THERMAL REMOTE SENSING

Introduction

The earth-atmosphere system derives its energy from the sun which being at a very high temperature, radiates maximum energy in the shorter wavelengths (visible, 0.20 to 0.80 µm). The earth-atmosphere system absorbs part of this energy (part due to its reflective properties due to surface albedo, clouds and other reflectors/scatterers in the atmosphere), which in turn heats it up and raises its temperature. This temperature being in the range of 300 degrees Kelvin, it will emit its own radiation in the longer wavelengths called 'thermal infrared'. The observations in the thermal wavelength of the electromagnetic spectrum (3-35 µm) are generally referred to as thermal remote sensing. In this region the radiation emitted by the earth due to its thermal state are far more intense than the solar reflected radiation, therefore any sensor operating in this wavelength region would primarily detect the thermal radiative properties of ground material.

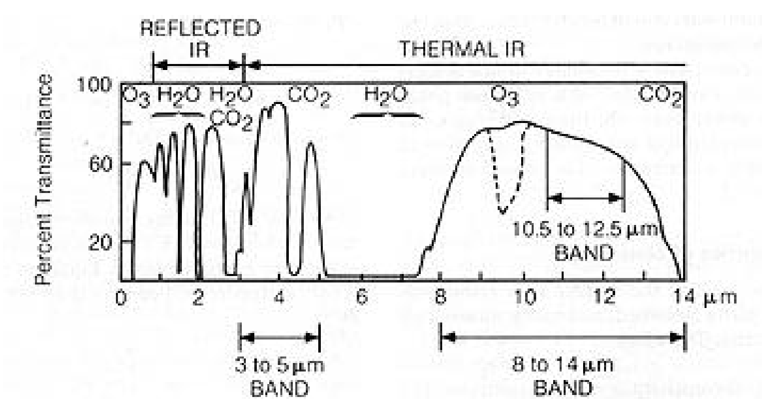
All materials having a temperature above absolute zero (-273°C or 0°K) both day and night emit Infrared energy Infrared sensing refers to the detection of remote objects by recording the amount of infrared energy emitted from various surfaces as a continuous tone image on photographic film. Thermal IR imagery is usually obtained in the wavelength regions 3 to 5.5µm and from 8 to 14µm because of atmospheric absorption at other wavelengths.

IR Region of the Electromagnetic Spectrum

The IR region covers wavelengths from 0.7 to 300µm. The reflected IR region ranges from wavelengths 0.7 to 3 µm and includes the photographic IR band (0.7 to 0.9 µm) that may be detected from IR film. IR radiation at wavelengths 3 to 14µm is called the thermal IR region. Since thermal IR radiation is absorbed by glass lenses of conventional cameras and can not be detected by photographic film. Special optical mechanical scanners are used to detect and record images in the thermal IR region. IR radiation at wavelengths larger than 14µm is not utilized in remote sensing as the radiation is absorbed by the earth's atmosphere.

Atmospheric transmission

Thermal sensing of solids and liquids occurs in two atmospheric windows, where absorption is a minimum, as shown in this spectral plot taken from Sabins (Remote Sensing: Principles and Interpretation, 1987).



Not all wavelengths of thermal IR radiation are transmitted uniformly through the atmosphere CO_2, Ozone and water vapor absorb energy at certain wavelengths IR and radiation at wavelengths from 3-5 µm and from 8-14 µm is readily transmitted through the atmosphere windows. A narrow absorption band occurs from 9-10 µm occurs due to the ozone layer present at the top of the earth's atmosphere. To avoid the affected of this absorption band, satellite thermal IR systems operate in 10.5 - 12.5µm. Systems on aircraft flying below the ozone layer are not affected and record the full 8-14µm band

The windows normally used from aircraft platforms are in the 3-5 mm and 8-14 µm wavelength regions. Space borne sensors commonly use windows between 3 and 4 µm and between 10.5-12.5 µm. None of the windows transmits 100 percent because water vapor and carbon dioxide absorb some of the energy across the spectrum and ozone absorbs energy in the 10.5-12.5 µm interval. In addition, solar reflectance contaminates the 3-5-µm windows to some degree during daylight hours, hence is used for Earth studies using nighttime measurements.

