GEOLeOIC APPLICATIONS OF THERMAL-INERTIA MAPPING FROM SATELLITE

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This study is an evaluation of HCMM (Heat Capacity Mapping Mission) satellite data to detect and map geologic features for energy-resource and mineral-deposit investigations. In the Powder River Basin, Wyo., narrow geologic units having thermal inertias which contrast with their surroundings can be discriminated in optimal images. A few subtle but mappable thermal-inertia anomalies coincide with areas of helium leakage believed to be associated with deep oil and gas concentrations. Similar changes were not found in areas of uranium deposits possibly due to their minor and discontinuous nature at satellite resolution.

The most important results involved delineation of tectonic framework elements some of which were not previously recognized. Thermal and thermal-inertia images also permit mapping of geomorphic textural domains. A thermal lineament not on existing geologic maps or detected on Landsat images appears to reveal a basement discontinuity which involves the famous Homestake Mine in the Black Hills, a zone of Tertiary igneous activity and facies control in oil-producing horizons. Applications of these data to the Cabeza Prieta, Ariz., area illustrate their potential for igneous rock-type discrimination. Extension to Yellowstone National Park resulted in the detection of additional structural information but surface hydrothermal features could not be distinguished with any confidence.

Advances in modeling and image analysis included the development of a new thermal-inertia mapping algorithm, a fast and accurate image-registration technique, and an efficient topographic-slope and elevation-correction method.
1.0 PREFACE

1.1 OBJECTIVES

The principal objective of this study was to investigate applications of HCMM (Heat Capacity Mapping Mission) satellite data in detecting and mapping geologic features for energy-resource and mineral-deposit studies. Other, related objectives involved the development of new techniques and approaches in thermal modeling and image processing.

1.2 SCOPE

The analysis was somewhat restricted by the limited number of sequential day/night image pairs free of major atmospheric/weather problems. For the Powder River Basin, Wyo. area, a single thermal-inertia image was formed using 20 August 1978 data. Four additional nighttime scenes were used to examine geologic formation boundaries and thermal lineaments. The analysis of the Cabeza Prieta, Ariz., area was done using a thermal-inertia image constructed from data acquired April 3 and 4, 1979. No successful U-2 aircraft data acquisition flights were conducted over these two sites so that comparison of different resolution thermal data was only conducted using USGS aircraft data. Despite all these limitations, significant geologic information was derived in this study, and the results suggest the importance of a follow-on thermal satellite experiment for improved mineral and energy resource exploration.
1.3 CONCLUSIONS

Despite limited data, investigations in the Powder River Basin area of eastern Wyoming and adjacent States clearly showed that geologic units as narrow as two or three resolution elements, but of moderate to high thermal-inertia contrast against surroundings, can be discriminated in optimal images. It appears likely that subtle facies differences in sedimentary basin-fill units can be delineated and mapped using satellite thermal-inertia images, especially if sequential images can be obtained during a drying cycle after rain or snow. A few subtle but mappable thermal-inertia anomalies coincide with areas of anomalous helium in soil gas believed to indicate leakage from deep oil and gas concentrations; the presence of thermal-inertia anomalies suggests that gas leakage has produced chemical changes and cementation at the surface. Such changes also are known to be associated with shallow uranium deposits and changes were looked for but not found in the thermal-inertia images; it is thought that the surface changes in this area are too minor and discontinuous to be detected from satellite.

The most consistently practical and important results involve delineation of tectonic framework elements such as lineaments bounding apparent structural blocks. These commonly can be seen even in less-than-optimal data. One pair of major thermal lineaments in the southern Powder River Basin seems to define structures not previously recognized but consistent with, and adding importantly to, an emerging story of basement-block movements and their direct influence on sedimentation, which in part controls the occurrence of large oil and gas resources. One of these lineaments matches up with aeromagnetic map data and appears to reveal a basement discontinuity which underlies the famous...
Homestake Mine in the Black Hills and a zone of Tertiary igneous activity. Along with the newly identified lineaments, the thermal images also permit mapping of geomorphic textural domains. The geologic significance of these is not yet understood, but it seems likely that they connote structural and lithologic conditions which affect or control local ground-water regimes.

Similar applications of HCMM data to the Cabeza Prieta, Ariz., area illustrate the potential of using thermal-inertia data for discrimination between extrusive and intrusive rocks and for detecting differences in the mafic content of volcanics. Other results included detection of differences among surficial units - tentatively ascribed to changes in soil-moisture retention, discovery of discrepancies in existing geologic maps, and possible application of the thermal-inertia technique to mapping buried pediments.

Extension from beyond the originally proposed study areas to Yellowstone National Park was made to examine the usefulness of HCMM data in geothermal studies. Although we found that the night-thermal data could not be used with any confidence to distinguish surface hydrothermal features, we did detect additional structural information concerning the outline of the caldera which is the source of the volcanic heat. This reinforces our conclusion that a major utility of these data is in providing information about local-area or regional tectonic framework.

We have also made significant advances in modeling analysis and image-registration techniques. A thermal-inertia mapping algorithm has been developed based on a new method to derive the regional meteorologic parameters solely from the satellite data. An algorithm for determining the sensible-heat flux from ground-station data was also constructed. Simple forms for
four of the atmospheric flux terms were constructed from field measurements made during circumstances when satellite data are likely to be most useful. These forms eliminate the need for extensive continuous ground station data. Also, a method to correct thermal and thermal-inertia data for elevation variations in sky and solar flux was determined. In addition, we have devised a fast topographic adjustment algorithm which can be used in conjunction with digital terrain data to correct the thermal-inertia image for simple topographic slope effects. Finally, a fast image registration technique was developed that proved to be considerably more accurate than the NASA registered products.

Our analysis of the HCMM data has resulted in the recognition of features which suggest the existence of previously unmapped and unknown geologic structures. Their relationship to other geophysical and geochemical data provides important information for a basic resource-exploration strategy. Additionally, substantial progress has been made in modeling and image-processing techniques. This report covers new areas and represents significant advances in the processing and interpretation of thermal satellite data and in the integration of thermal-infrared data in regional geologic exploration.

1.4 RECOMMENDATIONS

From our experience to date, we would recommend that serious consideration be given to a follow-on thermal satellite mission with these general characteristics.

1. The current NEAT of HCMM seems adequate for most regional studies. Higher thermal resolution does not appear necessary.
2. Some increase in ground resolution (possibly 100-200 m) would be useful; however, there are trade-offs to consider here. The 500-m resolution from HCMH has proven very useful for regional structures - it does not appear promising for detecting alteration.

3. Some increase in the repeat times over a site is desirable. The HCMH data we have seen have often baffled us because of changing meteorologic effects. The increased repeat time would enhance the chances of "stable-clear" conditions and also provide coverage of regions under several meteorological and soil moisture conditions. The repeat time involves the orbit parameter selection; a 5-10 day repeat of coverage would be desirable.

4. The current overflight times of HCMH appear appropriate for geologic analysis. It should also be noted that the daytime maximum represents an optimum time to acquire multispectral thermal measurements as well.

5. Our analysis of HCMH data requires registration of day and night images and subsequent registration to a topographic base. The registered data provided by NASA often contained large registration errors. An essential requirement for analysis of these data is that the clear scene images be registered (day/night images) to a pixel, and to digital terrain data. If this registration accuracy cannot be achieved routinely, it is recommended that registered products not be provided to users.
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2.0 INTRODUCTION

The HCMM data which we have examined have provided us with unique geologic information which is both complex to analyze and difficult to explain. In some cases we are astonished to see subtle distinctions of structure and geologic materials that are not found on detailed geologic maps. In other cases we are unable to differentiate widely dissimilar geologic materials or identify features which are clearly described on regional geologic maps or Landsat images. Commonly, geologic features are clearly displayed on a single image or part of an image and not on others. Further complicating the analysis of these data has been the experimental nature of the satellite mission, which has introduced both significant time lags between data acquisition and interpretation, and unique constraints in image registration and data calibration.

This report comprises pieces to a puzzle—a puzzle with tantalizing new information but sufficient gaps to preclude a complete overall assessment. We have examined the geologic implications of the HCMM data in the Powder River Basin of Wyoming and subsequently extended the analysis to the Cabeza Prieta area in Arizona. Enhanced nighttime images, thermal-inertia images based on our new algorithm, and several profiles of various data across the basin are presented in our analysis and subsequently compared with other map data (geologic, magnetic field, known areas of oil, gas, and uranium occurrence, helium anomalies, and ground water). Of equal importance with the geologic interpretation has been progress in modeling. We provide several new algorithms: thermal-inertia mapping, estimation of regional meteorological information from the fundamental remote sensing data, registration of satellite day-night
images, elevation correction of thermal and thermal-inertia data, and determination of sensible-heat flux. The concluding section of this report addresses our image processing techniques together with a listing of the computer programs used.

2.1 GEOLOGIC SETTING

The study areas are the Powder River Basin and environs in eastern Wyoming-Montana and the adjacent Dakotas and the Cabeza Prieta Range in southwest Arizona. The Powder River Basin (lat. 42°-45° N., long. 103°-107° W.) has large potential for coal, oil and gas, and uranium, and accordingly is now the target of several major geologic, water-resource, and land-use mapping projects. Covering an area of about 250 x 400 km, it is a semi-arid region of rolling low hills typically with thin to moderate grass and sage cover. Tertiary rock units (Fort Union and Wasatch Formations) in the central area of the basin, where the energy resources are known to occur, are exposed on scales sufficient for satellite measurements. The lower part of the Fort Union is sandstone exposed in belts 4 to 10 km wide; the upper Fort Union part is siltstone with major coal beds exposed in belts 10 to 30 km wide; and the Wasatch is siltstone and claystone covering areas 30 to 60 km wide.

The Cabeza Prieta Range in Arizona (lat. 32°-33° N., long. 112°-115° W.) is a proposed Wilderness area, and the USGS has begun a program to define the geology and mineral-resource potential of this virtually unmapped area. The State geologic map shows the area to contain granite, schist, mafic volcanic rocks, and alluvium. It lies very near the major mineral district at Ajo, Ariz., and contains old prospect developments in hydrothermally altered
ground. Because the area has been withdrawn from public access since World War II, the geology and mineral potential are barely known and thus the area is considered relatively important for modern study.

2.2. APPROACH

Initial data interpretation was performed by visual pattern recognition of areas significantly different than their surroundings. Several 1:1,000,000-scale photographic enlargements were made of the NASA thermal and reflectance images to match them to many of the other existing data map products (geologic, geophysical, topographic, Landsat lineaments, and so on). Because of the X-Y distortion and the large magnification, this method was not entirely satisfactory for detailed study. We then generated film products from the computer-compatible tapes (CCT's) and used a zoom transferscope with X-Y stretch capability to register the projected images onto a stream-network map. In most local areas, this permitted plotting of features to within one to three pixels of their true ground position. Few of the interpretations based on the temperature boundaries or on other features are significantly affected by this degree of mislocation.

During this stage of the investigation, we also discovered that the NASA-supplied ΔT and thermal-inertia images contained artifacts, such as double drainage, indicating misregistration in parts of these images of several to many pixels. Consequently we developed a registration algorithm (Watson and others, 1981b) which registers data to within two pixels. Also as part of the investigation, we developed a new thermal-inertia algorithm (Watson, 1981a) which was employed during the remainder of our analysis. Correlation of these
registered image products with the other geologic-geophysical data was performed primarily by using optically enlarged projections of the data on digitally enlarged image product at a scale of approximately 1:200,000. This enabled us to examine subtle features at the pixel level and also to employ our full profiling and histogram capability at the full dynamic range and resolution of the digital image data. We have thus been able to quantify many of the scene differences which had been observed on various image products.

We also examined the use of color-coded images for enhancing subtleties in the scene contrast. Generally this provided a more obvious demonstration of differences but did not appear to add any new information. Toward the end of our study, however, a color-coded thermal-inertia image was produced which provided a new - if unexplained - perspective of the scene. A north-northeast-trending rectangular pattern of ground, surrounding the Black Hills and roughly corresponding with major changes in the drainages of the Yellowstone and Missouri Rivers was observed. In retrospect, this feature can now also be seen on the black and white products. The color-coding of the image was also a very useful tool for quickly determining the numerical range of values. With an appropriate color-scale and using a high-powered magnification lens, it was possible to determine the thermal-inertia ranges of many geologic units quickly. In both these respects the color-coding can be regarded as a useful but not essential element in the analysis.
2.3 RESULTS

2.3.1 Thermal-inertia mapping for discrimination of geologic features

2.3.1.1 Delineation and subdivision of geologic units

Discrimination studies have been somewhat limited by the lack of sequential day-night image pairs free of major atmospheric/weather problems, but the 20 August 1978 set of day (AA0116-20010-1,2 and AA0116-20020-1,2) and night (AA0116-09040-3) scenes and our constructed temperature-difference (∆T) and thermal-inertia images show several geologically significant features. Other good nighttime data from 30 July 1978 (AA0095-09170-3), 5 September 1978 (AA0132-09050-3), 27 September 1978 (AA0154-09190-3), and 10 June 1979 (AA0410-08450-3) passes have been used for delineation of several geologic boundaries, including some not within the area of, or not identified in, the 20 August 1978 data set.

A measure of discrimination capability, using optimal images and selection of geologic units which contrast well with their surroundings, is the clear delineation of the Mesaverde Formation. South of the Bighorn Mountains, in the vicinity of the towns of Midwest and Edgerton Wyo., the Mesaverde - a relatively massive sandstone - crops out between the Fox Hills Sandstone and the Cody Shale. On the night image (fig. 1) for 30 July 1978, all three units are relatively warm; however, the Mesaverde can be traced as a distinctly warmer unit (1/4°-1/2° C), along at least 40 km of strike length in which a fold nose is clearly defined (fig. 2). The Mesaverde outcrop here is 1-2 km wide or 2-4 resolution elements (pixels).
Figure 1.— Night thermal image, July 30, 1978, of the Powder River Basin, Wyo., delineating the fold nose of the Hassard and the Frontier Inlier. The standard convention of dark for low values and light for high values is employed on all images in this report.
Figure 2.— Fold nose of the Meeaverde Formation as expressed on the July 30, 1978, nighttime HCMM image. An unmarked image is provided for comparison.
Southwest of that area, south of the town of Powder River, within a large area of Cody Shale, is a sandstone inlier of Frontier Formation surrounding older shale and sandstone of the Cloverly and Morrison Formations. In the 30 July image, the Frontier is clearly a warm annulus around a cool center of the other units (fig. 1 and 3). The units in the cool central area are about 5 km wide and the warm Frontier annulus is 3.5 km wide. What is additionally interesting in this area is the apparently clear definition of a similar but smaller such feature to the northwest which does not match the shape of the contacts on the most recent geologic map (Love and others, compilers, 1955). This feature has not been field checked.

Another measure of discrimination is found in the area of the Pumpkin Buttes. These are very sharply defined in the 5 September 1978 night image (fig. 4). North Butte is about 3 km wide, and the combined topographic/geologic prominence of Middle and South Buttes measures about 4 by 8 km. These are warmer than their surroundings, as is expected of tuffaceous sandstones of the White River Formation, dense and resistant enough to form buttes where erosional remnants lie upon the softer sandstones and mudstones of the Wasatch Formation. Once again, when the geologic map was projected onto this HCM scene, differences were observed. Unfortunately, on our only thermal-inertia image, clouds were present over the Buttes preventing the observation of the expected thermal-inertia contrast.

Definition of geologic features is highly variable from pass to pass and within single passes. The 30 July image (fig. 1) is excellent for the north half of the Powder River Basin and the areas west and southwest of the Basin. The image appears virtually washed out in the south half of the Basin,
Figure 3.—Inlier of the Frontier Formation as expressed on the July 30, 1978, nighttime HCM image. An unmarked image is provided for comparison.
Figure 4. — Night thermal image, September 5, 1978, of the Powder River Basin, Wy., showing the desalination of the Pumpkin Buttes.
showing high temperatures in an area conspicuously cool in all the other images. Because the image was examined long after it was acquired, it was not possible to obtain detailed field meteorological data. This is a generic problem in dealing with transient and local phenomena that commonly affect thermal surveys. Air temperature and precipitation data show fairly similar conditions at the 28 weather stations throughout the scene. From these data, the intrascene variations cannot readily be ascribed to local weather/moisture changes; however, the NOAA and DMSP (Defense Meteorological Satellite Program) Satellite data show that a major weather front had recently passed through the basin. Such intrascene differences are less pronounced or even absent in other passes, but none of the others expresses quite the same degree of geologic feature definition as the good portions of the 30 July image.

