; Watson, 1975; Kahle and others, 1976; Price, 1977; Pratt and Ellyett, 1979; Watson, 1981b) requires co-registering of images acquired at different times to construct temperature-difference and thermal-inertia images. In addition, refinements to use topographic corrections (Gillespie and Kahle, 1977; Miller and Watson, 1977; Watson, 1981a) and to compare thermal data with other data bases, such as Landsat images and geophysical and geologic maps, require further registration to a topographic

base. Thermal images have some unique characteristics that make this registration process more complex than registration of standard photographs and Landsat images. The inherent temporal behavior of the surface temperature, that depends on albedo, thermal and emissive properties, and slope, elevation, and moisture effects, makes the scene appear substantially different on day and night scenes. Texture and topography often are portrayed in an entirely different manner on thermal images acquired at different times during the day and night (Sabins, 1969; Rowan and others, 1970; Offield, 1975). The selection of reproducible control points associated with various features thus can be a difficult task and one subject to substantial error. For example, mislocation of a feature on an image with respect to a corresponding topographic ridge can result in a topographic correction being applied with the wrong sign! The Heat Capacity Mapping Mission (HCMM) data also presents an additional problem because the 500-m digital resolution masks many distinctive features--primarily cultural--that can be seen on the 80-m resolution Landsat data.

Errors resulting from the misregistration between images and among images and various data bases have been discussed previously (Miller and Watson, 1977). The purpose of this brief paper is to describe our current experience with the registration of HCMM data and to suggest the use of a simple method for registering the data that we have found to be more accurate than the registered products currently being made available.

## Method

We experimented with iterative registration, with using drainage-intersection maps for control, and with cross correlation techniques but none were found to be satisfactory. The procedure finally used to register the image pairs was to select control points and to map the night thermal image to the daytime thermal and reflectance images using an affine transformation on a 1300 by 1100 pixel image. The resulting image registration was accurate to better than two pixels (rms) and does not exhibit the significant misregistration that we have noted in the temperature-difference and thermal-inertia products supplied by NASA.

The affine transformation was determined using simple matrix arithmetic-- a step that can be performed rapidly with matrix hardware on a minicomputer such as a Hewlett-Packard HP9845<sup>1/</sup>.

Consider a set of control points  $x_i, y_i$  in the day image and the corresponding points  $x_i', y_i'$  in the night image. A best-fit affine transformation can then be computed:

$$\text{let } S' = (x_i, y_i)$$

$$S = (x_i, y_i, 1)$$

<sup>1/</sup>Use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

then the desired affine transformation

$$T = \begin{pmatrix} a & d \\ b & e \\ c & f \end{pmatrix}$$

satisfies the matrix equation  $S' = ST$  and thus

$$T = (S^T S)^{-1} (S^T S')$$
 where  $S^T$  is the transpose of  $S$ .

### Results

The affine transformation provides a rotation correction for the inclined day and night orbital tracks (see figure 1), an origin shift, and a scale change. Our previous experience with aircraft data has suggested the need to correct for platform instabilities due to pitch, yaw, and roll of the aircraft and this has required non-linear or piece-wise linear corrections. We did not find this necessary with the two HCMM image data sets that we have analyzed. Presumably the satellite, being more stable, is less subject to these effects.

The two most important considerations in selecting control features are that they are readily identifiable on both day and night data and that their locations cover the scene. We experimented with selecting different types of features as control points. The best features--those most reproducible on both day and night data--were the water-dam interfaces of reservoirs. Distinctive outlines of other water bodies were also reasonably identifiable. Drainages and topographic features were found to be the least reliable due to changes in their day-night appearance. In the first registration example (figure 2), nine water body features were used as control. In the second example (figure 3), few water bodies exist, and only three of the six selected

control features were water-associated. The other three points are topographic features. The accuracy of identifying these features was in part estimated by the magnitude of the residual errors. A high residual was indicative of the feature being misidentified. Figure 4 shows an example of the control vectors (a) and of the residuals (b) from the Powder River Basin scene registration.

We discovered that a simple transformation was satisfactory over large parts of an entire image in two relatively arid regions of the western United States, using a few accurately determined control points at bodies of water. The procedure should be more easily applied in other areas where bodies of water are likely to be more abundant. A listing of the computer program to perform this registration is provided in Appendix 1.