Radiation Principles

Planck Blackbody Law

Two material properties determine the amount of thermal radiation emitted by an object: internal temperature and emissivity. The Planck Blackbody Law gives the rate at which objects radiate energy:

$$E_? = C_1 ?^{-5} \ [\exp^{(C_2 / ?T)} - 1]^{-1},$$

Where: $E_?$ = spectral emission in W/m^2 at a wavelength ?
? = wavelength in m
C_1 = 3.74×10^{-6} $W.m^2$ (first radiation constant)
C_2 = 1.44×10^{-2} m.K (second radiation constant)
exp = 2.718 (base of natural logarithms)
T = absolute temperature (K)

A *perfect blackbody* is the concept of an ideal material that completely absorbs all incident radiation, converting it to internal energy. Therefore it does not permit any transmittance or reflectance but emits the absorbed energy at the maximum possible rate.

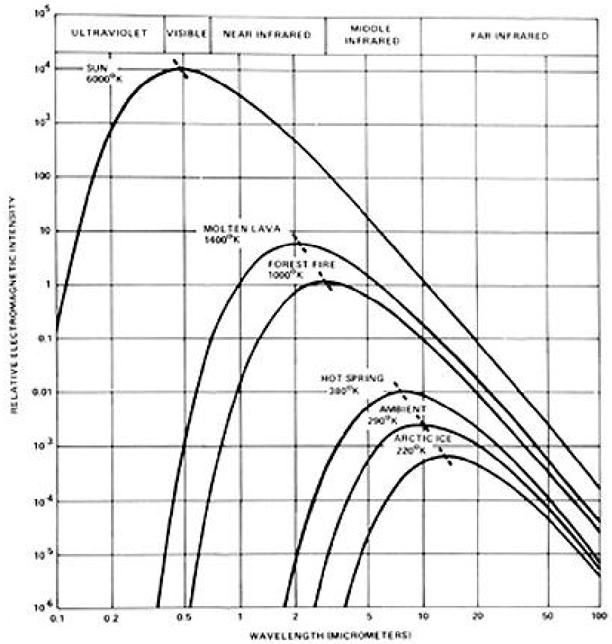
Stefan-Boltzmann Law

The total radiation emitted by a blackbody in the entire electromagnetic spectrum is obtained by integrating the area under Planck's distribution curve. It is given by the Stefan-Boltzmann Law.

E (blackbody) = sT^4

Where s = 5.67×10^{-8} W/m^2K^4

Wien Displacement Law and Emissivity Effects



The above plots spectral wavelength versus emitted radiance (as intensity) from thermal radiators at various peak radiant temperatures ranging from that of the Sun to the Earth's surface (average ambient temperature and sea ice). The hotter the radiating body, the greater is its radiance (intensity on the ordinate) over its range of wavelengths, and the shorter is its peak emission wavelength. The relation between peak wavelength and radiant body temperature is the Wien Displacement Law:

$$\lambda_m T = 2898 \ \mu m.K$$

Where λ_m is the wavelength at maximum radiant emittance and T is the absolute temperature in degrees Kelvin (°C + 273). The constant, 2898, is in units of µm °K. It is also given as (rounded off) 0.29 cm °K. For the Sun, with a photospheric radiant temperature of about 6000 °K, this peak is in the visible (centered on 0.58 µm). A forest fire peaks around 5.0 µm. The Earth, as observed from space, peaks within the 8-14 µm interval.

Spectral Emissivity and Kirchoff's Law

The three radiation laws mentioned above hold good for blackbody radiation only. All other substances are characterized by their spectral emissivity (e), defined as the ratio of spectral exitance of the material to the spectral exitance of a blackbody at the same temperature.

$e(?) = M_{?}$ (material, °K) / $M_{?}$ (blackbody °K)

Knowing the spectral emissivity of a body, its spectral exitance, total exitance and the wavelength of peak emission can be determined.

Kirchoff's law states that the spectral emissivity of a material is equal to its spectral absorptivity, i.e. e(?) = a(?). This implies that if a body is capable of emitting certain radiation, it will absorb that radiation when exposed to it.

The emissivity characteristics of material can be summarized as follows-

- Blackbody: e = 1 at all wavelengths
- Grey body: 0 < e < 1 (doesn't depend upon wavelength)
- Imperfect blackbody (perfect reflector): e = 0
- All other bodies: e = e(?) is a function of wavelength.