The multiple data sets of 20 August contain considerable geologic information, especially in comparing patterns seen variously in the day thermal, night thermal, ΔT, and thermal-inertia images. The day thermal image (fig. 5) shows large areas of warm ground north and east of the Black Hills. These do not correspond to lithologic subdivisions on any available geologic maps, nor to any patterns of weather across the scene during the previous few days. Small individual features of interest in the image are cool areas around the Tongue River and in a belt of small patches trending north-south up the center of the southern part of the basin. The very warm drainage area west of the Black Hills and the warm area south of the Black Hills are also noteworthy. The night image (fig. 6) offers busier patterns of finer scale definition, dominantly related to the topographic character of local areas. Much, but not all of the high ground between streams, is conspicuously warm. The long,
Figure 5. -- Day thermal image, August 20, 1978, of the Powder River Basin, Wyo., showing thermal boundaries.
Figure 6.— Night thermal image, August 20, 1978, of the Powder River Basin, Wyo., showing the conspicuously warm areas. The unlabeled lines are profiles A-A' (north line) and B-B' (south line).

0     100 Km
straight Powder River separates warm ground on its east flank from cooler ground on its west flank. This is not just an effect of east- vs. west-facing slopes, because most other stream areas do not show the same effect. The north-south belt in the southern part of the Basin shows as very warm patches of ground. Very warm areas ring the east flank of the Black Hills and occur just to the north throughout the Bear Lodge Mountains, but these do not correspond to the mapped geology. Other contrast stretches were tried including color slicing but the correlations of temperature areas with geology did not improve. What does appear to be true, however, is that within the Powder River Basin, conspicuously warm areas are much more abundant in the north half. For the most part, this is a result of greater dissection of the terrain and more exposure of bedrock, as compared with few outcrops and abundant windblown sand veneer in the south half.

Analysis of the thermal-inertia images, derived from our registration and modeling algorithms, showed that the Tongue River areas of cold ground in daytime are, in fact, areas of high thermal inertia (2000 Thermal inertia units (TIU); 1 TIU = 1 W sec^{1/2} m^{-2}). These areas (fig. 7) correspond quite well to areas mapped by Rainee (Rainee and others, 1978), using computer enhancements of Landsat images. They were mapped as the coarsest, sandiest lithofacies unit in the basin, which are relatively indurated and resistant and should crop out best and, depending on moisture conditions, should have the highest thermal inertia of the subunits in the Wasatch and Fort Union Formations. Other such correlations exist for several areas of this facies southeastward toward the Black Hills. Areas of the Wasatch and Fort Union, sampled from various parts of the Basin and which appear to be representative,
Figure 7.— Thermal-inertia image, August 20, 1978, of the Powder River Basin, Wyo.
of larger surrounding areas have thermal-inertias of 1525 TIU and 1450 TIU, respectively. However, the thermal-inertia of these two units varies considerably throughout the basin and in some cases values for these two units are statistically inseparable. A possible explanation is that these units generally form low or flat topography where windblown sand obscures the underlying geology in extremely irregular (and unmapped) patterns. Another reason is that these units retain moisture differently and longer than sandier facies, and thus may have great irregularities in both thermal-inertia values and wind cooling patterns. If they are slightly wet, and not cooled by surface winds, their thermal inertia will be higher.

The north-south belt of high thermal inertia (fig. 7) was initially thought to correspond to burned ground over ancient natural coal fires. The night thermal image (fig. 4) was carefully registered to a base map and a composite map was made showing the areas of clinkers (as determined from a color ratio composite Landsat image) and the warm areas on the HCMM image (fig. 8a). We then examined the thermal-inertia image and determined that the clinker areas in fact have an intermediate thermal inertia (1300 TIU) and the N-S belt of warm ground in the night image just east of the clinker hills has a higher thermal inertia (1500 TIU). This north-south belt has been mapped in detail and the surface geology provides no clue as to why these areas have high thermal inertia. This does not conform with conditions produced where windblown sand accumulates in the lee of topographic highs. It is suspected that the highly fractured clinker hills are readily drained of their near-surface moisture and this ground water tends to pond just eastward in the direction of normal drainage, causing an increase in thermal inertia. This
Figure 8a.— Base map of the Powder River Basin, Wyo., showing the location of the clinkers with respect to the warm areas which have high thermal inertias.
hypothesis is given credence by an examination of the NURE gamma-ray profiles in this area. These areas coincide with lows in the total gamma-ray measurements (fig. 8b) as would be expected for areas of higher moisture content.

A rough order of magnitude estimate from these data is that the anomalous areas are associated with a 20 percent increase in thermal inertia and a 5 to 10 percent decrease in the total count values. The thermal inertia of soils increases rapidly with increasing soil moisture content and the effect can be estimated for low moisture contents by considering only that increase due to density and specific heat capacity. The ratio of the fractional change in thermal inertia to density is just one half the ratio of the specific heat capacity of water to soil or approximately 2.5. Thus a 20 percent increase in thermal inertia could be produced by a soil moisture change which increases the density by 8 percent (and decreases the total count by an equivalent percent).

To examine the basin further, two northwest-southeast profiles across the 20 August image (fig. 6, profiles A-A', B-B') were constructed. These profiles enabled us to look in detail (pixel level) at variations in thermal-inertia values and to examine relationships between temperature or thermal-inertia patterns and topography. Topographic data were taken from 1:250,000 USGS base maps with a contour interval of 200 feet. Figures 9 through 14 show profiles of thermal-inertia, elevation, and topographic gradient along lines A-A' and B-B'.

The profiles on A-A' have several interesting features. The line begins in the Wasatch Formation at the northwest end, and thermal-inertia values (fig. 9) decline into a broad low, about coincident with the Powder River
Figure 8b.— Comparison between profiles of total count gamma ray and the anomalously warm areas. The straight lines indicate the geographic position of the profiles.
Figure 9.-- Thermal-inertia profile for line A-A'.
drainage seen so clearly in the topographic profile (fig. 10, 11), and then rise. This low approximately marks the basin axis, and the adjacent slopes of the thermal-inertia profile show the character of the upper part of the Wasatch on either side of that axis. The topography itself is somewhat different on opposite flanks of the Powder River drainage, and this probably explains the previous observation that the night-temperature image showed the two flanks differently, even though the thermal-inertia image indicated the two flanks to be underlain by similar material. The flanks have different slopes and bed dips, and the western flank generally is dissected more sharply and deeply than the eastern flank. At the next large drainage east of the Powder River, the thermal-inertia profile breaks sharply, suggesting either a previously unmapped lower unit of the Wasatch or a sharp change to the somewhat finer grained facies which has been noted in the lower part of the formation. Along this profile the Fort Union Formation has a roughly estimated average value of 1425 TIU, as compared with an equally rough, general average of the Wasatch of 1625 TIU. This difference is about what would be expected from the compositions of the two formations, although they are rather nonuniform on the scale of the whole basin. The "typical" areas of Fort Union and Wasatch that were sampled gave values of 1450 TIU and 1525 TIU, respectively. A sharp break in the thermal-inertia profile occurs between the two formations, but it falls 4 to 5 km west of the contact as shown on the geologic map. A break or dip also occurs in the profile at the contact of the upper (Lebo Shale) and lower (Tullock) members of the Fort Union, but overall the members have about the same thermal inertia. The elevation profile shows a marked change in character of topography from Wasatch to Fort Union, as does
Figure 10.-- Elevation profile for line A-A'.

Profile AA', PRB Area

Keyhole Reservoir

Powder River

Fort Union Formation

Wasatch Formation

Distance (km)

Elevation (m)
Figure 11.-- Topographic-gradient profile for line A-A'.

Profile AA' PRB Area

Fort Union Formation

Wasatch Formation

Gradient (m/km)

Distance (km)
the topographic-gradient profile. The warm north-south zone is a narrow but prominent thermal-inertia spike in the lower part of the Lebo Shale Member of the Fort Union. The Pierre Shale has the lowest thermal-inertia of any units along the profile (about 1330 TIU), in huge contrast with the adjacent spikes which mark Keyhole Reservoir.

Line B-B' presents a rather different character in the profiles. The Wasatch thermal inertia (fig. 12) is not at all like that on line A-A'; most of its width on line B-B' is an area of unexplainedly low values which mark a very distinctive and nonrepresentative area within the widespread formation. Wasatch with relatively normal-appearing thermal-inertia image character appears next to the cloud area at the northwest end of the line; there its estimated average thermal inertia is 1550 TIU, only 5 percent different from that seen on line A-A'. The area of low values does not appear to be related to microclimatic factors, nor to any geologic feature of which we are aware. For example, neither here nor elsewhere in the image area do thermal-inertia values closely and consistently correspond with the inferred lithofacies areas delineated in Landsat images. On this line, the Lebo Shale Member of the Fort Union has a roughly estimated thermal inertia of 1750 TIU, higher than the representative Wasatch values. Most of this is in the broadest part of the north-south warm zone, however, so the values almost certainly do not represent normal character. The Tullock Member of the Fort Union is estimated at 1300 TIU, almost 10 percent lower than the Fort Union of line A-A'. Such a change is believed to be both real and significant in terms of the geology, but no data are available as to possible lithologic changes of the unit between the two profile areas. The Pierre Shale has a thermal inertia of 1260
Figure 12.— Thermal inertia profile for line B-B'.

Profile BB', PRB Area

Cloud area

Power R.

Pierre Shale

Fort Union Formation

Wasatch Formation

Black Hills

Inertia(TIU)

Distance(km)

0 25 50 75 100 125 150 175 200 225 250

3000 2500 2000 1500 1000 500
Figure 13.—Elevation profile for line B-B'.
Figure 14.-- Topographic-gradient profile for line B-B'.

Profile BB' PRB Area

Gradient (m/km)

Distance (km)

Fort Union
Wasatch Formation

Figure 14.-- Topographic-gradient profile for line B-B'.
TIU, about 5 percent less than observed on line A-A', and again the lowest values of any geologic units on the profile. High and highly variable thermal inertia is seen in the Black Hills portion of the profile as expected in an area of alternating high vegetation density and bare rock exposures.

From this analysis, it appears that thermal data, especially when coupled with topographic information, can aid materially in discriminating geologic formation and member differences, even (as in the Powder River Basin) where units are so variable and exposures so poor that geologists have had real problems or have been unsuccessful in such efforts. It appears that thermal-inertia differences of perhaps as little as 5 percent, and certainly 10-15 percent, can be delineated and used in mapping, probably in terms of both rock units and generalized soil characteristics. So far, patterns seen in thermal-inertia images do not match with vegetation patterns seen in Landsat images and believed to correspond to subtle facies differences. This problem needs further investigation; it may relate to difference in resolution of the two satellites and to differences in depths “seen” by thermal-inertia measurements and vegetation root systems.

2.3.1.2 Geomorphic domains and linear features

An interesting and important aspect of using thermal-inertia images is that erroneous impressions gained from temperature patterns are corrected and a truer picture of surface properties obtained. This is particularly true of night thermal data. For example, the very warm zone around the Black Hills in the night image (fig. 6) disappears in the thermal-inertia image (fig. 7), and a whole new pattern emerges. The contrast of opposite flanks of the Powder
River also disappears, indicating no basic difference in geologic materials across the river. Thus we can use thermal, albedo, and thermal-inertia data in concert to separate physical properties differences (integrated over the top decimeter of the soil or rock profile) from those effects due to such parameters as slope, altitude, and surface reflectance.

For the units underlying most of the Powder River Basin, presently available thermal data and derived products show many unexplained patterns, some of which probably were due to transient (and now untrackable) atmospheric events. Others, however, are believed to reveal real differences in the geologic materials, but current maps in general do not offer a sufficiently detailed base for correlation. Certainly some correlations are found with Landsat-mapped lithofacies, but more day-night pairs covering varying moisture cycles would have been necessary to see through such "noise" as windblown sand, surface-wind cooling patterns, and local moisture variations.

Linear features, often long reaches of streams that appear straight at HCMR resolution, are readily defined in the night images. Many of these coincide with breaks or trends in contoured aeromagnetic data, suggesting that basement tectonic elements have printed through the thick sedimentary sequence to control stream courses. This implies that during sedimentation at earlier times, such features affected some control of sedimentary depositional patterns a conclusion recently elaborated for the Powder River Basin (Slack, 1981).

The most remarkable, previously unrecognized, linear feature appears prominently on the night image of 5 and 27 September (figs. 4 and 15) and also 20 August (fig. 6). Although it is not recognizable as a discrete linear
Figure 15.— Night thermal image, September 27, 1978, of the Powder River Basin, Wyo.

- Tongue River
- Powder River
- Big Horn Mts
- Linear Feature
feature on Landsat images (fig. 16a), topographic data (fig. 16b) show this lineament as a subtle drainage divide trending about N55°E. On the thermal images the southward-facing side is cooler by 3° or 4° C, and on the 20 August thermal-inertia image (fig. 7), the south side has a 17 percent lower thermal inertia (1215 TIU) than the north side (1460 TIU). Thus, the feature correlates with a subdued drainage divide but it cannot appear due to the slope effect and must represent—at least in part—a physical property difference across the divide. There is no explanation in existing geologic maps (at scales from 1:24,000 to 1:500,000) for this feature or why it separates temperature and topographic domains. The divide is parallel to the prevailing wind direction from the west-southwest as shown in eolian deposits south of the divide. Moreover, the divide also marks a change in direction of wind deposition; deposits to the north are laid down by winds from the north-northwest. It is possible that the relatively common eolian sand cover south of the divide has controlled drainage habit creating the distinctive topographic texture, and the sandy veneer might possibly cause the domain to have lower thermal inertia due to lower moisture retention. It is not likely, however, that the divide lineament itself is wind related. Extended to the northeast, it continues through the linear gap (of the same strike) between the Black Hills and the Bear Lodge Mountains. More important, it directly overlies one of the most significant breaks (fig. 17) in the aeromagnetic-map pattern (U.S. Dept. of Energy, 1979 a, b, and c) of the whole area, it is parallel to and roughly coincident with an inflection in the ground-water temperatures of the Madison Limestone (fig. 18), and its trend passes through several Tertiary intrusives (fig. 19) and possibly even through Lead, South
Figure 16a. — Landsat (Band 5) image of the Powder River Basin Area, Wyo. A north-south mosaic line is present roughly 100 Km west of the Black Hills.
Figure 16b.—Illuminated topography image of the Powder River Basin, Wyo., showing the drainage divide which is coincident with the thermal lineament. The image was computed with a solar declination of -7.8 degrees and a local time of 0930 hrs.
Figure 17.-- Total intensity magnetic field form line map, central Powder River Basin, Wyo. (U.S. Dept of Energy, 1979a-d). The heavy black line shows the position of the thermal lineament.
Figure 18.-- Ground water temperatures in the Madison Limestone and equivalent rocks (Head and others, 1978). Heavy black line indicates position of the thermal lineament.
Figure 19.— Location of the thermal lineament with respect to structural lineaments (Slack, 1981) in the Powder River Basin, Wyo.
Dakota location of the Homestake Mine. In addition, stress measurements at Lead (Aggsen and Hooker, 1980) imply that the preferred direction for normal faulting would be N50°E, virtually coincident with the orientation of the thermal lineament. Together these pieces of information provide permissive evidence for structural control relating to this feature. A recently published paper (Slack, 1981) presents substantial corroboration for the control. Using subsurface data, Slack proposes that a series of northeast-trending structural lineaments (fig. 19), which he calls the Belle Fourche Arch, have controlled sedimentation in this area and played an important role in determining hydrocarbon accumulation in the southern Powder River Basin. One of his lineaments, Gose Butte, is coincident with part of the thermal feature (fig. 19). Additional supportive evidence for structural control is reflected in the shape of the hydrocarbon producing horizons of the upper and lower parts of the Muddy Sandstone of Cretaceous age (fig. 19).

There is further corroborative satellite evidence for our explanation of the primary cause of the thermal lineament as a thermal-inertia contrast between dissimilar materials. The feature can be seen on two daytime Defense Meteorological Satellite Program (DMSP) thermal satellite images (near noon) and cannot be seen on a nighttime NOAA-5 thermal satellite image (near 9 pm). This latter image is acquired near the time when thermal data should largely be insensitive to thermal-inertia differences because it occurs near the crossing times of the diurnal curves.

We also examined USGS aircraft data across the lineament. Although we had not previously recognized the feature on these data, a very subtle thermal contrast could be observed in the vicinity of the lineament. Largely because
of the slight temperature difference and the regional extent of the feature, it was not recognized on the aircraft data, and this result illustrates convincingly the potential power of regional thermal satellite data over aircraft data for structural-tectonic analysis.

A second, parallel lineament, not a stream divide but separating surface-textural domains, occurs 30 km to the south (figs. 4 and 15) and also overlies an obvious aeromagnetic break. These features appear to mark fundamental structural elements of the southern Powder River Basin and are newly recognized in HCMM data. To the north, parallel lineaments are marked in the images by the Belle Fourche and Little Missouri Rivers.