Automatic registration using cross-correlation failed when we attempted to apply it to one site because of a pronounced topographic grain that produced a significant error along the direction of the grain.

Some sample results of our registration efforts are provided to illustrate the method and its simplicity. Figure 2 shows the transformed night image compared with the day image and the original untransformed night image. The second example is the Cabeza Prieta, Arizona, area in figure 3. Day, night, and thermal-inertia images are presented, the latter being computed from the registered day thermal, night thermal, and reflectance images using a new algorithm (Watson, 1981b). Figure 4 presents a comparison between the original control vectors and their residuals after applying the method to HCM data of the Powder River Basin, Wyoming, area.

### Acknowledgments

This research was supported in part under NASA contract S-40256-B.



## References

- Gillespie, A. R., and Kahle, A. B., 1977, Construction and interpretation of a digital thermal inertia image: *Photogrammetric Engineering and Remote Sensing*, v. 43, p. 983-1000.
- Kahle, A. B., Gillespie, A. R., and Goetz, A. F. H., 1976, Thermal inertia imaging--A new geologic mapping tool: *Geophysical Research Letters* 3, p. 26-28.
- Miller, S. H., and Watson, Kenneth, 1977, Evaluation of algorithms for geological thermal-inertia mapping: *Proceedings 11th International Symposium on Remote Sensing of Environment*, v. 2, p. 1147-1160.
- Offield, T. W., 1975, Thermal-infrared images as a basis for structure mapping, Front Range and adjacent plains in Colorado: *Geological Society of America Bulletin*, v. 86, p. 495-502.
- Pohn, H. A., Offield, T. W., and Watson, Kenneth, 1974, Thermal-inertia mapping from satellite discrimination of geologic units in Oman: *U.S. Geological Survey Journal of Research*, v. 2, no. 2, p. 147-158.
- Pratt, D. A., and Ellyett, C. D., 1979, The thermal inertia approach to mapping of soil moisture and geology: *Remote Sensing Environment*, v. 8, p. 151-168.
- Price, J. C., 1977, Thermal inertia mapping--A new view of the Earth: *Journal Geophysical Research*, v. 82, p. 2582-2590.
- Rowan, L. C., Offield, T. W., Watson, Kenneth, Cannon, P. J., and Watson R. D., 1970, Thermal infrared investigations, Arbuckle Mountains, Oklahoma: *Geological Society of America Bulletin*, v. 81, p. 3549-3562.

- Sabins, F. 1969, Thermal infrared imaging and its application to structural mapping, southern California: Geological Society of America Bulletin, v. 80, p. 397-404.
- Watson, Kenneth, 1971, A computer program of thermal modeling for interpretation of infrared images: National Technical Information Service PB-203-578.
- Watson, Kenneth, Pohn, H. A., and Offield, T. W., 1972, Thermal inertia mapping Nimbus satellite data: Eighth International Symposium on Remote Sensing of Environment (summaries), p. 122.
- Watson, Kenneth, 1975, Geologic applications of thermal infrared images: Proceedings Institute Electrical and Electronic Engineers, v. 63, no. 1, p. 128-137.
- Watson, Kenneth, 1981a, Topographic slope correction for analysis of thermal infrared images: Submitted to National Technical Information Service.
- Watson, Kenneth, 1981b, Regional thermal inertia mapping from an experimental satellite: Submitted to Geophysics.

