Remote Sensing Brief

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Calculation of Thermal Inertia from Day-Night Measurements Separated by Days or Weeks

If only relative thermal inertia across an area is required—as in many geologic applications—day-night temperature pairs separated by more than 36 hours might be used.

In order to calculate the thermal inertia of an area from remotely sensed data, one measures the surface albedo and determines the diurnal temperature range of the surface in image format (Pohn *et al.*, 1974; Watson, 1975; Kahle *et al.*, 1976; Gillespie and Kahle, 1977; Price, 1977). The albedo image is found from measurement of the broadband visible and near infrared radiance reflected from the surface. The temperature-range image is calculated from surface thermal radiance measured as near as possible to the time of maximum surface temperature and (pre-dawn) surface minimum temperature. Ordinarily, both surface-temperature images are measured within the same 12-hour period. If this is impossible, owing to weather conditions or satellite orbit or aircraft scheduling constraints, then the measurement of the pre-dawn surface radiance within a 36-hour period has been considered to be adequate, although less satisfactory. Aircraft thermal infrared programs are usually designed with these time constraints as an important factor, and the orbit of the Heat Capacity Mapping Mission (HCMM) satellite was chosen specifically to meet these measurement requirements (GSFC, 1978).

Once the maximum and minimum surface temperature (T_D, T_N) and surface albedo (A) have been obtained, thermal inertia can be calculated from models incorporating various heating parameters, or the apparent thermal inertia (ATI) can be computed from the formulation of Price (1977): i.e.,

$$ATI = \frac{2\,SVC}{\sqrt{\omega}[1 + \alpha^2 + \sqrt{2}\alpha]^{1/2}} \cdot \frac{(1 - A)}{\Delta T}$$

where ΔT = diurnal temperature range of the surface ($T_D - T_N$) and S is the solar constant (= 1.98 cal cm^{-2} min^{-1}), V is atmospheric transmittance at visible wave lengths (a value of 0.75 is used in this calculation), ω is the angular speed of the Earth's rotation (= 4.363×10^{-3} radians/min), α is a parameter which is proportional to the ratio of the heat flux density transferred by the surface to the air to that transferred into the ground, and C is a parameter which varies with solar declination (δ) and latitude (ϕ) according to

$$C = 1/\pi\,[\sin\delta \sin\phi \arccos(-\tan\delta \tan\phi) + \cos\delta \cos\phi\,(1 - \tan^2\delta \tan^2\phi)^{1/2}].$$

We have shown that the apparent thermal inertia is sufficiently accurate for many geologic applications (Kahle *et al.*, 1982). The apparent thermal inertia is usually within 20 percent of the more accurately modeled thermal inertia values we have derived. When images of thermal inertia and apparent thermal inertia are "stretched " to fill the dynamic range of the image display, the two images usually appear essentially identical, demonstrating that the apparent thermal inertia is "correct" in a relative sense across the scene.

During our HCMM investigation (Kahle *et al.*, 1981), we were fortunate to obtain several excellent day-night pairs of data, each pair acquired within a 12- to 36-hour period, under clear sky conditions. The availablity of these data allowed us to investigate the significance of acquiring the data within this period. We calculated both modeled and apparent thermal inertia for our Pisgah, California test site for each of eight data sets. We will call these the "standard" thermal inertia sets. Then, in order to