Information other than on geologic units per se can be gained from these images, most particularly in the demarcation of geomorphic (topographic-temperature) domains and in the discrimination of linear features. Night images are particularly useful in this regard. The 20 August 1978 image (fig. 6) provides very clear definition of major areas of distinctive topography, commonly linked with distinctive temperature patterns. The north and south halves of the basin are distinctly different; the areas east and northeast of the Black Hills differ from each other and from the domains of the basin. Other finer-scale units also are evident. These do not match the mapped geology and, like many geomorphic provinces, are products of a complex development history tied to more factors than the underlying bedrock. We believe that important information can be gained in this aspect of the HCMM images, especially in understanding surface processes during Tertiary and later time. Such information also may lead an understanding of near-surface groundwater hydrology across large, diverse areas. We have examined the domains
from the points of view of mapped geology, ground-water chemistry, mineral and hydrocarbon resources, and tectonic framework, and correspondences are not readily apparent. This is an aspect of the mission data that we did not originally anticipate. However, Schneider and others (1979) showed that the NOAA (National Oceanic and Aeronautics Administration) satellite VHRR (Very High Resolution Radiometer) data with 900-m resolution permitted the defining of geomorphic domains very clearly. This work and our present observations suggest that careful consideration of satellite thermal image data by geomorphologists and hydrologists should be undertaken.

2.3.2 Application to resource studies

2.3.2.1 Oil and gas

It was hypothesized that a few oil and gas fields of the Powder River Basin had enough leakage of gas, probably mostly CO₂, that calcite cementation would have occurred near the surface to make the bedrock more resistant, possibly to form local topographic highs. A few fields do indeed underlie local topographic highs, but this could be fortuitous, and no evidence of leakage and cementation has been cited in the literature. However, a reconnaissance survey of soil-gas helium shows 37 significant helium anomalies within the Wyoming portion of the basin (fig. 20), where most of the oil and gas occurs. The reconnaissance scale of helium sampling does not permit an accurate comparison with individual occurrences of oil and gas except for the largest fields, but it can be said that all but five of the helium anomalies occur over oil and gas fields, and those five are near producing fields. Many
Figure 20.— Location of helium anomalies, uranium fields, and oil-gas fields in the Powder River Basin, Wyo.
oil and gas fields do not have overlying helium anomalies, and the implication is considered to be that some fields leak gases upward and many more do not. Perhaps 15-20 percent of oil or gas fields might be considered to have leaked helium, although that number might easily prove twice as large if more detailed sampling were done. The percentage of fields where gases may have produced cementation, especially enough to cause detectable changes in surface-temperature character, clearly would be expected to be small. Thus, it is encouraging to note that visual discrimination suggests thermal-inertia anomalies (20 August image, fig. 7) for 9 out of the 37 areas with anomalous helium values (fig. 20). These areas have consistently and noticeably higher values than the surrounding areas, in keeping with expectations if cementation is locally increased. Most of the areas do not have noticeably different topography than their surroundings. Two of the helium-thermal-inertia areas do not overlie known oil or gas fields but both are surrounded by fields and have several dry holes within the areas. The dry holes may have had only subeconomic shows of oil or gas, in which case leakage to the surface may still have occurred; or perhaps holes simply have not been drilled in the right places. The two areally largest helium anomalies, one over a giant gas field and the other in one over the "barren" areas just described, are marked by fairly distinct oval rings in the thermal-inertia pattern.

Helium anomalies are numerous and areally large in the Montana portion of the basin. They occur in a roughly defined ring which corresponds to the perimeter of a roughly circular area of distinctive topography 75 km wide and approximately bisected by the Powder River. This area is virtually without oil-gas production and few wells are shown on available source maps. But the
helium anomalies correspond to the ring of very warm areas seen in the night 20 August image. We know of no reason to expect such helium anomalies in this region except in association with oil and gas, and the warm areas are mostly areas of outcrop, perhaps where cementation is increased. Information has not yet been found on facies in the subsurface rocks that might contain oil and gas. If the facies are not truly favorable, uneconomic amounts of oil and gas might have been present and leakage could have occurred. If the facies are favorable, the area deserves a closer look for exploration.

An additional point of interest is the possible relationship of HCMM lineaments and oil-gas occurrence. The major thermal lineaments transecting the southern part of the basin (fig. 21) define a block that contains most of the significant helium anomalies. Trends in the helium anomalies as contoured from present data commonly parallel HCMM lineaments. The two largest fields, Fiddler Creek and Clareton, are long and narrow and parallel in trend (and between) the basin-transecting thermal lineaments. The west end of the Clareton field ends in a prominent fork, with the southern one of the main lineaments passing through the fork junction.

2.3.2.2 Uranium

The uranium districts of the Powder River Basin (fig. 20) have local areas of surface alteration as large as 5 by 7 km. These, however, are exposed discontinuously, and differ only slightly in lithologic character and thermal properties relative to the surrounding unaltered ground. If the bedrock were totally exposed, an increase in thermal inertia of perhaps 10 percent might make the altered ground detectable. In any case, the only
Figure 21.— Major thermal and Landsat (Marrs and Raines, 1981) lineaments transecting the southern part of the Powder River Basin, Wyo. and boundaries of the topographic-temperature domains.
thermal-inertia data set does not cover the main uranium areas; the 20 August data and east of the districts or have clouds over the fringe areas where uranium ground occurs. We have examined low-altitude aircraft thermal data for the altered ground, and so far "noise" (soil cover, windblown sand, local topography, and moisture variations) seems to completely overwhelm "signal" related to the discrimination problem.

2.3.2.3 Geothermal flux

Another aspect of our study is to examine the utility of HCMM data for geothermal flux mapping. We found that the underground coal fires now burning north of Sheridan, Wyo., are detectable (barely) on nighttime HCMM thermal images. Comparison with a mosaic of aircraft thermal images of this area (fig. 22) illustrates the scale effects on the appearance of small geothermal anomalies. On the aircraft data the anomalies have a sharp, clearly defined pattern, whereas the satellite data show an indistinct pattern which is not distinguishable from geologic and topographic effects. Also, the satellite appearance of drainage features is distinctly different from the aircraft data. From nighttime aircraft data, the Tongue River appears as a sharp warm anomaly with cooler surroundings. The satellite image, because of its coarser resolution, does not discriminate the narrow water channel, and, thus, the drainage appears entirely as a cool zone.

To examine the expression of geothermal anomalies more fully, HCMM scenes of Yellowstone National Park were analyzed. The region has a classic expression of most of the typical hydrothermal features of a vapor-dominated system. A careful comparison between a nighttime image (fig. 23a) and a detailed
Figure 22.— Areas of underground coal fires near Sheridan, Wyo., as seen on HCMM and aircraft thermal data.
Figure 23a. — Nighttime thermal image of Yellowstone National Park with calderas outlined superimposed.

Figure 23b. — Location of hydrothermal features (Smith and Christiansen, 1980).
map of the hydrothermal features (Smith and Christiansen, 1980) (fig. 23b) was made using a zoom transfer scope. The hydrothermal features commonly were not expressed as warm anomalies (fig. 24a), and most of the warm anomalies on the images are not hydrothermal-associated features (fig. 24b). These results demonstrate that nighttime satellite images at this scale are unlikely to be useful for detecting similar features elsewhere. Of greater geologic interest was the correlation between the caldera outline, some thermal anomaly lows, and in particular the anomaly bounded by a sharp edge (fig. 23a) which coincides with that part of the gravity field map outlining the southwest side of the caldera (fig. 25b). Although this latter anomaly is a feature with no direct counterpart in Landsat images (fig. 25a), it may provide additional information on the volcanic-tectonic setting. From these brief observations we conclude that the HCMM data can be useful in understanding the regional structural setting of geothermal fields but are not likely to be useful for mapping hydrothermal features.

2.3.2.4 Mapping geologic units in an arid desert environment

The Cabeza Prieta area in Arizona is an arid desert environment with geologic units exposed at a scale suitable for discrimination in HCMM satellite images. The area lies very near the major copper district at Ajo and contains old prospect developments in hydrothermally altered ground. No detailed geologic mapping has been previously done of this area as it contains a proposed Wilderness site. The main objective of our investigation has been to extend the interpretation techniques developed in our Powder River Basin study.
Figure 24a. -- Nighttime temperatures of known hydrothermal features.

Figure 24b. -- Ranking of thermal night anomalies.
Figure 25a.—Landsat image of Yellowstone National Park with the calderas and park boundaries outlined.

Figure 25b.—Gravity field contours (Smith and Christiansen, 1980).
A thermal-inertia image (fig. 26) was constructed using the April 3 and 4, 1979 scenes (AA0342-09150-3; AA0343-20230-1, 2) with 36-h separation between the day and night acquisition times. The image was then compared to the Ajo geologic map (Kahle and others, compilers, 1978) and an estimate was made of the thermal-inertia values of various geologic materials (table 1). Among the sedimentary deposit materials, a wide range of thermal-inertia values was found. From highest to lowest values these included a wet coal-mine dump near Ajo (1890 TIU), active pediment areas (1360 TIU), stabilized dunes (1065-1300 TIU), and active dunes (830-1065 TIU). The most probable explanation for this ranking is due to the strong effect of moisture content on thermal inertia. Generally, active dunes should have the lowest thermal inertia, as observed, owing to their low density and low capacity to retain moisture.

A somewhat surprising result was that the thermal inertias of the various igneous rock units were measurably different, indicating a finer discrimination capability than previous laboratory data in the literature would suggest (Watson, 1979, 1981a). The literature values of thermal-inertias of igneous rocks show no correlation with either composition or grain size and are indistinguishable from each other. In Cabeza Prieta, however, we found that the felsic intrusives (together with gneiss and schist) had the highest thermal inertias (>2200 TIU), that extrusive rocks of mafic composition had intermediate thermal inertias (approximately 2000 TIU) and that extrusive rocks of less mafic composition had the lowest thermal inertia (<1900 TIU). We believe that the felsic intrusives have the highest thermal inertias because of their high quartz content and high surface density and that the differences among extrusive rocks occur because of density differences associated with the amount of
<table>
<thead>
<tr>
<th>Geologic Material</th>
<th>Thermal Inertia (TIU)</th>
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<tbody>
<tr>
<td></td>
<td>mean</td>
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<tr>
<td>Active Dunes</td>
<td>945</td>
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<tr>
<td>Partially stabilized dunes</td>
<td>1240</td>
</tr>
<tr>
<td>Cluster dunes</td>
<td>1180</td>
</tr>
<tr>
<td>Active pediment slope</td>
<td>1360</td>
</tr>
<tr>
<td>Wet mine dump (Ajo)</td>
<td>1890</td>
</tr>
<tr>
<td>Granite, gneiss, schist</td>
<td>2200</td>
</tr>
<tr>
<td>Mixed intermediate to mafic volcanic rocks</td>
<td>1750</td>
</tr>
<tr>
<td>Basalt</td>
<td>1950</td>
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volatiles present during their formation and their mafic content. Although these values are suggestive of the possibility of discriminating among the various units, the large overlap in the range of values (histograms) indicates that classification based solely on thermal inertia differences may not be feasible. The overlap between the units can be attributed to several causes. These units are exposed in the most rugged terrain of the region and thus topographic effects are most pronounced in these parts of the image. The ground that is "sensed" by the technique is a weighted average over the diurnal thermal wavelength (approximately 1 m), with the primary contribution coming from the rock and rock fragments of the upper decimeter. Thus differences in the effects of weathering processes on the various rock types in this environment can produce some degree of thermal-inertia differences.

Because the Powder River Basin was relatively flat terrain the topographic effects were not sufficiently important to be considered. In the Cabeza Prieta area, however, slopes in excess of 20° can be found. To examine the contribution of topography, the thermal inertia measured from remote observations we considered the aspects of elevation and slope separately. The elevation factor due to changes in the solar and sky radiation, has been examined and used to predict the equivalent change in the effective thermal inertia (i.e., that derived from remote rather than in situ measurement) as a function of elevation (Hummer-Miller, 1981b). The effective thermal-inertia gradient under clear-sky conditions should be roughly 100 TIU per kilometer. In Cabeza Prieta, where the maximum relief is 700 m, this maximum correction is only 70 TIU and the factor is additive for increasing elevation (i.e., rocks at higher elevations will appear in the image to have lower thermal inertias).
The slope factor was evaluated by using an algorithm recently developed (Watson, 1981b). The turn has an azimuthal variation proportional to \( \cos(\theta - 37.6^\circ) \) where \( \theta \) is the direction of slope measured counterclockwise from north, and thus ridges with an axial orientation of roughly N40\(^\circ\)W will display a minimal topographic effect. The most consistent topographic grain in the Cabeza Prieta area is northwest-southeast and thus generally satisfies this constraint. The correction can amount to several hundred TIU's for slopes in excess of ten degrees and orientations orthogonal to N40\(^\circ\)W (i.e., N50\(^\circ\)E).

The primary intent of this study area was to examine correlations between thermal-inertia values and a variety of common rock types exposed in an arid area. In the process of this analysis we also observed, on the night thermal image, a number of linear features associated with known major faults (San Andreas fault, Garlock fault) and the absence of lineaments in an area near Gila Bend which is noted for the absence of structural features (Gila gap). We also were able to determine a measure of the satellite's spatial frequency response (and thus its ability to detect high-contrast linear features) by the observation that Interstate-10 from Gila Bend to Yuma was observable.

3.0 MODEL DEVELOPMENT

Several advances have been made in the development of techniques to analyze thermal-infrared data. An algorithm to determine the sensible-heat flux from simple field measurements (wind speed, air and ground temperatures) has been developed. It provides a direct solution, in parametric form, that can be displayed graphically or tabularly. This method has an advantage over the previous iterative solution in that the computation is both very fast and
it also provides a clearer understanding of the drag coefficient, with its variation and response to different conditions. At low wind speeds the drag coefficient cannot be treated as a constant. Both the computational speed and analysis of the drag coefficient can be important for remote-sensing applications involving thermal scanner data (Watson, 1980).

A substantial advance was the development of a method, based solely on remote-sensing data, to estimate those meteorological effects which must be known for thermal-inertia mapping. It assumes that the atmospheric fluxes are spatially invariant and that the solar, sky, and sensible heat fluxes can be approximated by a simple mathematical form. Coefficients are determined from a least-squares method by fitting observational data to our thermal model. A comparison between field measurements and the model-derived flux shows that good agreement can be achieved. An analysis of the limitations of the method was also made (Watson and Hummer-Miller, 1981a).

This new method of estimating atmospheric parameters was the basis for a revised thermal-inertia algorithm (Watson, 1981a). The new form is:

\[ P_{ij} = (P \cdot \Delta V + C(\lambda, \delta) \cdot (A_{i} - A_{j})) / \Delta V_{ij} \]

where \( A_{i} \) and \( A_{j} \) are the corresponding albedo and temperature difference of the \( i \)th pixel and \( j \)th line. \( A \) and \( V \) are the mean values for the area in question, and \( P \) is a select value for the mean thermal inertia (generally 1500 TIU). \( C(\lambda, \delta) \) is a function of the site latitude, \( \lambda \), and the solar declination, \( \delta \). The advantage of this algorithm lies in the fact that we are dealing with albedo and thermal differences rather than absolute values. Thus, the computed thermal inertia is less sensitive to offsets caused by calibration.
errors or atmospheric backscattering and transmission effects.

Other modeling studies centered around developing an algorithm for elevation correction of temperature and thermal-inertia images (Hummer-Miller, 1981b). They are based on application of the linearized Fourier series method (Watson, 1975; Watson, 1979) to simple forms of the solar flux (Hummer-Miller, 1981a) derived from a representative set of field observations. It was found that flux variations with elevation can cause changes in the mean diurnal temperature gradient from -4° to -14° C per km (evaluated at 2000 m). Changes in the temperature-difference gradient of 1°-2° per km are also produced and these are equivalent to an effective thermal-inertia gradient of 100 TIU per km.

In addition, a simple topographic slope correction method has been developed using the linearized thermal model and assuming slopes less than about 20°. The correction can be used to analyze individual thermal images or composite products such as temperature difference or thermal inertia. Simple curves were determined for latitudes of 30° and 50° (Watson, 1981b). The form is easily adapted for analysis of HCMM images using the DMA (Defense Mapping Agency) digital terrain data (Watson, 1981b).

A major concern in this investigation has been the accurate registration of day and night images. We have developed an image-registration algorithm which appears to be substantially better than the current registration products provided by NASA (Watson and others, 1981). The initial test of this algorithm used the 20 August 1978 data of the Powder River Basin. A small number, less than ten, of very clearly delineated features, generally the water-dam interfaces of reservoirs, were selected as control. Subsequently,
an affine transformation was determined by best fitting these points. Our first test indicates a residual error of < 2 pixels. The NASA product for the same scene displays errors of many pixels resulting in "double drainage" effects and an offset of several kilometers.