APPENDIX 1

ORIGINAL PAGE IS  
OF POOR QUALITY

```

PROGRAM GEOMX4
C.....
C.....
C..... REMOTE SENSING ARRAY PROCESSING PROCEDURES
C..... U. S. GEOLOGICAL SURVEY, DENVER, COLORADO
C..... BRANCH OF PETROPHYSICS AND REMOTE SENSING
C..... DON L. SAWATZKY
C.....
C
C   GEOMX4 GENERATES A RECTIFIED IMAGE FILE FROM A DISTORTED IMAGE
C FILE AND FROM COEFFICIENTS FOR RECTIFICATION, R AND S, DETERMINED FOR AN
C AFFINE TRANSFORMATION OF THE DISTORTED FILE.
C INPUT FILE STRUCTURE CONSISTS OF A HEADER RECORD CONTAINING TWO
C INTEGERS FOR LINE LENGTH, LENREC, IN PIXELS AND NUMBER OF LINES,
C NORECS. NORECS NUMBER OF DATA RECORDS FOLLOW, EACH RECORD CONTAINING LENREC
C BYTES OF 8-BIT DATA. OUTPUT FILE HEADER RECORD CONTAINS TWO INTEGERS OF LINE
C LENGTH, NPIXOUT, AND NUMBER OF RECORDS, LMAX. INPUT PARAMETERS, IPIXIN AND NPIX
C , AND MXPPIX ARE SELECTED ON THE LINE LENGTH OF THE INPUT FILE AND DEGREE
C OF ROTATION REQUIRED FOR RECTIFICATION. SECTIONS OF THE OUTPUT FILE OF LENGTH
C LMAX AND CONTAINING PIXELS MNPPIX TO MXPPIX ARE GENERATED BY ONE OR MORE ITER
C ATIONS OF THIS PROGRAM. SECTIONS ARE CONCATENATED IN SUBSEQUENT PROCESSING.
C SECTIONING THE OUTPUT FILE IS DONE IN RESPONSE TO THE MESSAGE: "INBUF ARRAY
C TOO SMALL."
C
C.....DECLARATIONS
      REAL R(3),S(3)
      LOGICAL*1 INBUF(200000),OUTBUF(3000)
      INTEGER FCBIN(35),FCBOUT(35)
C.....
C.....SET PARAMETERS
      WRITE(6,99)
99  FORMAT(1X,'ENTER PIXEL/LINE COEFFICIENTS ':)
      READ(5,96) R,S
      WRITE(6,98)
98  FORMAT(1X,'ENTER INPUT FIRST PIXEL, NO. PIXELS')
      READ(5,96) IPIXIN,NPIXIN
      WRITE(6,97)
97  FORMAT(1X,'ENTER MAX. OUTPUT LINES,MIN/MAX PIXEL ':)
      READ(5,96) LMAX,MNPPIX,MXPPIX
96  FORMAT(G16.0)
C.....
C.....OPEN DATA FILE TO TRANSFORM
      READ(8) LENREC,NORECS
C.....SETUP WORK ARRAY
      NRECS=MIN(200000/LENREC,NORECS)
      MXLINE=NRECS
      MNLIN=1
      J1=LENREC*MOD(1,NRECS)+1
      J2=J1+LENREC-1
      DO 90 I=1,NRECS
90  READ(8) (INBUF(J),J=J1,J2)
C.....
C.....OPEN OUTPUT DATA FILE
      NPIXOUT=MXPPIX-MNPPIX+1
      IF(NPIXOUT.LE.3000.AND.NPIXIN.LE.3000)GO TO 110
100 STOP ' ?DATA FILES EXCEED BUFFER WIDTH.'
110 WRITE(9) NPIXOUT,LMAX
C.....READ/WRITE LOOP
      DO 210 LINE=1,LMAX
      DO 200 IPX=MNPPIX,MXPPIX

```

ORIGINAL PAGE IS  
OF POOR QUALITY

```
INPX=R(1)*(IPX) + R(2)*(LINE) + R(3)
IF(INPX.LT.1.OR.INPX.GT.NPIXIN) THEN
OUTBUF(IPX-MPIX+1)=.FALSE.
ELSE
INLINE=S(1)*(IPX) + S(2)*(LINE) + S(3)
IF(INLINE.LT.1.OR.INLINE.GT.NORECS) THEN
OUTBUF(IPX-MPIX+1)=.FALSE.
ELSE
C..... CHECK LIST FOR SCANLINE IN WORK ARRAY
IF(INLINE.GE.MNLINE.AND.INLINE.LE.MXLINE) GOTO120
C..... ELSE READ SCANLINE INTO LIST AND WORK ARRAY
IF(INLINE.LT.MNLINE) STOP'INBUF ARRAY TOO SMALL!!'
DO 115 I=MXLINE+1,INLINE
IREC=MOD(I,NRECS)*LENREC
115 READ(S,REC=INLINE) (INBUF(J),J=IREC+1,IREC+NPIXIN)
MXLINE=INLINE
MNLINE=MXLINE-NRECS+1
120 OUTBUF(IPX-MPIX+1)=INBUF(LENREC*MOD(INLINE,NRECS)+INPX)
ENDIF
ENDIF
200 CONTINUE
210 WRITE(9) (OUTBUF(J),J=1,NPXOUT)
C.....
C..... FINIS
300 STOP
END
```