The relationship between reflectance, absorptivity and transmittance was given by

?(?) + a(?) + ?(?) = 1

It can be written as

?(?) + e(?) + ?(?) = 1

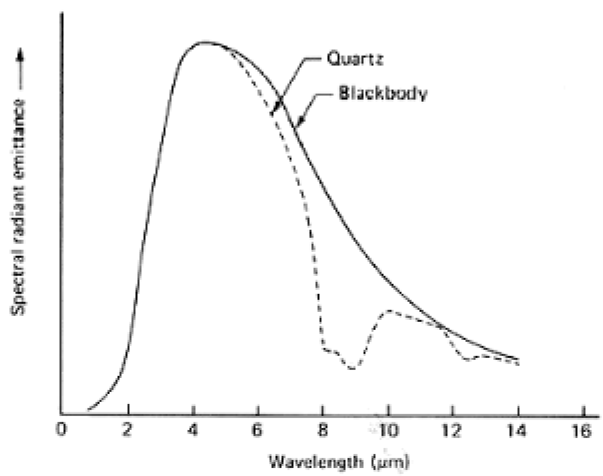
For opaque substances, ?(?) = 0; hence, emissivity and reflectance are related by

e(?) = 1 - ?(?)

Kinetic Temperature and Radiant Temperature

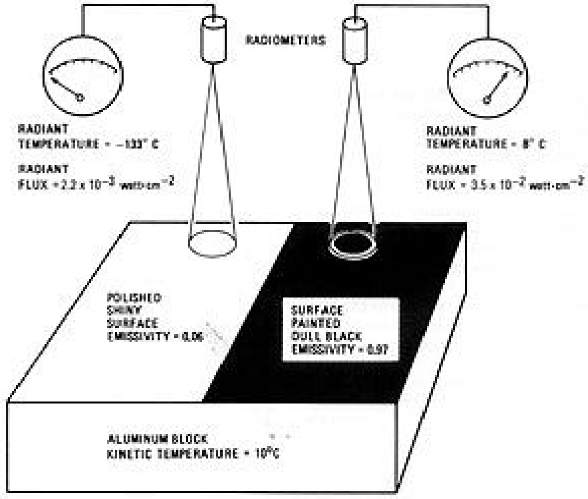
A body's temperature can represent one thermal state but can be expressed by two temperatures: the first is its internal temperature (from the kinetic motion of its atoms) as measured by an inserted thermometer whereas the second is the external temperature measured by its emitted radiation. The radiant flux E_B emanating from a body is related its internal (kinetic) temperature T_k by the Stefan-Boltzmann Law, $\mathbf{E_B = s\ T_k^4}$

The quantity of radiant emission, and thus the effective temperature that is measured externally as radiation, also depends on the emissivity e of the object in the spectral region of interest. Emissivity is a dimensionless number that expresses the ratio of the radiant flux of a real material E_R to the radiant flux of a perfect blackbody E_B (one that completely absorbs incoming radiant energy, with none being partitioned into transmitted or reflected components), or E_R/E_B = e. It is a measure of the efficiency of emitted radiance of any real body to that of a perfect radiator (for which e = 1.0). Values of e vary from 0 to 1 and are spectrally dependent, i.e., can change with λ. Here is an example comparing the spectral radiant emittance of the common mineral quartz to a perfect blackbody when they are at thermal equilibrium at a given temperature (here, at 600 °K).



In general, for opaque materials, e = l 1 - ? l , where rho is the material's optical reflectance. Thus, as ? ? 1, with high reflectance of radiation (poor absorptance), the emittance will be low (thus, thermal radiation decreases). Water, which has a high emissivity in the thermal infrared in the 8-10 µm interval, is a poor reflector over that range; quartz (and many silicate rocks) is a good emitter at lower thermal wavelengths but poor in this interval. From this, one might predict that rock surfaces would appear darker than water in the 8 -10 µm interval but this holds only for certain conditions.