During the initial stages of our experimentation with control points, we expected that the drainage pattern in the Powder River Basin was substantial enough to provide extensive control for registration. We discovered, however, that drainages are often unreliable identification features and the resulting control points were too inaccurate to provide the transformation coordinates. We also experimented with cross-correlation techniques in the Cabeza Prieta area but were unsuccessful owing to the strong topographic grain. The affine transformation which we employed has the additional advantage that it can be adapted to very fast computer processing schemes (Braccini and Marino, 1980).

4.0 DIGITAL IMAGE PROCESSING

This section presents an outline of the image processing techniques used in this study. Figure 27 is a simplified flow diagram of the basic processing steps; the computer programs referenced in this diagram are included in Appendix A. The initial processing involves obtaining the HCMM computer-compatible tapes (CCT) and altering the data format to be consistent with our computer software. Sometimes the area of interest spans two scenes and, consequently, must be appended into a single file. To produce enhanced images of these products, the appropriate area of the image is statistically sampled to form a histogram and to derive the mean, median, mode, variance, standard
Figure 27.— Flow chart of the image processing procedure.
deviation, and cumulative frequencies. With these statistics a decision is made as to how the scene contrast should be enhanced using an appropriate transformation of the scene brightness. From our experience a 1 or at most 2 percent linear stretch of the data produces a good starting point. Thus the 1 or 2 percent and 98 or 99 percent points are transformed linearly to the extremes of a 256-step gray scale (0 and 255) and the center density value (Dn) of the distribution is transformed linearly to the center of the gray scale (127 Dn). Other useful products include linear stretches on paper where a single print character is assigned for each Dn value and color-coding on film.

The next processing operation is performed to register the night-thermal file to the day files. This operation, including a discussion of the general considerations, are detailed in Watson and others (1981). Control features are selected from the positive transparency images produced from the CCT and locations are measured to one pixel accuracy. These values are then used to determine the affine coefficients for a best-fit transformation (REGALG). This transformation provides a rotation correction for the inclined satellite orbital tracks, an origin shift, and scale changes both along and across the scan line. The actual registration of the night file is then performed using the affine transformation coefficients in the GEOMX4 computer program. This program assigns radiometric values to the newly registered image employing a nearest-neighbor method.

At this stage the data are in the appropriate format for thermal-inertia and temperature-difference mapping. The algorithms which we use (Watson, 1981a) employ average scene values of albedo, day temperature, and night
temperature. The portion of the scene from which these values are determined is based on the assumption of atmospheric invariance and thus, as a minimum constraint must be cloud-free on both images. The program RAPFIT is then used to compute the appropriate coefficients for this algorithm, and the program HCMTIDT is employed to construct both temperature-difference and thermal inertia files. The resulting files are then processed using these techniques described in the beginning paragraph of 4.0.

Another analysis technique used in this study is to construct profiles across the image data. The endpoints of particular profiles are chosen and digital values along the line are obtained for all products: day reflectance, day thermal, registered night thermal, and thermal inertia using a nearest-neighbor algorithm. The corresponding elevation profile is obtained by digitizing the appropriate portion of a 1:250,000 topographic map and adjusting it to match the satellite data. This task is made easier if the profiles cross distinct features such as reservoirs and rivers. After the elevation data are registered to the satellite data, the program PROFILE is used to plot the profiles and cross plot pairs of data values. The profiles can be plotted at various scales and thus directly overlaid on any base material for comparison. The cross-plotting option is valuable for examining correlations (for example, we observed that the day thermal versus elevation data fit the adiabatic lapse rate).
5.0 REFERENCES


Hummer-Miller, 1981a, Diurnal variation of four flux parameters fit to field observations: Submitted to Journal of Geophysical Research.


1981a, Regional thermal-inertia mapping from an experimental satellite: Geophysics (in press).


5.1 APPENDIXES

Listings of the following computer programs described in section 4.0 follow:

- REGALG
- RAPFIT
- GEOMX4
- HCMTIDT
- PROFILE
10 REM To compute best fit affine transformation for HCMM regist.
20 Program language is extended Basic.
30 Program written by K. Watson
40 OPTION BASE 1
50 STANDARD
60 INTEGER 1, Print
70 DIM Xolo(100), Yolo(100), Xnew(100), Ynew(100), Name$[50], S(3), X(100), Y(100), C(50), Count(100), Pal(4), Lnl(4)
80 PRINT IS 16
90 INPUT "Do you wish to read an input file Y or enter values manually N", Anz$ 
100 IF Anz$="Y" THEN GOTO 130
110 INPUT "Do you wish to store an input file Y or N", Any$ 
120 IF Any$="N" THEN GOTO 350
130 INPUT "Enter Filename for Day(new) points", File1$ 
140 IF Any$="Y" THEN CREATE File1$, 10
150 INPUT "Enter Filename for Night(old) points", File2$ 
160 IF Any$="Y" THEN GOTO 350
170 ASSIGN #1 TO File1$ 
180 ASSIGN #1 TO File2$ 
190 READ #1:N
200 Nnum=N
210 REDIM Counter(N) 
220 READ #1:GS  ; Implies a title which is ignored 
230 FOR I=1 TO N
240 READ #1:Ynew(I), Xnew(I) 
250 Counter(I)=1
260 NEXT I
270 ASSIGN #1 TO File1$ 
280 ASSIGN #1 TO File2$ 
290 READ #1: Lmax 
300 REDIM Xolo(N), Yold(N), Xnew(N), Ynew(N), Xl(N), Yl(N), Cointer(N) 
310 Printer=16
320 PRINT PAGE 
330 PRINT LIN(10), SPA(5), "To enter control points use the format:"
340 PRINT " Day(new) Night(old)"
350 PRINT " scan no,pixel no , scan no,pixel no"
360 FOR I=1 TO N
370 INPUT "Scan new, Pixel new, Scan old, Pixel old" . Ynew(I), Xnew(I), Yold(I), Xold(I) 
380 Counter(I)=I
390 NEXT I
400 GOTO 530
410 INPUT "Enter number of control point quadruples", N 
420 REDIM Xolo(N), Yold(N), Xnew(N), Ynew(N), Xl(N), Yl(N), Cointer(N) 
430 Printer=16
440 PRINT PAGE 
450 PRINT LIN(10), SPA(5), "To enter control points use the format:"
460 PRINT " Day(new) Night(old)"
470 INPUT "Scan new,Pixel_new, Scan_old, Pixel_old", Ynew(I), Xnew(I), Yold(I), Xold(I) 
480 Counter(I)=I
490 NEXT I
500 PRINT PAGE 
510 NEXT I
520 IF Any$="Y" THEN PRINT IS 16
530 PRINT PAGE 
540 PRINT LIN(10), SPA(15), " DATA CHECK" 
550 PRINT " Control no NEW OLD"
560 PRINT " Line Pixel Line Pixel"
570 FOR I=1 TO N 
580 PRINT USING 550; Counter(I), Ynew(I), Xnew(I), Yold(I), Xold(I)
LINPUT "Are values correct - Y or N ?", Ans$
IF Ans$(1,1)="Y" THEN GOTO Cont
LINPUT "Do you wish to delete values YES or NO ?", Ans$
IF Ans$(1,1)="Y" THEN GOTO 840
LINPUT "How many controls to delete ?", Num
DIM Check(50)
REDim Check(Number)
PRINT "Enter control numbers in any order"
MAT INPUT Check
MAT Sort Check(*) DES
FOR Z = 1 TO Number
    Xold(1) = Xold(Z+1)
    Yold(1) = Yold(Z+1)
    Xnew(1) = Xnew(Z+1)
    Ynew(1) = Ynew(Z+1)
    Counter(1) = Counter(1 + 1)
NEXT 1
NEXT 2
REDIM Xold(N), Yold(N), Xnew(N), Ynew(N)
GOTO 530
LINPUT "Enter control number for incorrect values", K
PRINT LIN(20), SPA(5), "Ynew,Xnew,Yold,Xold=";Ynew(K), Xnew(K), Yold(K), Xold(K)
LINPUT "Enter correct values for all 4 parameters", Ynew(K), Xnew(K), Yold(K), Xold(K)
GOTO 530
Cont: LINPUT "do you wish to list control points on printer?", List$
IF List$(1,1)<>'Y' THEN GOTO 980
PRINTER IS 0
PRINT "Control no NEW OLD"
PRINT Line	Pixel Line Pixel
FOR I = 1 TO N
    PRINT USING 590; Counter(I), Ynew(3), Xnew(3), Yold(3), Xold(3)
NEXT 1
PRINT LIN(5)
CALL Bilinear(Xnew(1), Xnew(N), Xold(1), R(1), N)
CALL Bilinear(Xnew(1), Ynew(1), Yold(1), S(1), N)
    Where: Xold*R(1)+Xnew*R(2)+Ynew*S(3)
    Yold+S(1)+Xnew*S(2)+Ynew*S(3)
    Thus to transform a night image the new DN values are computed:
    DNnew(Pixel,Line)=DNold(P,L)
    where P=R(1)*Pixel+R(2)*Line+R(3)
    and L=S(1)*Pixel+S(2)*Line+S(3)
PRINTER IS 0
Dell2=R(1)*S(2)-S(1)*R(2)
Dell3=R(3)*S(1)-S(3)*R(1)
Dell4=R(2)*S(3)-R(3)*S(2)
Fxl(1)=S(2)-R(2)
Pxl(2)=S(2)*Pmax-R(2)
Pxl(3)=S(2)*Pmax-R(2)*Lmax
Fxl(4)=S(2)-R(2)*Lmax
Lxl(1)=R(1)-S(1)
Lxl(2)=R(1)-S(1)*Pmax
Lxl(3)=R(1)*Lmax-S(1)*Pmax
Lxl(4)=R(1)*Lmax-S(1)
MAT Lxl=Lxl*(Dell3)
MAT Lx1=Lx1/(Del12)
MAT Px1=Px1/(Del23)
MAT Lx1=Lx1/(Del12)
MAT SEARCH Px1(•),MAX;Pxmax
MAT SEARCH Px1(•),MIN;Pxmin
MAT SEARCH Lx1(•),MAX;Lxmax
MAT SEARCH Lx1(•),MIN;Lxmin
Dpix=Pxmax-Pxmin
Dlin=Lxmax-Lxmin
Alpha=R(1)*(Pxmin-1)+R(2)*(Lxmin-1)+R(3)
Beta=S(1)*(Pxmin-1)+S(2)*(Lxmin-1)+S(3)
C2=Alpha*S(2)-Beta*R(2)
C3=Alpha*S(1)-Beta*R(1)
Pix old_mean=SUM(Xold)/N
Lin new_mean=SUM(Ynew)/N
Lin old_mean=SUM(Yold)/N
Del=Del2
Pix off=S(2)/Del*Pix old_mean-R(2)/Del*Lin old_mean-C2/Del*Pix new_mean
C3*Alpha1*S(1)-Beta*R(1)
C2=Alpha*S(2)-Beta*R(2)
Pix new_mean=SUM(Xnew)/N
Lin new_mean=SUM(Ynew)/N
Lin old_mean=SUM(Yold)/N
Cos=teta=(R(1)-S(2))/2
Sin=teta=(S(1)-R(2))/2
Theta=ATN(Sin theta/Cos theta)
Mag_x=SQR(R(1)^2+S(1)^2)
Mag_y=SQR(R(2)^2+S(2)^2)
PRINT "SOLUTION FOR:"
PRINT Name$
PRINT "Original image is " ;Pmax;" pixels by ";Lmax;" lines."
PRINT "Mean rotation angle :" ;Theta
PRINT "Magnification :" ;Mag_x ;" X ";Mag_y
PRINT Offset: Pixels ";Pix off
PRINT Lines ";Lin off
PRINT "New image size: ";Dpix;" pixels by ";Dlin;" lines."
PRINT "Mean rotation angle :" ;Theta
PRINT "Magnification :" ;Mag_x ;" X ";Mag_y
PRINT offset: Pixels ";Pix off
PRINT lines ";Lin off
PRINT "Initial controls:" ,xold(*) ,yold(*) ,xnew(*) ,ynew(*) ,N,Name,Center(*)
Residual=0
PRINTER IS 0
PRINTER IS 0
Max residual=0
PRINT "Control no. 
Yt " ;xt Residual*
1790 C3=Del13
1800 FOR I=1 TO N
1810 X(I)=Xold(I) + Yold(I) * R(I) - C2 / Del
1820 Y(I)=(Xold(I) - Yold(I) * R(I) - C3) / Del
1830 Max_red=(X(I) - Xnew(I))**2 + (Y(I) - Ynew(I))**2
1840 PRINT Counter(I), X(I), Y(I), SQR(Max_red)
1850 Residual=Max_red*Residual
1860 Max_residual=MAX(Max_red,Max_residual)
1870 IF Max_residual=Max_red THEN Max_res=Counter(I)
1880 NEXT I
1890 Max_res=SQR(Max_residual)
1900 Residual=SQR(Residual/(N-1))
1910 FIXED 2
1920 PRINTER IS 0
1930 PRINT
1940 PRINT
1950 PRINT "Mean residual vector length = " Residual " pixels"
1960 PRINT "Max residual vector length = " Max_res " pixels" at point " ;Max_res
1970 PRINT
1980 IF Max = 0
1990 CALL Plot("Transformed controls:");Xt(I),Yt(I),Xnew(I),Ynew(I),N,Names,Counter(I))
2000 GOTO Enter
2010 END
2020 SUB Bilinear(X(*),Y(*),Z(*),M(*),N)
2030 Z=0:1:2=0:(X(1)*X(2)*Y(3)) LEAST SQUARES ESTIMATE FOR M
2040 OPTION BASE 1
2050 DIM S(100,3),Transposes(3,100),Inverse(100,100),Dur(100,100),Z(100,1)
2060 REDIM S(N,3),Transposes(N),Inverse(N,N),Dur(N,N),Z(N,1)
2070 FOR I=1 TO N
2080 S(I,1)=X(I)
2090 S(I,2)=Y(I)
2100 S(I,3)=Z(I)
2110 NEXT I
2120 SUBEND
2130 SUB Plot(Plot_title$& Names,Xnew(*),Ynew(*),Xold(*),Yold(*),N,Names,Counter(*))
2140 OPTION BASE 3
2150 INTEGER I
2160 STANDARD
2170 PLOTTER IS 13,"GRAPHICS"
2180 GRAPHICS
2190 LOCATE 5,150,5,95
2200 MOVE 10,97
2210 LABEL Plot_title$="&Names
2220 MAT SEARCH Xnew(MAX);Xmax
2230 MAT SEARCH Xold(MAX);Xmax1
2240 MAT SEARCH Yold(MAX);Ymax
2250 MAT SEARCH Ynew(MAX);Ymax1
2260 Ymax=MAX(Ymax,Ymax1)
2270 MAT SEARCH Ynew(MIN);Ymin
2280 MAT SEARCH Xold(MIN);Xmin
2290 MAT SEARCH Xnew(MIN)
2390 Ymin=MIN(Ymin,Ymin1)
2400 MAT SEARCH Xold,MIN;Xmin
2410 MAT SEARCH Xnew,MIN;Xmin
2420 Xmin=MIN(Xmin,Xmin1)
2430 SHOW Xmin-25,Xmax+25,Ymax+25,Ymin-25
2440 LINE TYPE 1
2450 FRAME
2460 LORG 2
2470 CSIZE 2.5
2480 FOR I=1 TO N
2490 MOVE Xold(I),Yold(I)
2500 DRAM Xnew(I),Ynew(I)
2510 Xx=Xnew(I)-Xold(I)
2520 Yy=Ynew(I)-Yold(I)
2530 IF Yy=0 THEN GOTO 2550
2540 LDIR Xx,Yy
2550 MOVE Xnew(I),Ynew(I)
2560 IF Xx>0 THEN LABEL "">"&VALS(Counter(I))
2570 IF Xx>0 THEN GOTO 2620
2580 LORG 8
2590 LDIR -Xx,-Yy
2600 LABEL VALS(Counter(I))&"<"
2610 LORG 2
2620 NEXT I
2630 SETGU
2640 LDIR 0
2650 CSIZE 3.3
2660 MOVE 69,3
2670 LORG 5
2680 LABEL "CONT to continue; DUMP GRAPHICS for hard copy"
2690 PAUSE
2700 EXIT GRAPHICS
2710 SUBEND
2720 END
RAPFIT To perform the regional atmospheric fitting.
Program language is extended Basic.
Program written by K. Watson

ENTER: SITE LATITUDE AND SOLAR DECLINATION.
PROGRAM COMPUTES Tday AND Tnite FOR THE HCMA TIMES,
VARIES THE Tsky AND Sky_factor.
INPUT OBSERVATIONAL DATA:
Tdayo,Tniteo,Albedo

COMPUTE THE Standard Deviation for temp data - Shade print output.