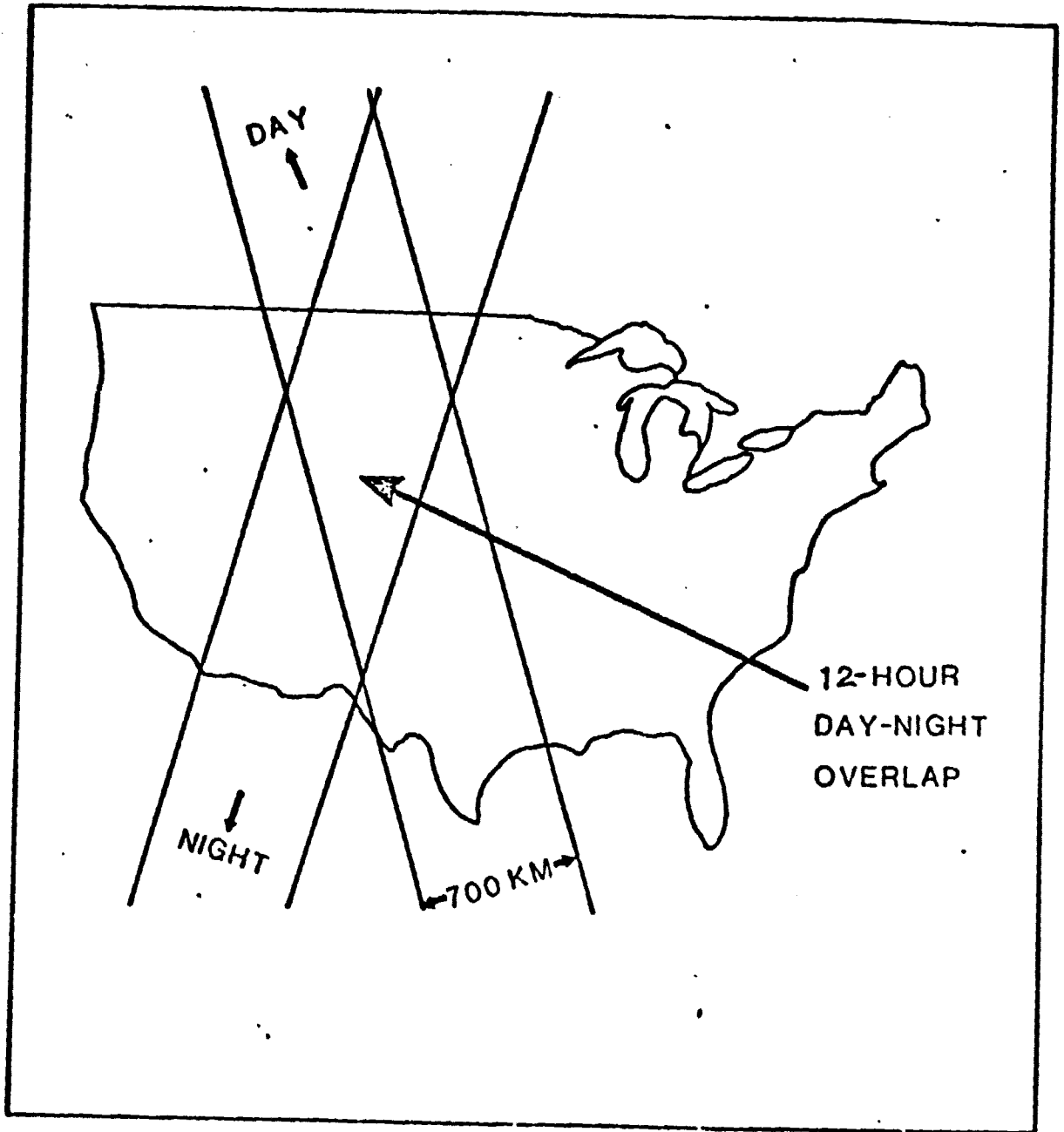
## List of illustrations

Figure 1.--The day and night orbital tracks of the HCM satellite are inclined with respect to each other, and the area of overlap is a diamond. For this example, the scan lines are inclined at an angle of about  $30^{\circ}$ .