The radiant (sensed) temperature differs from a body's kinetic (internal) temperature according to the relation $\mathbf{T} = e^{1/4}\ \mathbf{T_K}$; for real bodies (known as gray bodies) radiant temperatures are always less than kinetic temperatures. Thus, from figure below, the radiant temperature is significantly higher for a blackened surface (high e) than for a shiny surface (lower e), even if the two materials are at the same kinetic temperature.



From F.F. Sabins, Jr., Remote Sensing: Principles and Interpretation. 2nd Ed., © 1987.
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The amount of solar radiation reflected from land and sea surfaces, as well as the amount absorbed, depends partly on that portion of the spectral distribution of transmitted irradiant energy from the Sun that finally reaches these surfaces. The radiance rises rapidly to a peak at 0.48 µm, then trails off to near zero through wavelengths out to ~4.0 µm.

A thermal sensor picks up radiant emitted energy from a surface target heated through radiation (solar insulation and sky radiance), convection (atmospheric circulation) and conduction (through the ground). Thus, most sensed heat from surfaces has its origin in solar illumination, that varies with both diurnal and seasonal changes as well as cloud cover, but there is also a small, nearly constant contribution from internal heat flux from the Earth's interior (much of this is due to thermal inputs from radioactive decay). Heat is transferred into and out of near surface layers owing to external heating by the thermal processes of conduction, convection, and radiation.

The emissivities of the most of the substances fall within the relatively narrow range of 0.81 to 0.96. The final product of a thermal mapping system is a map showing apparent surface temperature. The system is sensitive not only to changes in surface temperature but also to change in emissivity of the scanned surfaces. Common surface materials like rocks, soil, vegetation etc. have emissivity values falling between 0.75 and 0.95 and hence surface temperature differences resulting from emissivity changes alone are quite small when compared to the temperature differences produced by other factors. Therefore interpretation of only the most subtle anomalies require consideration of emissivity.

Table 1: Emissivity of materials measured in 8 - 12µm region

Material	Emissivity
Granite	0.815
Quartz sand, large grains	0.914
Asphalt paving	0.959
Concrete walkway	0.966
Water with a thin film of petroleum	0.972
Water, pure	0.993
Polished metal surfaces	0.060

Thermal Properties of Materials

A primary objective of temperature measurements and related thermal responses is to infer something about the nature of the composition and other physical attributes of materials at the Earth's surface (and, in its atmosphere). For any given material, certain characteristic internal properties play important roles in governing the temperature of a body at equilibrium with its surroundings. These properties include:

Heat Capacity (C): The measure of the increase in thermal energy content (Q) per degree of temperature rise. It is given in c.g.s. units of calories per cubic cm. per degree Centigrade, and it denotes the capacity of a material to store heat (recall from physics that a calorie [cal] is the quantity of heat needed to raise one gram of water by one degree Centigrade). Heat capacity is calculated as the ratio of the amount of heat energy, in calories, required to raise a given volume of a material by one degree Centigrade (at a standard temperature of 15º Centigrade.) to the amount needed to raise the same volume of water by one degree Centigrade. A related quantity, *specific heat* (c), is defined as

$$C = \frac{Q}{m.T}$$

where Q = amount of energy
m = mass of substance
T = Difference in final & initial temperature

(units: calories per gram per degree Centigrade) where; this associates Heat Capacity to the thermal energy required to raise a mass of 1 gram of water by 1 degree Centigrade.

Thermal Conductivity (K): The rate at which heat will pass through a specific thickness of a substance, measured as the calories delivered in 1 second across a 1 centimeter square area through a thickness of 1 cm at a temperature gradient of 1 degree Centigrade (units: calories per centimeter per second per degree Centigrade)

Thermal Inertia (P): The resistance of a material to temperature change, indicated by the time dependent variations in temperature during a full heating/cooling cycle (a 24-hour day for the Earth); defined as

$$P = (K\ C\ ?)^{1/2}$$

P is a measure of the heat transfer rate across a boundary between two materials. e.g., air/soil. Because materials with high P possess a strong inertial resistance to temperature fluctuations at a surface boundary, they show less temperature variation per heating/cooling cycle than those with lower thermal inertia. Some characteristic values of these intrinsic thermal properties:

Table 2: Thermal properties

	Water	**Sandy Soil**	**Basalt**	**Stainless Steel**
K	0.0014	0.0014	0.0050	0.030
c	1.0	0.24	0.20	0.12
r	1.0	1.82	2.80	7.83
P	0.038	0.024	0.053	0.168