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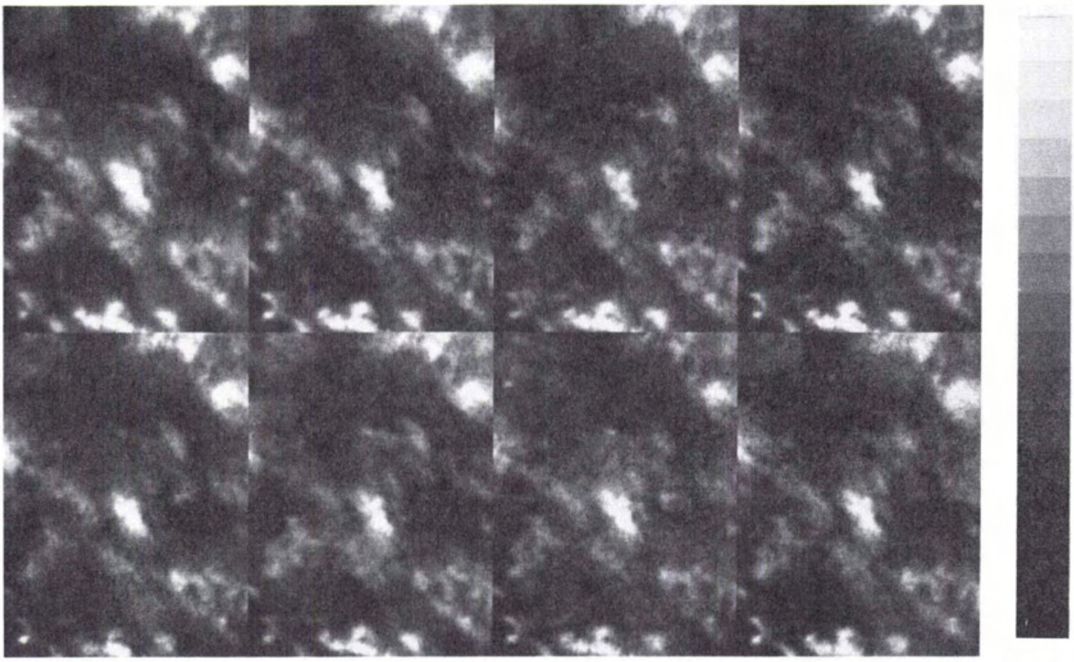

FIG. 1. Apparent thermal inertia at Pisgah, California derived from 17 July 1978 daytime data, and night temperature data (left to right) from 13 May 1978, 29 May 1978, 5 July 1978, 16 July 1978, 22 July 1978, 17 August 1978, 18 September 1978, and 4 April 1979. The area covered by each image is approximately 35 by 40 km. The Sunshine lava flow is the bright area near the center of each image, with the Pisgah flow 10 km to the northeast.

assess the time-of-acquisition effect, we calculated the "non-standard" apparent thermal inertia combining different day-night pairs. In Figure 1 we show eight separate non-standard apparent thermal inertia (ATI) images of the Pisgah, California test site. All images were composed using the 17 July 1978 daytime HCMM data, but each image used a different nighttime thermal component. The dates of the nighttime images used were 13 May 1978; 29 May 1978; 5 July 1978; 16 July 1978; 22 July 1978; 17 August 1978; 18 September 1978; and 4 April 1979. Only the upper right image is a standard ATI, because it was formed using the 16 July nighttime data, with the 17 July daytime image. The eight images look very similar. The only readily discernible differences between the eight images are at Lavic playa, 6-km east of Sunshine lava flow, where we can expect soil moisture changes.

In order to put this visual impression in quantitative terms, correlation coefficients were computed. Comparing the standard 16 July image to the seven non-standard images, the correlation coefficients ranged from 0.853 (18 September) to 0.938 (29 May) with an average of 0.903. For comparison, the standard ATI images for the same dates have correlation coefficients ranging from 0.786 (18 September) to 0.908 (5 July) with an average of 0.845. That is, the non-standard ATI images from widely separated day-night pairs are actually more similar to each other than standard ATI acquired at different times of the year.

The similarity between the images of apparent thermal inertia is reasonable. At the time of maximum heating, the low thermal inertia materials will be hottest and the high thermal inertia materials coolest, and vice versa at the time of minimum surface temperature, regardless of how many days separate the measurements. By using stretched apparent thermal inertia images, we get excellent qualitative agreement between the images despite quantitative differences in the unstretched data. The higher correlation between the non-standard ATI's than between the standard ATI is probably due to there being less variation across an area in nighttime temperatures than in daytime temperatures, and all non-standard images were based on the same daytime image.

Based on the results shown here, we suggest that where only relative thermal inertia across an area is required—as in many geologic applications—investigators should consider using the best day-night temperature pairs available, even if not acquired within the usually prescribed 12 to 36 hour period.

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