Figure 2.--Images of the Powder River Basin area, Wyoming. Figure 2a is the transformed night thermal image, figure 2b is the day thermal image, and figure 2c is the original night thermal image. The scale of the original images is approximately 1:5,000,000. The Bighorn Mountains, Wyoming, are to the lower left, the Black Hills, South Dakota, are near the bottom center, and the large body of water at the top of the scene is Lake Sakakawea, North Dakota. Significant changes in the appearance of the landscape are evident between the day and night images. The most apparent aspect of the affine transformation is a rotation; however, there are also scale changes in both directions. The usual convention of light associated with high values and dark with low values was employed. Extensive cloud cover is present in the upper left hand corner of the night image and the lower left hand corner of the day image.

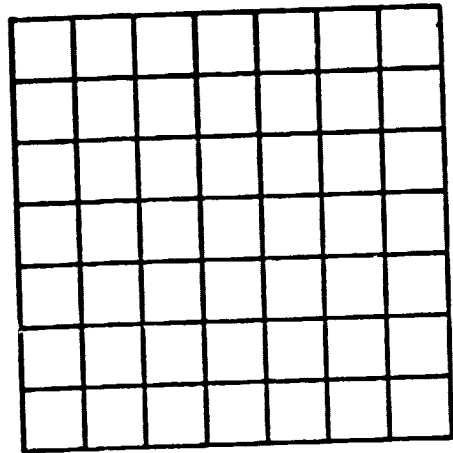
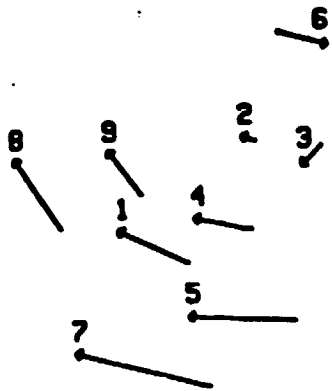
Figure 3.--Images of the Cabeza Prieta area, southwestern United States and Mexico. Figure 3a is the day thermal image, figure 3b is the night thermal image, and figure 3c is a thermal inertia image constructed by applying a model to registered day-thermal, reflectance, and night thermal images. The scale of the original image is approximately 1:5,000,000. The Gulf of California is at the bottom of the scene and Salton Sea, California is in the upper left corner. Clouds are present in the upper right hand corner of the night image.

Figure 4.--Registration vectors between two sets of control points for the Powder River Basin area, Wyoming. Figure 4a shows the vectors between the day and night images. Figure 4b shows the residual vectors after applying the affine transformation. Maximum residual is 2 pixels.

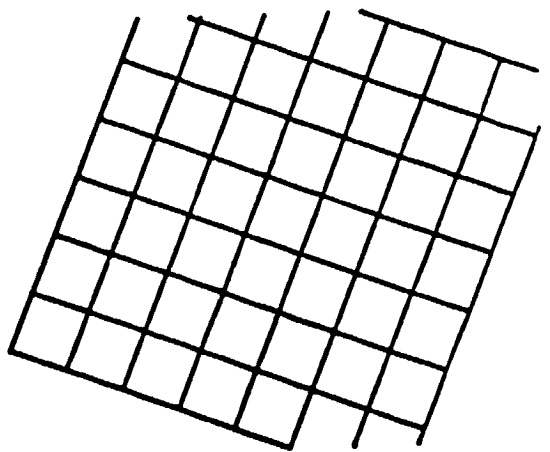
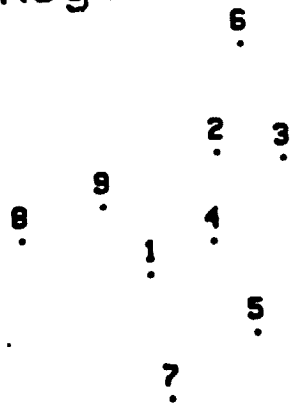




4a) Unregistered



4b) Registered





RECEIVED BY THE BOARD OF DIRECTORS  
AT THE CITY OF DENVER ON 11/20/01

ORIGINAL PAGE IS  
OF POOR QUALITY

THE BOARD OF DIRECTORS OF THE  
FEDERAL RESERVE SYSTEM

THE BOARD OF DIRECTORS OF THE  
FEDERAL RESERVE SYSTEM

ORIGINAL PAGE IS  
OF POOR QUALITY



REPRODUCED FROM THE MAPS OF CABEZON VILLAS  
IN THE YEAR 1887



REPRODUCED FROM THE MAPS OF CABEZON VILLAS  
IN THE YEAR 1887



REPRODUCED FROM THE MAPS OF CABEZON VILLAS  
IN THE YEAR 1887