Apparent Thermal inertia

Thermal inertia cannot be determined by remote sensing methods because conductivity, density and thermal capacity must be measured by contact methods. Maximum and Minimum radiant temperature can be recorded from daytime and nighttime image. The fact that ΔT is low for materials with high thermal inertia and vice versa, it is based to determine a property called apparent thermal inertia (ATI) by

$$ATI = \frac{I - A}{\Delta T}$$

Where, A is the albedo in the visible band. Albedo is used to compensate for the effects that differences in absorptivity have on radiant temperature. ATI image must be interpreted with caution because ΔT may be influenced by factors other than thermal inertia.

Thermal diffusivity

Thermal diffusivity (κ) is a measure of the rate at which heat is transferred within the substance.

$$\kappa = K/\rho.c$$

Where K = thermal conductivity
ρ = density
c = thermal capacity

It governs the rate at which heat is conducted from surface to depth in the daytime and from depth to surface in the nighttime. Water passes high specific heat and therefore minor changes in moisture content have significant effects on thermal diffusivity of soils.

IR - Radiometers

Non-imaging IR radiometers measure the radiant temperature using detectors sensitive to 8 to 14 µm wavelengths. Temperature sensitivity is typically 0.2°C. The instantaneous field of view of a typical radiometer is either 2° or 20°. Radiant temperature may be measured either from air or on the ground using portable IR radiometers. These measurements are useful for collecting ground truth.

Airborne and Satellite TIR Scanner System

Thermal remote sensing data is collected by radiometers and scanners. The most basic form of radiant temperature is the thermal radiometer. This non-imaging device measures the radiant temperature using detectors sensitive to 8-14µm wavelengths.

Thermal scanners are imaging devices and are used for use in aircraft or spacecraft. The airborne scanner system consists of thee basic components - an optical mechanical scanning subsystem, a thermal infrared detector and an image recording subsystem Fig (1). Quantum or photon detectors are used as thermal detectors. These detectors operate on the principle of direct interaction between photons of radiation incident on them and the energy levels of electrical charge carriers within the detector material. For maximum sensitivity, the detector is cooled to temperature approaching absolute zero to minimize their own thermal emissions. Normally the detector is surrounded by liquid nitrogen at 77° K. Number of aerial scanners are available from various manufacturers with a spatial resolution ranging from 1 to 3 Km and a total field of view ranging from 30° to 120°.

The use of broad band thermal scanners from orbital platforms commenced with meteorological missions e.g. (TIROS, NOAA) having a typical spatial resolution of 1-5 Km. Later a thermal channel was included in missions like Heat Capacity Mapping Mission (HCMM) and Landsat TM. HCMM satellite carried Heat Capacity Mapping Radiometer as the sensor operating in the spectral range of 10.5 - 12.5µm, with a spatial resolution of 600m. Whereas for Landsat the sensor used is TM (Thematic Mapper) working in the spectral range 10.4 - 12.5 µm (band 6) with a spatial resolution of 120m.

Table 3: Characteristics of images from HCMM and Landsat TM satellites

	HCMM	**TM**
Operational period	1978-1980	1982 to present
Orbital altitude	620 Km	705 Km
Image coverage	700 by 700 Km	185 by 170 Km
Acquisition time, day	1:30 p.m.	10:30 a.m.
Acquisition time, night	2:30 a.m.	9:30 p.m.
Visible and reflected IR detectors		
Number of bands	1	6
Spectral range	0.5 0 - 1.1µm	0.4 - 2.35 µm
Ground resolution cell	500 by 500 m	30 by 30 m
Thermal IR detector		
Spectral range	10.5 - 12.5 µm	10.5 - 12.5µm
Ground resolution cell	600 by 600 m	120 by 120m 60m by 60 m in Landsat 7

CHARACTERISTICS OF IR IMAGES

i) Scanner distortion:

Thermal scanners, like all remote sensing instruments generate geometric errors as they gather data. Some errors are caused by aircraft instability. As aircraft rolls and pitches, the scan line lose their correct positional relationship Fig.2

Thermal imagery also exhibits relief displacement. Like aerial photographs thermal imagery do not have a central perspective but rather a separate nadir for each scan line. Thus relief displacement is projected from a line that follows the center of the long axis of the image. At the center of the image the sensor views the object directly overhead and planimetric positions are correct. As the distance from, the central line increases; sensor tends to view the side rather than the top of the features. Fig 3 (a & b).