OPTION BASE 1
DIM Flux1(24),Temp(24),Phi(24),Flux(24),Strings(10)(80)
DIM Pi(24,24),P5(24,24),Cos1(24),Dev(20,20)
INTEGER I,K,L,Delik

DECL
RECALL THE Phi's.
ASSIGN #1 TO "Phi_m"
READ #1;M
IF M<24 THEN GOTO 230
PRINT "ERROR: M VALUES - SHOULD BE 24"
STOP
READ #1;Phi(*)
ASSIGN #1 TO "Phi_m"
INPUT "Enter the site latitude(Degrees)", Latitude
INPUT "Enter the solar declination(Degrees)", Solar_dec
OUTPUT 9;"R"
K=F1/12
WI=Fl/(12*3600)
Sun=1360
S=5.67E-6
Emissivity=1
Slope=0
Azimuth=0
Flux diffuse=0
INPUT "Enter the mean day Temp (DEG K) from scene data", Tdayo
INPUT "Enter the mean nite Temp (DEG K) from scene data", Tniteo
C1=COS(Latitude)*COS(Solar_dec)
S1=SIN(Latitude)*SIN(Solar_dec)
Cost1=C1+S1
FOR K=2 TO 24
Cost2(K)=C1*(K-1)*15+S1
IF Cost2(K)<0 THEN Cost2(K)=0
NEXT K
C2=SIH(Slope)*SIN(Azimuth)*COS(Solar_dec)
C2=COS(Latitude)*COS(Azimuth)*SIN(Slope)*COS(Azimuth)*SIN(Latitude)
C2=COS2*COS(Solar_dec)
C3=CA1*CA1*COS2*SIN(Slope)*COS2*CA1*SIN(Slope)
INPUT "Enter mean A", Albedo
Inertia=1500
Deviation=10000
Cons2=Inertia/Picons
LOOP PARAMETERS.
PRINT " Tsky", "Sky_factor", " Deviation"
Return: PRINTER IS 16
600 INPUT "Tsky_max,Tsky_max
610 INPUT "Tsky_min,Tsky_min
620 INPUT "Dtsky",Dtsky
630 INPUT "Sky_factor_max",Sky_factor_max
640 INPUT "Sky_factor_min",Sky_factor_min
650 INPUT "Dsky_factor",Dsky_factor
660 Dev_min=15
670 KEYPAD FOR Tsky*Tsky_min TO Tsky_max STEP Dtsky
680 PRINT "Tsky";Tsky
690 Flux_sky=Sigma*Tsky^4
700 FOR Sky_factor=Sky_factor_min TO Sky_factor_max STEP Dsky_factor
710 OUTPUT 5:"R";
720 EING Month,Day,Hour,Minute,Second
730 PRINT TAB(20);"Sky_factor";Sky_factor;Hour;Minute
740 Flux_direct=So^1(1-Sky_factor)
750 FOR T=1 TO 24
760 X=(1-I)*15
770 Cos2=Cos2(I)
780 IF Cos2=0 THEN Cos2=0
790 Flux(I)=(1-Alesai)*Flux_diffuse+Cos2*Flux_direct+Emissivity*Flux_sky
800 NEXT I
810 Sun=0
820 FOR I=1 TO 24
830 Sun=Sun+Sun/M
840 NEXT I
850 V0=(Sun/(Emissivity*S_SI^2))^.25
860 Alpha=3*Emissivity^5*S_SI^4*V0^3
870 CCons=Cons Alpha
880 Cons=Alpha^4/3
890 FOR I=1 TO 24
900 Flux(I)=(I-1)+Alpha*V0
910 NEXT I
920 Sun=0
930 FOR I=1 TO 24
940 FOR K=1 TO 24
950 L=K+1
960 IF L=1 THEN L=L+24
970 DelK=0
980 IF I=K THEN DelK=1
990 P5(I,K)=Cons2*P5(I,L)+Cons1*DelK
1000 NEXT K
1010 NEXT I
1020 MAT P5=INV(P5)
1030 FOR K, Temp
1040 MAT Temp(K)=at time K=1 hours, measured from noon
1050 Tsky=(Temp(K)*Temp(3))*.5
1060 Tnito=(Temp(14)+Temp(15))*.5
1070 J1=(Sky_factor-Sky_factor_min)/Dsky_factor+1
1080 Dev(I,J1)=SQR((Tsky-Tnito)^2+(Tnito-Tnito)^2)
1090 Dev_min=MIN(Dev_min,Dev(I,J1))
1100 IF Dev(I,J1)=Dev_min THEN Tsky_opt=Tsky
1110 IF Dev(I,J1)=Dev_min THEN Sky_factor_opt=Sky_factor
1120 PRINTER IS 0
1130 PRINT Tsky,Sky_factor
1140 IF Dev(I,J1)=Dev_min THEN Tsky=Sky_factor
1150 PRINTER IS 16
1160 NEXT Sky_factor
1170 NEXT Tsky
1180 BEEP
1210 END
1220 INPUT "Enter THE I(Tsky) AND J(Sky_factor) VALUES", I,J
1230 Ts=Ts+10*(I-1)*10
1240 Sky_factor=+(J-1)*.05
1250 I=1
1260 LOOP PARAMETERS.
1270 FOR Tk=Ts-2 TO Tk+2 STEP 1
1280 PRINT "Tsky=";Tk,
1290 Flux_sky=Sign(Tsky)*4
1290 FOR Sky_factor=Sky_factor-.02 TO Sky_factor+.02 STEP .01
1300 OUTPUT A,"F
1310 Enter 9:Montn,Day,Hour,Minute,Second
1320 PRINT TAB(20);"Sky_factor=";Sky_factor,Hour,"=";Minute
1330 Flux_direct=SQRT*(I-Sky_factor)
1340 IF I=1 TO 24
1350 X(I)=15
1360 CG21=Cosz(I)
1370 IF CG21<0 THEN CG21=0
1380 Flux(I)=(1-Albedo)*FluxDiffuse*Cosz1*FluxDirect+Emissivity*Flux_sky
1390 NEXT I
1400 SUM=0
1410 FOR I=1 TO 24
1420 S=S+Flux(I)+SUM
1430 NEXT I
1440 SUM=S
1450 CG21=Cosz(I)
1460 IF CG21<0 THEN CG21=0
1470 Flux(I)=Flux(I)+Albedo*Vo
1480 NEXT I
1490 FOR I=1 TO 24
1500 Flux(I)=Flux(I)+Albedo*Vo
1510 NEXT I
1520 FOR I=1 TO 24
1530 FOR K=1 TO 24
1540 L=I+K
1550 IF L>24 THEN L=L-24
1560 Delik=0
1570 IF I<K THEN Delik=1
1580 Ps(I,K)=Cons2*Phi(L)+Cons1*Delik
1590 NEXT K
1600 NEXT I
1610 MAT PI=INV(P5)
1620 I FORW Temp
1630 MAT Temp=PI*Flux
1640 I RLMBDR Temp(K) is at time K-1 hours. (measured from noon)
1650 Ts=Temp(2)+Temp(3)*.5
1660 Tk=Temp(14)+Temp(15)*.5
1670 Ts=Ts-250/.51
1680 J=Sky_factor+.05
1690 Dev(I,J)=SUM((J-Sky_Tsk)*2+(Tk-Tk_1)*2)
1700 PRINT Tk,J,Sky_factor,Dev(I,J)
1710 NEXT Sky_factor
1720 NEXT Tk
1730 MIN=DEF15
1740 FOR I=1 TO 3
1750 FOR J=1 TO 6
1760 MIN=min(MIN,Dev(I,J))
1770 IF Dev(I,J)=MIN THEN I=1
1780 NEXT J
1790 NEXT I
1800 END
179u NEXT 1
1800 Tsky = Tsky + (10-1)*
1810 Sky_factor = Sky_factor + (Jo-3)*.01
1820 STOP
1830 END
PROGRAM GEOMX4

C ************
C REMOTE SENSING ARRAY PROCESSING PROCEDURES
C U. S. GEOLOGICAL SURVEY, DENVER, COLORADO
C BRANCH OF PHYSICS AND REMOTE SENSING
C DON L. SAWATIKY
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, NPXOUT, AND NUMBER OF RECORDS, LMAX. INPUT PARAMETERS, IPXIN AND NPX
C XIN, ALLOW TAKING A SUBSET OF THE INPUT FILE. OUTPUT PARAMETERS LMAX, MNPIX
C, AND MXPIX 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 MNPIX PIXELS. MNPIX TO MXPIX 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 ************
C DECLARATIONS
REAL R(3), S(3)
LOGICAL INBUF(200000), OUTBUF(3000)
INTEGER FCBIN(35), FCBOUT(35)
C
C SET PARAMETERS
WRITE(6,99)
99 FORMAT(1X9'ENTER PIXEL/LINE COEFFICIENTS':)
READ(5,96) R, S
WRITE(6,98)
98 FORMAT(1X,'ENTER INPUT FIRST PIXEL, NO. PIXELS')
READ(5,96) IPXIN, NPXIN
WRITE(6,97)
97 FORMAT(1X,'ENTER MAX. OUTPUT LINES, MIN/MAX PIXEL':)
READ(5,96) LMAX, MNPIX, MXPIX
96 FORMAT(G16.0)
C
C OPEN DATA FILE TO TRANSFORM
READ(S) LENREC, NORECS
C SETUP WORK ARRAY
NRECS=MIN(200000/LENREC, NORECS)
NLINE=NRECS
J1=LENREC MOD(1, NRECS) +1
J2=J1+LENREC-1
DO 90 I=1, NRECS
90 READ(S) (INBUF(J), J=J1, J2)
C
C OPEN OUTPUT DATA FILE
NPXOUT=MXPIX-MNPIX+1
IF(NPXOUT.LE.3000. AND. NPXIN.LE.3000) GO TO 110
STOP 'DATA FILES EXCEED BUFFER WIDTH.'
100 WRITE(9) NPXOUT, LMAX
110 WRITE(9) NPXOUT, LMAX
C
C READ/WRITE LOOP
DO 210 LINE=1, LMAX
DO 200 IPX=MNPIX, MXPIX

ORIGINAL PAGE IS OF POOR QUALITY
INPX*R(1)*(IPX) + R(2)*(LINE) + R(3)
IF(INPX.LT.1.OR.INPX.GT.NPIXIN) THEN
  OUTPUT(IPX-MNP1X+1)=.FALSE.
ELSE
  INLINC=S(1)*(IPX) + S(2)*(LINE) + S(3)
  IF(INLINE.LT.1.OR.INLINE.GT.NRECS) THEN
    OUTPUT(IPX-MNP1X+1)=.FALSE.
ELSE
  C.....CHECK LIST FOR SCANLINE IN WORK ARRAY
  IF(INLINE.LE.MNLINE.AND.INLINE.LE.MXLINE) GOTO120
  ELSE READ SCANLINE INTO LIST AND WORK ARRAY
  IF(INLINE.LT.MNLINE) STOP 'INBUF ARRAY TOO SMALL!!'
  DO 115 I=INLINE+1,INLINE
       IREC=MOD(I,NRECS)*LENREC
  115 READ(3,REC=INLINE) (INBUF(J), J=IREC+1,IREC+NPIXIN)
       XLINE=INLINE
       MNLINE=INLINE-NRECS+1
  120 OUTPUT(IPX-MNP1X+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
PROGRAM HCMTID
C THIS PROGRAM COMPUTES A RELATIVE THERMAL INERTIA AND TEMP DIFF
C IMAGE FILES FROM HCMT DATA.
C
DIMENSION I(J), 12(J), 15(J), 14(J), 16(J), 18(J), 12(J), 16(J), 18(J)
6, 18(J)
DIMENSION TEMP(J), ALB(J), 15(J)
DIMENSION ID(J), DUM(J), IDT(J)
DATA 11/0.1, 1.1.20*0.1, 1.1.20*0.1, 1.1.20*0./
DATA 14/16.0.1, 1.1.20*0./, 15/5.0.0.0.0.0./, 16/5.0.0.0.1.1.3.0*0./
INTEGER 2, 17(2000)
C
OPEN NOON THERMAL FILE
C
WRITE(6, FMT=(''' OPEN NOON THERMAL FILE'''))
CALL DISKIO (0, 12, 16, 18)
C
OPEN NIGHT THERMAL FILE
C
WRITE(6, FMT=(''' OPEN NIGHT THERMAL FILE'''))
CALL DISKIO (0, 13, 17, 18)
C
OPEN NOON ALBEDO FILE
C
WRITE(6, FMT=(''' OPEN NOON ALBEDO FILE'''))
CALL DISKIO (0, 14, 15, 16)
C
OPEN THERMAL INERTIA OUTPUT FILE
C
WRITE(6, FMT=(''' OPEN THERMAL INERTIA OUTPUT FILE'''))
W=0(J)
X=1(J)
Y=1(J)
W1=1(J)
X1=1(J)
Y1=1(J)
MAXP=AMAX(W1, X1, Y1)
MAXL=AMAX(W1, X1, Y1)
14(J)=MAXP
15(J)=MAXL
CALL DISKIO (0, 15, 16)
C
OPEN TEMP DIFF OUTPUT FILE
C
WRITE(6, FMT=(''' OPEN TEMP DIFF OUTPUT FILE'''))
15(J)=MAXP
16(J)=MAXL
CALL DISKIO (0, 16, 17)
C
OPEN DUMMY FILE
C
WRITE(6, FMT=(''' OPEN DUMMY FILE'''))
16(J)=MAXP
16(J)=MAXL
CALL DISKIO (0, 17, 18)
C
INPUT AVERAGE PARMS
C
WRITE (6, FMT=(''' ENTER AVERAGE VALUES A, ATD, ATN'''))
ACCEPT *, AA, ATD, ATN
TYPE *, AA, ATD, ATN
WRITE (6, FMT=(''' ENTER LATITUDE AND SOLAR DEC IN DEG'''))
ACCEPT .XLM,DELTA
TYPE .XLM,DELTA
XLM=FLAM*0.017453
DELT=DELTA*0.017453
DE**1./(COS'+XAM-DELTA))
COS**1.2=1.05/(1-2.*(ATN))
C=0.09181*18*(COS(XLM)+0.4*(DELTA)*SIN(XLM))
W=(ATD-ATN)1500-C*AVE
TYPE .000
TYPE .C
TYPE .B
WRITE (6,FMT=(''' P REL = (B*(ALB)/100)'))

C COMPUTE TEMP AND ALB CALIBRATION FILES.

DO 2 I=1,256
2     ALB(K)=K-1.0,000*2157
     CI=2421.557
     C2=1251.184
     CO=-118.21376
     DO 11 LI=1,256
11     TEMP(LI)=C2/(ALOG(C1/(LI-1-C2)+1))

C MAIN READ/WRITE LOOP

DO 3 I=1,MAX
3     CALL DISK10 (K,12,1B1,11)
     CALL UNFAC11B1,1,12)
     CALL DISK10 (K,13,1B2,12)
     CALL UNFAC11B2,1121)
     CALL DISK10 (K,14,1B3,13)
     CALL UNFAC11B3,1221)

C DO 4 I=1,MAX
4      NUM1=IB1(K)+1
      NUM2=IB2(K)+1
      NUM3=IB3(K)+1
      TD=TEMP(NUM1)
      TN=TEMP(NUM2)
      AA=ALB(NUM3)
      IDUM(K)=255
      S=TD-TN
      X=(AA-AVE)*100
      Y=ATD-TD
      IF (X.GE.2,AND.Y.GE.15) GO TO 21
      IF (TN.LE.205) GO TO 21
      Z=S
      IF (S.LE.0,AND.T.LTE.10) GO TO 22
      IF (S.LE.0) GO TO 21
      IT(K)=(E+C*AA)/S
      IDT(K)=S
      IF (IT(K).EQ.3500) IT(K)=3560
      IF (IT(K).EQ.1000) IT(K)=990
      GO TO 4
21     IT(K)=1000
      IDT(K)=255
      IDUM(K)=0
      GO TO 4
22     IT(K)=3550
      IDT(K)=0
      IDUM(K)=255
      CONTINUE
     CALL DISK10 (10,15,1T,14)
CALL PACK (IDT, 15(2))
CALL DISKIO (10, 14, IDT, 15)
CALL PACK (IDUM, 16(2))
CALL DISKIO (10, 17, IDUM, 16)
CONTINUE