The scanning mirror rotates at a constant angular rate but the imagery is recorded at a constant linear rate, the projection of the IFOV onto the ground surface does not move (relative to the ground) at equal speed because of varied distance from the aircraft to the ground. At nadir the sensor is closer to the ground than at the edge of the image, resulting in image compression toward the edges. This effect is known as tangential scale distortion Fig 3(c). Images near flight line are more circular, whereas shapes of those nearest the edge of the image are compressed along the axis perpendicular to the flight line. IR imagery, initially recorded as signals on magnetic tape, may be processed during printing on photographic film to correct for such scanner distortion.

ii) Image irregularities:

Aircraft roll, if not corrected by gyro systems, may cause wavelike distortion in the imagery. Transmissions from aircraft radios may cause strong interference patterns on images. During processing of image film, the faulty alignment of pressure rollers may cause developer streaks. During interpretation, all the above irregularities should be kept in mind otherwise they may be considered as thermal anomalies.

iii) Film density and recorded temperature range:

The density change on the film is linear over a relatively narrow range of temperature. Above and below this narrow temperature range, large temperature differences produce only slight density differences. Hence, a thermal mapping system using film as a recording medium does not measure absolute surface temperature but it can record temperature differences of a few degrees Celsius over a limited temperature range as distinguishable tonal differences on the film.

Effects of Weather on Images

1. **Clouds:** Typically have the patchy warm and cool pattern, where the dark signatures are relatively cool and bright signatures are relatively warm. Scattered rain showers produce a pattern of streaks parallel with the scan lines on the images. A heavy overcast reduces the thermal contrasts between terrain and cloud layer.

2. **Surface Winds:** They produce characteristic pattern of smears and streaks on images. Wind smears are parallel curved lines of alternating lighter and darker signatures that extend over wide expanses of the image. Wind smears and streaks can be avoided by acquiring images only on calm nights.

3. **Penetration of smoke plumes: Cloud** consists of finely dived particles of ice or water that have the same temperature as surrounding air. Images acquired from aircraft or satellites above cloudbanks record the radiant temperature of the clouds. Energy from the earth's surface cannot penetrate the clouds but is absorbed and re-radiated. Smoke plumes however consists of ash particles and other combustion products so fine that they are readily penetrated by relatively long wavelengths of thermal IR radiation. Visible image and thermal image acquired simultaneously during daytime flight over a forest fire, the smoke plumes completely conceals the ground in the visible image whereas the terrain features are clearly visible in the TIR image and the burning front of the fire has a bright signature. These images provide information about the fire location that cannot be obtained by visual observation through the smoke plumes.

INTERPRETATION OF THERMAL (RADIANT TEMPERATURE) IMAGERY - Common Responses

The interpretation of thermal data and images depicting temperature distribution over an area is not a simple, in many instances, efforts must be confined to looking for patterns of relative temperature differences rather than the absolute values because of the many complex factors that make quantitative determinations difficult, such as:

- Number and distribution of different material classes in the instantaneous field of view
- Variations in the angle of thermal insulation relative to sensor position
- Dependency of thermal response on composition, density and texture of the materials
- Emissivities of the surface materials
- Contributions from geothermal (internal) heat flux; usually small and local
- Topographic irregularities including elevation, slope angle, and aspect (surface direction relative to Sun's position)
- Rainfall history, soil-moisture content, and evaporative cooling effects near surface
- Vegetation canopy characteristics, including height, leaf geometry, plant shape
- Leaf temperatures as a function of evapotranspiration and plant stress
- Near surface (1 to 3 meters) air temperature; relative humidity; wind effects
- Temperature history of atmosphere above surface zone
- Cloud-cover history (during heating/cooling cycle)
- Absorption and re-emission of thermal radiation by aerosols, water vapor, air gases

Some factors have fixed or constant effects; others vary with each sensor overpass. It may be possible to correct for the influence of some of the variable factors but this is difficult to do routinely. Measurements made at isolated individual points in a scene and extrapolated to the general scene have limited validity.

Figure 4 shows the diurnal radiant temperature curves for water, vegetation and soils. The thermal inertia of water is similar to that of soils and rocks, but during the day water bodies have a cooler surface temperature than soils and rocks. At night the surface temperatures are reversed with water becoming warmer than soils and rocks. The reason is that convention currents maintain a relatively uniform temperature at the surface of the water body. Vegetation has a warm signature during nighttime and has a cooler signature compared to adjacent soils during daytime.

A quasi equilibrium condition is reached just before dawn, where the slopes of the temperature curves for these materials are small. After dawn, this equilibrium is upset and the materials warm up to a peak that is reached sometime in the afternoon. Maximum scene contrast occurs at this time and cooling takes place thereafter. Temperature extremes and heating and cooling rates can often furnish significant information about the type and condition of an object. For, e.g. the temperature curve for water is distinctive for two reasons. Firstly its range of temperature is quite small as compared to that of rocks and soils and secondly it reaches a maximum temperature an hour or two after the other materials. As a result terrain temperatures are higher than those of water during the day and lower than water temperature during the night. Shortly after dawn and near sunset, the curves for water and other features intersect. These points are called thermal crossovers and indicate times at which no radiant temperature difference exists between two materials. For proper interpretation of the IR thermal imagery, the time of acquisition should be known as the signatures vary during day and night.

Qualitative image interpretation is based on the usual elements of photo-interpretation. Some typical features commonly seen on the radiant temperature images are discussed below

1) **Topography:** Topographical features are enhanced on daytime thermal images due to differential heating and shadowing. The hill slopes facing the sun receive more solar energy than those sloping away from it, and some of the hill slopes may lie in the shadows, owing to rugged topography. These effects lead to local differences in thermal energy budgets and consequent kinetic temperature differences. However, on the nighttime images, the topography becomes subdued.

2) **Land surface (rocks and soils):** Becomes heated in the day and cools at night, thus showing temperature variations in a diurnal cycle.

3) **Standing water:** Relative to land, standing water appears brighter (relatively warmer) on the nighttime image and darker (cooler) on the daytime IR image. Although thermal inertia values of rocks and water are nearly equal, the unique thermal pattern of water is related to convection, circulation and evaporative cooling over water bodies. In the daytime, as temperature of the surface water rises, evaporation takes place and becomes stronger with increasing temperature. Due to evaporation, energy is transported from the water to the air and water appears cooler. At night, as cooling of the surface water proceeds, convection brings warmer water from the depth of the surface, decreasing the net drop in temperature of surface water, and the water appears warmer.

4) **Damp terrain:** Moisture content present in soils directly affects thermal inertial values, and therefore influences thermal pattern in a day-and-night cycle. A damp terrain has a very different thermal response to either standing water or land. The moisture present in materials leads to evaporative cooling and therefore the temperature of damp terrain is generally quite low and the thermal contrast in the day and night images is also less.

5) **Metallic objects:** Have high solar reflectivity or in other words low emissivity, and exhibit low radiant temperatures. Metallic objects always appear dark (cool), day and night.

6) **Vegetation:** In general, is warmer on the nighttime and cooler on the daytime image, in comparison to the adjoining un-vegetated land. The daytime lower temperature is related to the transpiration process in the plants and the nighttime high temperature to the higher moisture content in leaves. Dry vegetation lying on the ground insulates the ground from the atmosphere and causes warmer nighttime and cooler daytime responses.

Interpretation of Day and Nighttime Thermal Image

Water appears cooler (darker) than its surroundings during the daytime and warmer (lighter) at night. The kinetic water temperature will change little during the few hours of elapsed time between these images. However the surrounding land areas have cooled considerably during the evening hours. Again, water appears cooler than its surroundings on daytime thermal images, except for the case of open water surrounded by frozen or snow covered ground where the water would appear warmer day and night. Trees generally appear warmer cooler than their surroundings during the daytime and warmer during the night. Tree shadows appear in many places in the daytime thermal image. Residential areas are visible in daytime image and are not noticeable in the nighttime image. Paved areas (streets and parking lots) appear relatively warmer both day and night. The pavement surface heats up to temperature higher than the surroundings during the daytime and loses heat relatively slowly at night, thus retaining a temperature higher than their surroundings.