CLOSE FILES

CALL DISKIO (6, 12, 0, 11)
CALL DISKIO (6, 13, 0, 12)
CALL DISKIO (6, 14, 0, 13)
CALL DISKIO (6, 15, 0, 14)
CALL DISKIO (6, 16, 0, 15)
CALL DISKIO (6, 17, 0, 16)
STOP
END
10 1 FILET  Profiling routines, 3/2/81
20 1 Program language is extended Basic.
30 1 Program written by K. Watson
40 1 Option base 1
50 DIM Tuay(1500),Thite(1500),Elev(1500),X(1500),Y(1500),Der(1500),Iert(1500)
60 ,Dt(1500),Topo(1500),Mean(1500)
80 DIM (4000)
90 PRINTER IS 16
100 Lev_corr=0 1 Initialize elevation correction indicator
110 Emptie=0 1 Initialize for profile plotting
120 INPUT "Enter profile i.e., A,B",Profile$[1,1]
130 Profile=Profile$+Profile$%4"%
140 INPUT "Enter area name i.e.,PR",Area$
150 File_#%Area$%Profile$[1,1]
160 Function_keys: 1
170 ON KEY 0 GOTO topo_gen
180 ON KEY 1 GOTO Image_gen
190 ON KEY 2 GOTO Prof_plot
200 ON KEY 3 GOTO Feature
210 ON KEY 4 GOTO File_edit
220 ON KEY 5 GOTO Cross_cor
230 ON KEY 6 GOTO Cross_plot_file
240 ON KEY 7 GOTO Cross_plot_match
250 ON KEY 8 GOTO topo_resample
260 ON KEY 9 GOTO Elev_correct
270 ON KEY 10 GOTO Report_plot
280 IF Elev_corr=1 THEN Profile$=Profile$% elev corr%
290 MASS STORAGE IS "C"
300 EXIT GRAPHICS
310 PRINT PAGE
320 PRINT 0 Goto topo_gen
330 PRINT "KEY 0 Generate topo binary file from PERKIN output"
340 PRINT "KEY 1 Generate image binary file"
350 PRINT "KEY 2 Plot a profile"
360 PRINT "KEY 3 Select a feature for matching profiles"
370 PRINT "KEY 4 File edit"
380 PRINT "KEY 5 Cross correlate two images"
390 PRINT "KEY 6 Cross plot two data files (report)"
400 PRINT "KEY 7 Cross plot multiple data files"
410 PRINT "KEY 8 Resample the topo data to match images"
420 PRINT "KEY 9 Determine elevation correction to temp data"
430 PRINT "KEY 10 Profile plotting (report)"
440 PRINT "MASS STORAGE SET "%C"
450 DISP "Select option"
460 GOTO 430
470 1
480 1
490 1
500 1
510 1
520 1
530 1
540 1
550 1
560 1
570 ON END 1 GOTO 640
580 ASSIGN 1 TO File$
READ $1:K
REDIM R(K)
READ $1:Curve$
READ $1:Lower,Xupper
READ $1:R(*)
ASSIGN #1 TO *
FOR L=1 TO K
$(L+1+2)*R(L)*12*.0254 | Convert from ft to m.
NEXT L
I=I+K
NEXT N
REWIND ":T15"
REDIM Z(I+2)
Z(1)=1
2(2)=.15875 | 1 km. Assumes 1/40 " spacing on 1:250,000 map
FILEOUT$="TopoProfile$[1,2]
FCREATE Fileout$,52
FPRINT Fileout$,2(*)
DISP "Finished"%IT 500
SERIAL
GOTO Function_keys
1
***************
810 I
820 Image_gen: 1 To generate image binary files.
830 OVERLAP
840 PRINT PAGE
850 INPUT 'Enter file type ie Tday,Tnite,Ref1',Filex$)
860 IF Filex$="Tday" THEN FS="TD"x$;
870 IF Filex$="Tnite" THEN FS="TN"x$;
880 IF Filex$="Ref1" THEN FS="RD"x$;
890 INPUT "Enter starting pixel and line",Ps,Ls
900 INPUT "Enter ending pixel and line",Pn,Ln
910 Cu=(Ls-Ln)/(Ps-Pn)
920 PROFILE ELEMENT COUNTER
930 FOR I=1 TO No блокs
940 CAT TO A4(•);F$&VAL5(I)
950 IF LEN(AS(I))<>0 THEN GOTO 1090
960 FOR K=1 TO Pixels
970 IF LEN(AS(I))<>0 THEN GOTO 1090
980 REWIND ":T15"
990 PRINT "F$&VAL$(I) not on tape. Insert correct tape and CONT"
1000 PAUSE
1010 GOTO 1030
1020 FOR I=1 TO No блокs
1030 CAT TO A$(";");F$&VAL$(I)
1040 IF LEN(A$(I))<>0 THEN GOTO 1090
1050 REWIND ":T15"
1060 PRINT "F$&VAL$(I) not on tape. Insert correct tape and CONT"
1070 PAUSE
1080 GOTO 1030
1090 ASSIGN #1 TO F$&VAL$(I)
1100 READ #1:S$
1110 N=POS(S$,"Lines")
1120 Lines=VAL(S$[N+5,N+7])
1130 M=POS(S$,"Pixels")
1140 Pixels=VAL(S$[M+6,M+8])
1150 PRINT "Lines,Pixels=";Lines,Pixels
1160 REDIM Dn(Pixels*Lines)
1170 READ #1:Dn(*)
1180 FOR K=1 TO Pixels
1190  \text{Yy} = C1 \times (K-1) + 1
1200  L1 = \text{INT}(Yy)
1210  \text{IF } Yy \geq L1 \times 0.5 \text{ THEN } L1 + L1 + 1
1220  (J) = Bn \times (L1 - 1) + \text{Pixels} + K
1230  \text{PRINT } J, I(J) \quad \text{I Use for editing.}
1240  J = J + 1 \quad \text{I Increment profile counter}
1250  \text{NEXT K}
1260  \text{ASSIGN } J \text{ TO } *
1270  \text{NEXT } I
1280  \text{REIND } ";:15"
1290  J = J - 1 \quad \text{I Reset pixel counter}
1300  \text{REDIM } Z(J)
1310  \text{KI} = 14421.587 \quad \text{I Temp calib Dn to Temp}
1320  \text{K2} = 1251.1591
1330  \text{K3} = -118.21376
1340  \text{Dist} = \sqrt{(Pn-Ps)^2 + (Ln-Ls)^2} \times 0.47717 / J \quad \text{I km approx units}
1350  \text{REDIM } Z(J), X(J)
1360  \text{IF } (\text{Filex} = "\text{Tday}"
1370  \text{THEN GOTO Temp_cal}
1380  \text{IF Filex = "Refl" THEN GOTO Refl_cal}
1390  \text{Temp_cal: FOR } I = 1 \text{ TO } J
1400  \text{Z(I)} = K2 / \text{LOG}(1/(Z(1) - K3) + 1)
1410  \text{NEXT } I
1420  \text{GOTO Sin Store}
1430  \text{Refl_cal: FOR } I = 1 \text{ TO } J
1440  \text{Z(I)} = Z(I) / 255 \times 100 \quad \text{I refl}
1450  \text{NEXT } I
1460  \text{GOSUB } Bin\_store
1470  \text{GOTO } Function\_keys
1480  \text{Bin\_store: I}
1490  \text{DISP } "\text{Binary store}"
1500  \text{Dum(1)} = J \quad \text{I No Values}
1510  \text{Dum(2)} = \text{Dist} \quad \text{I DE increment in km.}
1520  \text{FOR } I = 3 \text{ TO } J+2
1530  \text{Dum(I)} = Z(I-2) \quad \text{I Normal statement.}
1540  \text{NEXT } I
1550  \text{REDIM } Dum(J+2)
1560  \text{Filex} = \text{File}\_x[1, 41 \& \text{Profile}\_x[1, 2]
1570  \text{FCREATE } Filex, 52
1580  \text{FPRINT } Filex, Dum(*)
1590  \text{PRINT PAGE}
1600  \text{DISP } "\text{Finished}"
1610  \text{SERIAL}
1620  \text{RETURN}
1630  \text{1}
1640  \text{1}
1650  \text{Prof\_plot: 1 On CRT or at 1:1,000,000 on 9872S.}
1660  \text{1670 INPUT } "\text{Select plotter option: 0 CRT, 1 9872S, Plotter}"
1680  \text{PRINT PAGE}
1690  \text{GOSUB } File\_read
1700  \text{GOSUB } File\_plot
1710  \text{IF Plotter = 0 THEN EXIT GRAPHICS}
1720  \text{IF } V = 1 \text{ THEN GOTO 1690}
1730  \text{GOTO Function\_keys}
1740  \text{File\_read: INPUT } "\text{Enter file type ie Tday,Tnite,Refl,Elev,Derv,Dt,Inert,Mean}, \text{Files}\_x[1, 141 \& \text{Profiles}\_x[1, 2]
1750  \text{REDIM } X[1500], Y[1500], Z[1500]
1760  \text{Filex} = \text{File}\_x[1, 41 \& \text{Profiles}\_x[1, 2]
1770  \text{IF } (\text{Filex} = "\text{Tday}
1780  \text{IF } (\text{Filex} = "\text{Refl}
1790  \text{GOTO 2080}
1790  \text{GOTO 2080}
1790 IF Files$="Deriv" THEN GOTO 2080
1800 IF Files$="Mean" THEN GOTO 1620
1810 IF (Files$="Dist") OR (Files$="Inert") THEN GOTO Dl_form
1820 Dl form: READ "Today"&Profiles$[1,2],x(*)
1830 J=Ax(1)
1840 Dist=x(2)
1850 READ "Titl"&Profiles$[1,2],y(*)
1860 REDIM x(J+2),y(J+2),z(J+2)
1870 IF (Files$="Dist") OR (Files$="Inert") THEN MAT Z=X-Y
1880 IF Files$="Mean" THEN MAT Z=X+Y
1890 IF Files$="Mean" THEN MAT Z=Z^2(,5)
1900 IF (Files$="Dist") OR (Files$="Mean") THEN GOTO 2110
1910 Inert form: READ "Refl"&Profiles$[1,2],x(*)
1920 IF A$="PHD" THEN GOTO 1950
1930 PRINT "Need to reset alpha,beta coeff at Inert_form"
1940 FALSE
1950 Alpha=52265.6 Power River Basin Parameters.
1960 Beta=6744
1970 MAT X=X(,01) 1 Convert to fractions
1980 FOR L=2 TO J+2
1990 IF z(L)>0 THEN GOTO 2020
2000 Z(L)=2550
2010 GOTO 2060
2020 Z(L)=(Alpha+Beta*X(L))/Z(L)
2030 IF Z(L)<500 THEN Z(L)=450
2040 IF Z(L)>3000 THEN Z(L)=3000
2050 Dist=Z Dist 1 Dx increment i, km.
2060 NEXT L
2070 GOTO 2110
2080 FREAD filenames,2(*)
2090 J=J(1)
2100 FOR L=1 TO J
2110 FOR I=1 TO J
2120 Z(I)=Z(1+2)
2130 X(I)=(1-1)*Dist
2140 NEXT I
2150 REDIM X(J),Z(J)
2160 RETURN
2170
2180
2190
2200 File plot: SERIAL 1 IF V=1 THEN REPEAT
2210 IF Enable=1 THEN GOTO File_cont
2220 IF Plotter=0 THEN PLOTTER IS 13,"GRAPHICS"
2230 IF Plotter=0 THEN GRAPHICS
2240 IF Plotter=0 THEN GOTO File_cont
2250 IF V=0 THEN PLOTTER IS 7,5,"9872A" 1 First time
2260 File_cont: BEEP
2270 Dz=5
2280 IF (Files$[1,1]="E") OR (Files$[1,2]="To") THEN Dz=100
2290 IF Files$[1,2]="De" THEN :-10
2300 IF Files$[1,2]="In" THEN Dz=500
2310 Y$=Files$[1,1]
2320 IF (Y$[1,1]="T") OR (Y$[1,1]="D") THEN Y$=Y$&"(K)"
2330 IF Y$[1,1]="M" THEN Y$="Mean temp(K)"
2340 IF Y$[1,1]="E" THEN Y$=Y$&"(m)"
2350 IF Y$[1,1]="R" THEN Y$=Y$&"(%)"
2360 IF Y$[1,2]="De" THEN Y$="Gradient(m/km)"
2370 IF Y$[1,2]="Di" THEN Y$="Temp diff(K)"
2380 IF Y$[1,1]="I" THEN Y$="Inertia(TIU)"

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2390 X$="Distance(km)"
2400 MAT SEARCH Z(·),MAX;Zmax
2410 MAT SEARCH Z(·),MIN;Zmin
2420 Zmin=INT(Zmin/Dt)*Dt
2430 Zmax=(INT(Zmax/Dt)+1)*Dt
2440 Dzs=(Zmax-Zmin)*.125/8.5
2450 Dzs=X(J)*.125/8.5
2460 FOR I=1 TO J
2470 X(I)=(I-1)*Dist
2480 NEXT I
2490 IF Plotter=0 THEN GOTO 2670
2500 DEG
2510 LIMIT 0,400,0,285
2520 LORG 5
2530 CSIZE 2.75
2540 X1=(1.5*25.4-12.5)*100/285
2550 X2=X1+X(J)*100/285 ! Proper scale
2560 Y1=(1.5*25.4+14)*100/285
2570 Y2=Y1+500/285
2580 MOVE (X1+X2)/2.5,Y1-.5*25.4*100/285
2590 LABEL X$
2600 LDIR 90
2610 MOVE X1-.9*25.4*100/285,(Y1+Y2)/2.5
2620 LABEL Y$
2630 LDIR 0
2640 LOCATE X1,X2,Y1,Y2
2650 FRAME
2660 LORG 5
2670 SCALE 0,X(J),Zmin,Zmax
2680 OUTPUT 705;"VS2;"
2690 MOVE 0,Zmax
2700 DRAW X(J),Zmax
2710 DRAW X(J),Zmin
2720 AXES 10,Dz,0,Zmin,10,2
2730 FOR I=1 TO J
2740 IF I=1 THEN MOVE X(I),Z(I)
2750 DRAW X(I),Z(I)
2760 NEXT I
2770 OUTPUT 705;"VN;"
2780 CSIZE 2
2790 LORG 8
2800 FOR Ys-Zmin TO Zmax STEP Dzs
2810 MOVE -Dxs,Ys
2820 LABEL VALS(Ys)
2830 NEXT Ys
2840 LORG 6
2850 FOR w=0 TO X(J) STEP 20
2860 MOVE w,Zmin-Dzs
2870 LABEL VALS(W)
2880 NEXT W
2890 LORG 5
2900 MOVE X(J)*.5,2max-Dzs*2
2910 LABEL "Profile "&Profile$[1,2]""&" &Area$&" Area"
2920 IF Plotter=0 THEN LABEL "CONT to continue"
2930 IF Plotter=0 THEN PAUSE
2940 PEN 0
2950 IF Plotter=0 THEN EXIT GRAPHICS
2960 IF Plotter=0 THEN GOTO 2990
2970 IF X(J)>25.4 THEN OUTPUT 705;"AF;"
2980 IF X(J)<25.4 THEN OUTPUT 705;"AH;"
2994 \textbf{INPUT} "Enter 0 to \text{END} and 1 to plot another profile", V
3000 \textbf{IF} V=0 \textbf{THEN} \textbf{RETURN}
3010 \textbf{IF} Plotter=0 \textbf{THEN} \textbf{GOTo} 10 End
3020 \textbf{IF} X(J)*25.4>7 \textbf{THEN} OUTPUT 705;"AF;"
3030 \textbf{IF} X(J)*25.4<7 \textbf{THEN} OUTPUT 705;"AH;"
3040 \textbf{END} : \textbf{GOTo} \text{FUNCTION}
3050 1
3060 1
3070 1
3080 \textbf{Feature: GOSUB file \text{read}}
3090 \textbf{Feature: \text{INPUT} "Enter feature and approx pixel value",K$; Jp}
3100 \text{J1=J1+12}
3110 \textbf{IF} J1<1 \textbf{THEN} J1=1
3120 J2=J1+12
3130 \textbf{IF} J2>J THEN J2=J
3140 \textbf{Sp}=1
3150 \textbf{INPUT} "Use \text{COMT} to list and 1 to plot",Sp
3160 \textbf{IF} Sp=0 \textbf{THEN} \text{GOTo} \text{LIST}
3170 \textbf{READ}: \text{X2(J2-J1+1)},DuM(J2-J1+1)
3180 L=0
3190 \textbf{FOR} K=1 \textbf{TO} J2
3200 L=L+1
3210 X2(L)=K
3220 DuM(L)\text{=}L\text{/(K)}
3230 \textbf{NEXT} K
3240 Lmax=L
3250 \textbf{MAT} \text{SEARCH} DuM(*),MAX;Rmax
3260 \textbf{MAT} \text{SEARCH} DuM(*),MIN;Rmin
3270 Dr=Rmax-Rmin
3280 \textbf{Feature: plot: PLOTTER IS !;"GRAPHICS"
3290 GRAPH
3300 LOCATE J1,100,20,90
3310 SCALE J1,J2,Rmin,Rmax
3320 GRID L,(Rmax-Rmin)*.1,J1,Rmin
3330 \textbf{FOR} L=1 \textbf{TO} Lmax
3340 \textbf{IF} L=1 \textbf{THEN} \text{MOVE} X2(L),DuM(L)
3350 \textbf{DRAW} X2(L),DuM(L)
3360 \textbf{NEXT} L
3370 LONG 6
3380 \textbf{FOR} L=1 \textbf{TO} Lmax \text{STEP} 2
3390 \textbf{MOVE} X2(L),Rmin-(Rmax-Rmin)*.05
3400 \textbf{LABEL} VALS(X2(L))
3410 \textbf{NEXT} L
3420 LONG 4
3430 \textbf{MOVE} (J1+J2)*.5,Rmin-.04*Dr
3440 \textbf{LABEL} Files
3450 \textbf{MOVE} Jp,Rmax+Dr*.02
3460 \textbf{LABEL} K$
3470 LONG 1
3480 \textbf{MOVE} X2(L),Rmax+Dr*.02
3490 \textbf{LABEL} "CONT to continue"
3500 \textbf{PAUSE}
3510 PEN 0
3520 \textbf{EXIT} GRAPHICS
3530 \textbf{GOTO} 3630
3540 \textbf{LIST}: \text{PRINT} SPA(10),"Feature ";K$
3550 \text{Min=}1E99
3560 \textbf{FOR} I=J1 \textbf{TO} J2
3570 Min=\text{MIN}(Z(I),Min)
3580 \textbf{NEXT} I

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3590 FOR I=J1 TO J2
3600 IF A(I)<MIN THEN PRINT I,2(I)
3610 IF Z(I)<MIN THEN PRINT I,2(I),"....."
3620 X=AT 1
3630 INPUT "Enter 0 to examine other features; 1 to terminate", T
3640 IF T=0 THEN GOTO Feature
3650 IF T=1 THEN GOTO Function_keys
3660 IF T=1 THEN GOTO Feature_keys
3670 I
3680 ***********
3690 Cross cor: I PROFIL3 To cross correlate profiling data for images.
3700 I Method: Shift means to 0 and variances to 1
3710 I Form cross correl sum for varying delays.
3720 I Take data in 100 pixel sets( see kmx)
3730 PRINT PAGE
3740 INPUT "Enter function1 ie TJay,Tnute,Refl ....",X$ 
3750 INPUT "Enter function2 ie TJay,Tnute,Refl ....",Y$
3760 DISP "Cross correlative." 
3770 IF A(I1)<1 AND X(I1)=1 THEN GOTO 3830 
3780 IF A(I2)<1 AND X(I2)=1 THEN GOTO 3830 
3790 PRINT "Files are not same type - reccheck"
3800 INPUT "Do you wish to continue anyway?",Ans$ 
3810 IF Ans$="N" THEN STOP 
3820 J+X(I1)
3830 PRINT=T+X(I2)
3840 I
3860 IF E=AT 1 THEN 100 
3870 J+UU 
3880 PRINT E IS 0 
3890 PRINT E
3940 PRINT "List of correlation for ";X$" and ";Y$; Profile";Profile$ 
3950 PRINT E
3960 FOR E=1 TO kmx 
3970 IL=(E-1)*UU+1 
3980 IS=11+J-1 
3990 PRINT "From pixel ";IL" to ";IS+1 
4000 FOR I=11 TO IS 
4010 X(1+I)=A(I+2) 
4020 Y(1+I)=R(I+2) 
4030 NEXT I 
4040 IF E=AT 1 THEN 100 
4050 REGIM X(J),Y(J),Dur(J),Z(J) 
4060 MeanX=SUN(X)/J 1 Transform to Mean=0 Dev=1 
4070 MeanY=SUN(Y)/J 
4080 MAT X=MEANX+X 
4090 MAT Y=MEANY+Y 
4100 MAT DUR=X,X 
4110 MAT Var=SUN(DUR)/J 
4120 MAT X=(1/SQR(Var))*X 
4130 MAT Y=(1/SQR(Var))*Y 
4140 PRINT E Delay ";X$".;Y$ 
4150 FOR Delay=10 TO 5 
4160 SUM=0 
4170 FOR E=1 TO 5 
4180 SUM+=A(I)*Y(I)+SUM 
4190 NEXT Delay 
4200 PRINT E Delay;SUM

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NLXT Delay
NLXT 0
PRINTER IS 16
GO TO function_keys

Cros_plot_angle: 1
PLOT_count=1

DEF = "Cross plotting - single."
INPUT "Select plotter option: 0 CRT, 1 9872A",Plotter
IF Plotter=0 THEN PLOTTER IS 13,"GRAPHICS"
IF Plotter=1 THEN PLOTTER IS 7.5,"9872A"

Cross_cont: INPUT "Enter filename for Xaxis t Tday,Tnite...",X$".
INPUT "Enter filename for Yaxis t Tday,Tnite...",Y$.

IF Fx$="X$[1,2]"
  IF Fy$="Y$[1,2]" THEN FREAD "Tday"&Profiles[1,2],X(*)
  IF Fx$="X$[1,2]" THEN FREAD "Tnit"&Profiles[1,2],Y(*)
  IF Fy$="Y$[1,2]" THEN FREAD "Rei"&Profiles[1,2],X(*)
  IF Fx$="X$[1,2]" THEN FREAD "Elev"&Profiles[1,2],Y(*)
  IF Fy$="Y$[1,2]" THEN FREAD "Dev"&Profiles[1,2],X(*)
  IF Fx$="X$[1,2]" THEN FREAD "Dev"&Profiles[1,2],Y(*)
  IF (Fx$="In") OR (Fy$="In") THEN GOTO Inert_read
  IF (Fx$="D") OR (Fy$="D") THEN GOTO Dt_read
  IF (Fx$="He") OR (Fy$="He") THEN GOTO De_read
  IF (Fx$="Me") OR (Fy$="Me") THEN GOTO Me_read
  IF (Fx$="dt") OR (Fy$="Me") THEN GOTO Me_read
  IF (Fx$="Me") OR (Fy$="dt") THEN GOTO Me_read

  IF X2<1000 THEN X2=1000
  IF X2>3000 THEN X2=3000
  IF Fx$="In" THEN MAT X=X2
  IF Fy$="In" THEN MAT Y=X2
  GOTO 446u

  IF (Fx$="D") OR (Fy$="D") THEN GOTO Dt_read
  IF (Fx$="He") OR (Fy$="He") THEN GOTO De_read
  IF (Fx$="Me") OR (Fy$="Me") THEN GOTO Me_read
  IF (Fx$="dt") OR (Fy$="Me") THEN GOTO Me_read
  IF (Fx$="Me") OR (Fy$="dt") THEN GOTO Me_read

  IF X2<1000 THEN X2=1000
  IF X2>3000 THEN X2=3000
  IF Fx$="In" THEN MAT X=X2
  IF Fy$="In" THEN MAT Y=X2
  GOTO 446u

  GOTO 4500

Inert_read: 1

ALPHA=52265.8 1 Powder River Basin Parameters.

Beta=617.44

FREAD "Tday"&Profiles[1,2],X(1)
FREAD "Trnt"&Profiles[1,2],Y(1)
FREAD "Rei"&Profiles[1,2],X(1)
FREAD "Elev"&Profiles[1,2],Y(1)

KEDI Dum=(X2)
MAT Dum=Dum*(.01) 1 Convert Reel to a fraction

MAT X2=X2*2
MAT X2+X2+(ALPHA)

FOR I=1 TO Rom(X2)
  IF X2(1)<1000 THEN X2(1)=1000
  IF X2(1)>3000 THEN X2(1)=3000
  IF Fx$="In" THEN MAT X=X2
  IF Fy$="In" THEN MAT Y=X2
  GOTO 446u

DT_read: FREAD "Tday"&Profiles[1,2],X(*)
FREAD "Trnt"&Profiles[1,2],Y(*)

IF (Fx$="D") OR (Fy$="D") THEN MAT X2=X2-1
IF (Fx$="He") OR (Fy$="He") THEN MAT X2=X2+1
IF (Fx$="Me") OR (Fy$="Me") THEN MAT X2=X2-1
IF (Fx$="Me") OR (Fy$="Me") THEN MAT X2=X2+1
IF (Fx$="dt") OR (Fy$="dt") THEN MAT X=X2
IF (Fx$="dt") OR (Fy$="dt") THEN MAT Y=X2
GOTO 4500

Plotting_setup: IF (Fx$="In") OR (Fy$="In") THEN J=X(1)
IF (Fx$="dt") OR (Fy$="dt") THEN X(2)
4790 IF (F$="in") OR (F$="Dt") THEN J=J(1)
4800 IF F$="Me" THEN J=J(1)
4810 IF (F$="in") OR (F$="Dt") THEN Dist=Z(2)
4820 IF F$="Me" THEN Dist=Z(2)

FOR I=1 TO J
4840 X(I)=A(I+2)
4850 Y(I)=Y(I+2)
4860 NEXT I
4870 REDIM X(J),Y(J),X2(J),Z(J)
4880 DX=10
4890 Dy=10
4900 IF X+1,1]="L" THEN DX=100
4910 IF Y=1,1]="L" THEN Dy=100
4920 IF Xs[1,1]="L" THEN DX=50
4930 IF Ys[1,1]="L" THEN Dy=50
4940 IF (Xs[1,2]="In") OR (Ys[1,2]="Dt") THEN DX=5
4950 IF Xs[1,2]="Me" THEN Dist=5
4960 IF (Ys[1,2]="In") OR (Ys[1,2]="Dt") THEN Dy=5
4970 IF Ys[1,1]="Me" THEN Dy=5
4980 IF Xs[1,1]="R" THEN DX=5
4990 IF Y=1,1]="R" THEN Dy=5
5000 IF Plotter=0 THEN LOCATE 2,10,10,90
5010 GOSU Point_plot
5020 CSIZL 2
5030 LOR 5
5040 MOVE (Xmax+ymin)•.5,Ymax
5050 LABEL "Profile ",Profile$...
5060 IF Plotter#=0 THEN GOTO 5210
5070 INPUT "Enter O to END and 1 to continue plots", Sz
5080 IF Sz=0 THEN GOTO 5160
5090 IF Plot_count=4 THEN GOTO Reset_plot
5100 Plot_count=Plot_count+1 1 Increment plot counter
5110 GOTO Cross_cont...
5120 Reset_plots: OUTPUT 705;"AH:" Next page
5130 OUTPUT 705;"AH:" Cross_plot=1
5140 GOTO Cross_cont...
5150 GOTO Cross_plot
5160 OUTPUT 705;"AH:" Cross
5170 OUTPUT 705;"AH:" Cross
5180 DISP "FINISHED:"
5190 PEN 0
5200 GOTO Function_keys
5210 LOR G 2
5220 MOVE Xmin,Ymax+Yr
5230 LABEL "Cont to continue; DUMP GRAPHICS to copy"
5240 PAUSE
5250 PEN 0
5260 EXIT GRAPHICS
5270 INPUT "Enter 0 to continue and 1 to DIGITIZE plotted points", Sz
5280 IF Sz=0 THEN GOTO Function_keys
5290 GRAPHICS...
5300 POINTERS (Xmin+Xmax)•.5,(Ymin+Ymax)•.5,2
5310 DIGITIZE XG,Yd 1 Position cursor
5320 MAT L*X xd
5330 MAT 2=2,2
5340 MAT x2=y-yd
5350 MAT x2=x2,x2
5360 MAT 2=2,x2
5370 MAT SEARCH 2(*),MIN;Zmin
5380 MAT SEARCH 2(*),LOC(Z(K)=Zmin);K
PROCEDURE: MULTIPLE CROSS-PLACKETING

1. Set the plotter option to CHT
2. Plots of Tday, Tnite, etc., 2/20/81
3. PRINT PAGE
4. If Area = "PKD" THEN GOTO 5570
5. PRINT "Need to revise P mapping parms at Pcoetf"
6. GOTO CONT mult
7. Pcoetf: Alpha = 5225,6 (Powder River Basin Parameters)
8. Beta = 374
9. FREAD "Tday" &PS, Tnfl(*)
10. FREAD "Elev" &PS, Topo(*)
11. FREAD "Tnite" &PS, Tnite(*)
12. FREAD "Der" &PS, Der(*)
13. FREAD "Refl" &PS, Refl(*)
14. Dist for (*2)
15. FOR L = 1 TO J
16. X(L) = (L-1)*Dist
17. Tday(L) = Tday(L+2)
18. Tnite(L) = Tnite(L+2)
19. Topo(L) = Topo(L+2)
20. Der(L) = Der(L+2)
21. Dt(L) = Derv(L)-Tnite(L)
22. Mean(L) = (Tday(L)+Tnite(L))/2
23. Inert(L) = (Alpha+Beta*Refl(L))/Dt(L)
24. IF Inert(L) > 2500 THEN Inert(L) = 2950
25. IF Inert(L) < 1000 THEN Inert(L) = 550
26. IF Refl(L) > 2 THEN Refl(L) = 245
27. IF Der(L) > 30 THEN Der(L) = 35
28. IF Der(L) < -30 THEN Der(L) = -35
29. NEXT L
30. REDIM Tday(J), Tnite(J), Topo(J), X(J), Y(J), Der(J), Dt(J), Inert(J), Refl(J), Mean(J)
31. RETURN

CONT mult: 1
32. IF Plotter = 0 THEN PLOTTER = 13,"GRAPHICS"
33. IF Plotter = 1 THEN PLOTTER = 7,5,"9872A"
34. FOR K = 1 TO 20
35. IF K MOD 4 = 1 THEN LOCATE 10, 50, 60, 90
36. IF K MOD 4 = 2 THEN LOCATE 10, 50, 10, 40
37. IF K MOD 4 = 3 THEN LOCATE 10, 110, 60, 90
38. IF K MOD 4 = 0 THEN LOCATE 10, 110, 10, 40
39. ON K GOSUB P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20
40. IF (K MOD 4 = 0) AND (Plotter = 0) THEN PLOTTER = 13, "GRAPHICS"
41. IF (K MOD 4 = 0) AND (Plotter = 1) THEN OUTPUT 705; "EC"; Enable cutter
42. IF (K MOD 4 = 0) AND (Plotter = 1) THEN OUTPUT 705; "AF"; Adv and cut
43. NEXT K
44. IF Plotter = 1 THEN OUTPUT 705; "AH"; Adv and cut
P1: MAT X=Topo  | Tday vs Elev
MAT Y=Tday
XS="Topo"
YS="Tday"
DX=100
DY=5
GOTO Cont

P2: MAT X=Der  | Tday vs Der
MAT Y=Tday
XS="Der"
YS="Tday"
DX=10
DY=5
GOTO Cont

P3: MAT X=Refl  | Tday vs Refl
MAT Y=Tday
XS="Refl"
YS="Tday"
DX=10
DY=5
GOTO Cont

P4: MAT X=Der  | Tnite vs Der
MAT Y=Tnite
XS="Der"
YS="Tnite"
DX=10
DY=5
GOTO Cont

P5: MAT X=Topo  | Tnite vs Topo
MAT Y=Tnite
XS="Topo"
YS="Tnite"
DX=100
DY=5
GOTO Cont

P6: MAT X=Refl  | Tnite vs Refl
MAT Y=Tnite
XS="Refl"
YS="Tnite"
DX=0.05
DY=5
GOTO Cont

P7: MAT X=Topo  | Refl vs Topo
MAT Y=Refl
XS="Topo"
YS="Refl"
DX=100
DY=0.05
GOTO Cont

P8: MAT X=Inert  | Refl vs Inert
MAT Y=Refl
XS="Inert"
YS="Refl"
DX=500
DY=0.05
GOTO Cont
6540 P10: MAT X=Derv  I Resi vs Derv
6660 MAT Y=Resi
6560 X$="Derv"
6640 Y$="Resi"
6520 Dx=1
6640 Dy=.05
6650 GOTO Cont
6660 P13: MAT X=Dt  I Inert vs Dt
6670 MAT Y=Inert
6680 X$="Dt"
6690 Y$="Inert"
6700 Dx=5
6710 Dy=500
6720 GOTO Cont
6730 P13: MAT X=Topo! Inert vs Topo
6740 MAT Y=Inert
6750 X$="Topo"
6760 Y$="Inert"
6770 Dx=100
6780 Dy=500
6790 GOTO Cont
6800 P14: MAT X=Derv! Inert vs Derv
6810 MAT Y=Inert
6820 X$="Derv"
6830 Y$="Inert"
6840 Dx=10
6850 Dy=500
6860 GOTO Cont
6870 P17: MAT X=Topo! Dt vs Elev
6880 MAT Y=Dt
6890 X$="Elev"
6900 Y$="Dt"
6910 Dx=500
6920 Dy=5
6930 GOTO Cont
6940 P18: MAT X=Tnite! Tdøy vs Tnite
6950 MAT Y=Tdøy
6960 X$="Tnite"
6970 Y$="Tdøy"
6980 Dx=10
6990 Dy=5
7000 GOTO Cont
7010 P19: MAT X=Tnite! Tdøy vs Tnite
7020 MAT Y=Tnite
7030 X$="Tnite"
7040 Y$="Tdøy"
7050 Dx=5
7060 Dy=10
7070 GOTO Cont
7080 P4:  I LABEL
7090 P8:  I
7100 P12:  I
7110 P16:  I
7120 P20: GOTO Plot_label
7130 Cont:  I
7140 Point plot:  I
7150 MAT SEARCH X(*) MAX;Xmax
7160 MAT SEARCH Y(*) MAX;Ymax
7170 MAT SEARCH X(*) MIN;Xmin
7180 MAT SEARCH Y(*) MIN;Ymin
rAOP^` ![Image with text]

7190 Xmin=INT(Xmin/Dx)*Dx
7200 Xmax=(INT(Xmax/Dx)+1)*Dx
7210 Ymin=INT(Ymin/Dy)*Dy
7220 Ymax=INT(Ymax/Dy)+1)*Dy
7230 Xr=(Xmax-Xmin)*.05
7240 Yr=(Ymax-Ymin)*.05
7250 IF Plotter=1 THEN GOTO 7540
7260 LORG 5
7270 C.LE 2
7280 IF Plot_count=1 THEN GOTO Plt-1
7290 IF Plot_count=2 THEN GOTO Plt-2
7300 IF Plot_count=3 THEN GOTO Plt-3
7310 Plt-1: X=Xset+8.5*25.4
7320 X1=Xset+69.85
7330 X2=X1+3.75*25.4
7340 Y1=Yset+75
7350 Y2=254
7360 GOTO 7520
7370 Plt-2: X=Xset+69.85
7380 X1=Xset+69.85
7390 Y1=Yset+75
7400 Y2=254
7410 GOTO 7520
7420 Plt-3: X=Xset+69.85
7430 X1=Xset+69.85
7440 Y1=Yset+75
7450 Y2=254
7460 GOTO 7520
7470 Plt-1: X=Xset+69.85
7480 X1=Xset+69.85
7490 X2=Xset+165.1
7500 Y1=Yset+75
7510 Y2=233.35
7520 X=X1+110/(11*25.4)
7530 LOCATE X1+X2,X=Y1+Y2,Y1+Y2
7540 SCALL Xmin,Xmax,Ymin,Ymax
7550 AXES Dx,Dy,Xmin,Ymin
7560 LORG 6
7570 MOVE (Xmin+Xmax)/2,Ymin-Yr*1.5
7580 FOR R=1 TO 2
7590 IF R=1 THEN Z$=X$-Y$+1.5
7600 IF R=2 THEN Z$=X$+Y$-1.5
7610 IF Z$=1 THEN Z$=mean temp(K)
7620 IF Z$=1 THEN Z$=Temp diff(K)
7630 IF Z$=1 THEN Z$=Gradient(m/km)
7640 IF Z$=1 THEN Z$=Elevation(m)
7650 IF Z$=1 THEN Z$=Inertia(TIU)
7660 IF Z$=1 THEN Z$=Refl(I)
7670 IF R=1 THEN X$=Z$-15
7680 IF R=2 THEN X$=Z$+15
7690 NEXT R
7700 NEXT R
7710 LABEL X$+15
7720 DEG
7730 LDIR 90
7740 LORG 4
7750 MOVE Xmin-Xr*3.5, (Ymin+Ymax)/2
7760 LABEL Y$+15
7770 LDIR 0
7780 FOR I=1 TO J
7790 MOVE X(I),Y(I)
7800 LABEL "."
7810 NLT 1
7820 CSIZE 2.2
7830 LORG 6
7840 FOR X=Xmin TO Xmax STEP Dx
7850 MOVE X,Ymin-Yr*.5
7860 LABEL VAL$(X)
7870 NEXT X
7880 LORG 6
7890 FOR Ya=Ymin TO Ymax STEP Dy
7900 MOVE Xmin-Xr*.5,Ya
7910 LABEL VAL$(Ya)
7920 NEXT Ya
7930 CSIZE 3.3
7940 RETURN
7950 Pict label: 1
7960 SCALE 0.1,0.1
7970 LORG 1
7990 MOVE .2,.75
8000 IF Area$="PRB" THEN LABEL "Powder River Basin Area"
8010 IF Area$="CP" THEN LABEL "Cabeza Prieta Area"
8020 IF Area$="PRB" THEN LABEL "Aug 20,1978"
8030 IF Area$="CP" THEN LABEL "Apr 3-4,1979"
8040 MOVE .5,.25
8050 LABEL "Profile" PROFILE$
8060 IF Plotter=0 THEN DUMP GRAPHCICS
8070 RETURN
8080 1
8090 ***************
8100 1
8110 Topo resample: 1 To spline-smooth topo data and restore as Elev binary.
8120 1 and Derv binary.
8130 1 Special correction to Dist and for topo interp.
8140 PRINT PAGE
8150 DISP "Topo resample."
8160 FREAD "Toay"&Profile$(1,2),Tyay(*)
8170 FREAD "Topo"&Profile$(1,2),Topx(*)
8180 J=Toay(1)
8190 Distz=Topz(2)
8200 K=Topx(1)
8210 Distz=Topx(2)
8220 FOR I=1 TO J
8230 X(1)=[(I-1)*Dist 1 Image file
8240 NEXT I
8250 FOR I=1 TO K
8260 Topx(I)=Topx(I+2)
8270 X2(I)=[(I-1)*Distz
8280 NEXT I
8290 1 To interpolate topo data
8300 DIM Xb(4,3),Xbtim(3,4),Dumx(3,3),Inv(3,3),P(4,1),Rum(3,1),G(3,1)
8310 MAT Xb(1)
8320 Xb(1,1)=((0=Xb(1,2))=Xb(1,3))
8330 Xb(3,1)=4
8340 Xb(3,2)=2
8350 Xb(4,1)=9
8360 Xb(4,2)=3
8370 MAT Xbtim=TRN(Xb)
8380 MAT Dumx=Xbtim*XB
8390 1
4390 NAT.Inv=INV(Dumx)
4400 Dist=Dist/(2*Distz)
4410 L=1
4420 Jmax=INT(Distz*K/Dist)
4430 IF J>Jmax THEN J=Jmax  
         ! Truncate all tiles to Jmax
4440 FOR I=2 TO J-
4450 IF (X(I)>X2(L)) AND (X(I)<X2(L+1)) THEN GOTO Intep
4460 L=L+1
4470 GOTO &450
4480 Intep:  f(1,1)=Topx(L-1)
4490 F(2,1)=Topx(L)
4500 F(3,1)=Topx(L+1)
4510 F(4,1)=Topx(L+2)
4520 NAT.Inv=Kotm*F
4530 NAT=G.Inv*Num
4540 Zb=(L-1)*2*el-(L-2)
4550 Dum(I)=G(I,1)/3*(Del*2+3*2b2)+G(2,1)*2b-G(3,1)
4560 Derv(I)=2*G(I,1)*2b-G(2,1)
4570 NextI:  NEXT I
4580 Dum(I)=Topx(L)  ! End points
4590 Dum(J)=Topx(J)
4600 Derv(I)=(Topx(2)-Topx(1))/Dist
4610 Derv(J)=(Topx(J)-Topx(J-1))/Dist
4620 REDIM Dum(J),Derv(J),2(J)
4630 NAT 2=Dum
4640 REDIM Topo(J+2),Derv(J+2)  ! Store output as binary tiles.
4650 FOR I=J TO 1 STEP -1
4660 Topo(I+2)=Dum(I)
4670 Derv(I+2)=Derv(I)
4680 NEXT I
4690 Topo(1)=J
4700 Derv(1)=J
4710 Topo(2)=Dist
4720 Derv(2)=Dist
4730 REDIM Topo(J+2),Derv(J+2)
4740 DISP "Storing binary tiles."
4750 FCREATE "Elev"&Profile$[1,2],52
4760 FCREAT "Derv"&Profile$[1,2],52
4770 FPRINT "Elev"&Profile$[1,2],Topo(*)
4780 FPRINT "Derv"&Profile$[1,2],Derv(*)
4790 DISP "FINISHED"
4800 GOTO Function_keys
4810 I  ***************
4820 I
4830 I
4840 File_edit:  To edit binary files.
4850 PRINT PAGE
4860 INPUT "Enter File to be edited ie, Tday,Tnite,Ref1,Topo...,",Filein$  
4870 Filename$=Filein$[1,4]&Profile$[1,2]
4880 REDIM Dun(150)
4890 FREAD Filename$,Dum(*)
4900 J=Dum(1)
4910 Dist=Dum(2)
4930 PRINT Lin(1)
4940 PRINT "Dum(3)=";Dum(3),"Dum("&VAL$(J+2)&")=";Dum(J+2)
4950 Edit_feature:  PRINT "PAUSE AT Edit_feature"
4960 PAUSE
4970 Dun(1)=494  ! ********** SPECIAL MOD FOR PRB BB **********
FOR I=1 TO 4961 Sp cludge for BB
DUM(1)=DUM(1+2)
NEXT I
REDIM DUM(49b)
BLEP
PAUSE
INPUT "Do you wish to re-store this file?",A$ IF A=$"Y",Y" THEN GOTO Last_feature
PURGE Filenames
FOR I=1 TO 52
PFILE Filename,DUM(*)
GOTO function keys
10 1
10 1
14 1
Llev correct: DISP "Elevation correction."
FILED "Tuay"&Profile$[1,2],Tuay(*)
FILED "Tnit"&Profile$[1,2],Tnite(*)
FREAD "Elev"&Profile$[1,2],Topo(*)
J=Topo(C(1)
Dist=Topo(2)
L=W
INPUT "Enter starting and ending distances for elev correl",D1,D2
10 40 FOR I=1+2 TO 12+2
10 50 L=W+1
10 60 X(L)=Tuay(1)
10 70 Y(L)=Topo(1)
10 80 Z(L)=Tnite(1)
10 90 X2(L)=Tuay(1)+Tnite(1)/2
10 30 DIFF LS 0
10 10 PRINT LIN(5)
10 15 PRINT "Use CONT to rename Tuay and Tnite as Tday and Tnt."
10 20 PRINT "and store elevation correction values in Tday and Tnt."
10 25 PAUSE
10 30 RENAME "Tuay"&Profile$[1,2] TO "Tday"&Profile$[1,2]
10 40 RENAME "Tnite"&Profile$[1,2] TO "Tnt"&Profile$[1,2]
10 50 FCREATE "Tday"&Profile$[1,2],52
10 60 FCREATE "Tnt"&Profile$[1,2],52
10 70 Elevel_correl 1 Set elevation correction indicator
10 80 Alpha=Alpha_mean
10 90 FOR I=1 TO 3
10 10 Tuay(I+2)=Tuay(I+2)-Alpha*(Topo(I+2)-1400)
10 11 Tnite(I+2)=Tnite(I+2)-Alpha*(Topo(I+2)-1400)
10 12 NEXT I
10 13 FPRINT "Tuay"&Profile$[1,2],Tuay(*)
10 14 FPRINT "Tnt"&Profile$[1,2],Tnite(*)
10 15 FOR I=1 TO 52
10 16 PRINT FILENAME,DUM(*)
10 17 PRINT "Use CONT to rename Tuay and Tnite as Tday and Tnt."
10 18 PRINT "and store elevation correction values in Tday and Tnt."
10 19 PAUSE
10 20 RENAME "Tuay"&Profile$[1,2] TO "Tday"&Profile$[1,2]
10 21 RENAME "Tnite"&Profile$[1,2] TO "Tnt"&Profile$[1,2]
10 22 FCREATE "Tday"&Profile$[1,2],52
10 23 FCREATE "Tnt"&Profile$[1,2],52
10 24 Elevel_correl 1 Set elevation correction indicator
10 25 Alpha=Alpha_mean
10 26 FOR I=1 TO 3
10 27 Tuay(I+2)=Tuay(I+2)-Alpha*(Topo(I+2)-1400)
10 28 Tnite(I+2)=Tnite(I+2)-Alpha*(Topo(I+2)-1400)
10 29 NEXT I
10 30 FPRINT "Tuay"&Profile$[1,2],Tuay(*)
10 31 FPRINT "Tnt"&Profile$[1,2],Tnite(*)
10 32 FOR I=1 TO 52
10 33 PRINT FILENAME,DUM(*)
10 34 PRINT "Use CONT to rename Tuay and Tnite as Tday and Tnt."
10 35 PRINT "and store elevation correction values in Tday and Tnt."
10 36 PAUSE
10 37 RENAME "Tuay"&Profile$[1,2] TO "Tday"&Profile$[1,2]
10 38 RENAME "Tnite"&Profile$[1,2] TO "Tnt"&Profile$[1,2]
10 39 FCREATE "Tday"&Profile$[1,2],52
10 40 FCREATE "Tnt"&Profile$[1,2],52
10 41 Elevel_correl 1 Set elevation correction indicator
10 42 Alpha=Alpha_mean
10 43 FOR I=1 TO 3
10 44 Tuay(I+2)=Tuay(I+2)-Alpha*(Topo(I+2)-1400)
10 45 Tnite(I+2)=Tnite(I+2)-Alpha*(Topo(I+2)-1400)
10 46 NEXT I
10 47 FPRINT "Tuay"&Profile$[1,2],Tuay(*)
10 48 FPRINT "Tnt"&Profile$[1,2],Tnite(*)
REPORT PLOT: 1
DISP "Report plotting."
SERIAL
PLOTTER IS 7.5,"9672A"
GOSUB mult_file_read
MAT Reil=KEl*(TU)  ! Convert back to T
DX=25
XW="Distance(Km)"
MAT SEARCH X(1),MAX=Xmax
Xmin=0
DX=(Xmax-Xmin)*.125/6
DEG
FOR I=1 TO 4: Four sheets
IF I=1 THEN GOTO Plots1
IF I=2 THEN GOTO Plots2
IF I=3 THEN GOTO Plots3
IF I=4 THEN GOTO Plots4
Plots1: MAT Y=Day
YS="Temp(K)"
Dy=5
Sp2=" - Day."
MAT Dun=Thile
DS="Temp(K)"
Dy=5
Sp2=" - Night."
GOTO 10230
Plots2: MAT Y=Temp(K)
YS="Elevation(m)"
Dy=100
Sp2=" - Day."
MAT Dun=Deriv
DS="Gradient(m/Km)"
Sp2=" - Day."
Dy=10
GOTO 10230
Plots3: MAT Y=Temp(K)
YS="Temp(K)"
Dy=5
Sp2=" - Temp count."
MAT Dun=mean
DS=YS
Sp2=" - Temp mean."
Dy=10
GOTO 10230
Plots4: MAT Y=Refl
YS="Refl(k)"
Dy=5
Sp2=""
1070G NEXT 1
1080G OUTPUT 7051:"Ami"
1090G GOTO Function_keys
1091G 1
1092G 1
1093G 1
1094G SUM Linear(X(*),Y(*),L,Alpna,Beta,Dev)
1095G |Fit Y = Alpna*X + Beta +/- Dev
1096G |OPT1: HASE 1
1097G |Dev = Al((500),1),Y(500),1),xtres(1,500),D(1,1),-(1,1),F(1,1)
1098G |REDI1 Al(L,L),Y(L,L),xtres(L,L)
1099G |FON I=1 TO L
1100G |AI(1,1)=A(1)
1101G |Y(1,1)=Y(1)
1102G |AI*L=AI 1
1103G |Almean=SUM(Al)/L
1104G |Ymean=SUM(Y)/L
1105G |AI(1,1)=Al(1)-Almean
1106G |Y(1,1)=Y(1)-Ymean
1107G |Almean=Al(1)-AI(mean)
1108G |Ymean=Y(1)-Y(mean)
1109G |AI(1,1)=Al(1)+Beta
1110G |Y(1,1)=Y(1)+Beta
1111G |Dev=SUM((Y(1,1))/(L-1))
1112G |SUMLD
1113G Sub Fast_list(X(*),Dx,L,upper,xlower,xmin,xmax)
1114G |Output X upper,xlower,Almean,Almax
1115G |OPTION: BASE 1
1116G |RED1 K(X)
1117G |AI=xup(X)/L DIV Dx*Dx
1118G |nAT SEARCH X(*),LOC(>upper);upper
1119G |AI=xlow=AI+Dx
1120G |MAX SEARCH: MAX SEARCH X(*),LOC(>xmax);Xmax
1121G |IF X-upper<=0 THEN MIN
1122G |Xmax=xmax-Dx
1123G |GOTO MAX SEARCH
1124G |HIN: HAT SEARCH X(*),LOC(=xlower);lower
1125G |amin=amin-Dx
1126G |HIN SEARCH: HAT SEARCH X(*),LOC(<amin);amin
1127G |IF X-lower<=0 THEN Finish
1128G |amin=Xamin-Dx
1129G |GOTO HIN SEARCH
1130G Finish:SUBLEND
1131G END

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5.2 REFERENCE MATERIAL