Conducting IR Surveys

i) Time of day:

Thermal infrared scanners are used most frequently at night when there is no interference from reflected solar radiation. The usual flying time is just before dawn, when the effects of differential solar heating are at their lowest level.

Nighttime imagery is necessary for most geologic applications because the thermal effects of differential solar heating and shadowing are greatly reduced. On daytime images topography is typically the dominant expression because of these differential solar effects. As the radiant temperatures are relatively constant in the pre-down hours, thermal imagery obtained during such hours is preferable for interpretation purposes.

ii) Spatial resolution:

Spatial resolution of IR imagery depends upon the flight altitude and the instantaneous field of view of the detector. At an altitude of 2000m with an instantaneous field of view of 3 milliradians, the ground resolution becomes 6m. Flight altitude of 2000 m. is considered best for conducting IR surveys. IFOV typically ranges from 2-3 milliradians.

iii) Wavelength Bands

Thermal IR images may be acquired at wavelength bands of 3-5μm band corresponds to the radiant energy peak for temperatures of 600°K and greater that are associated with lava flows, fires and other hot features. The 8-14μm band spans the radiant energy peak for a temperature of 300°K. It is the ambient temperature of the earth having the radiant energy peak at 9.7μm. Hence 8-14 μm images are optimum for terrain mapping whereas 3-5μm images are optimum for mapping hot targets such as fires.

iv) Orientation & altitude of flight lines

Flight altitude influences image scale, lateral ground coverage and spatial resolution. For geologic projects, it is useful to know the regional structural strike or tectonic grain of the area in advance of an IR survey. It helps in determining the optimum orientation of flight lines. If flight lines are oriented normal to the regional strike, it may mask linear geologic features. Hence it is preferable to orient flight lines with or at an acute angle to the regional strike.

vi) Ground measurements

Weather and surface conditions play a large role in determining terrain expression on IR images. It may be useful to collect ground information on weather conditions, soil moisture and vegetation at the time of IR survey. Ground measurements are most valuable if they are made at localities that have image signatures.

ADVANTAGES OF THERMAL IMAGERY

Applications of Thermal infrared remote sensing can be broadly classified into two categories one in which surface temperature is governed by man made sources of heat and other in which it is governed by solar radiation. In the former case the technique has been used from airborne platforms for determining heat losses from buildings and other engineering structures. In the latter case, TIR remote sensing has been used for identifying crop types, soil moisture, measuring water stress, etc. Some of the applications areas of TIR remote sensing are given below

i) Geology:

Denser rocks such as basalt and sandstone have higher thermal inertia and on night thermal IR images they show warm signature compared to less dense rocks such as siltstone, cinders etc. Hence differentiation of rock types is possible. Faults may be marked by cooler linear anomalies caused by evaporative cooling of moisture trapped along the fault zone. Folds may be indicated by thermal patterns caused by out-crops of different rock types. Surface temperatures of volcanic terrain may be mapped.

ii) Military:

Military applications of thermal mapping are varied and often classified. Unusual concentration of troops, weaponry, military vehicles, jungle trails etc. can be identified by the tonal changes in the thermal imagery.

iii) Hydrology:

Cool underground springs that discharge into warmer courses of water may be discovered by thermal imagery. Hot industrial effluents that pollute water may be detected and the diffusion pattern may be mapped. Hot springs are clearly identifiable in IR imagery.

iv) Agriculture:

Thermal images have been utilized for the identification of crop species and soil types, for detecting crop diseases, for making animal censuses and for determining relative moisture content of various soils.

v) Botany:

Leaf temperatures can be remotely measured using 3 to 5μm band. Such knowledge is useful for assessing plant health, age, relative water supply or degree of irrigation. Thermal damage of frost damage to fruit groves can also be assessed.

vi) Forestry:

Forest fires beneath a forest cover story can be located with thermal IR. During extensive fires, damage caused can be assessed even under excessive smoke conditions.

vii) Heat Loss Surveys:

To survey heated buildings, factories and buried steam lines for anomalous hot spots that may indicate leakage and poorly insulated roofs.

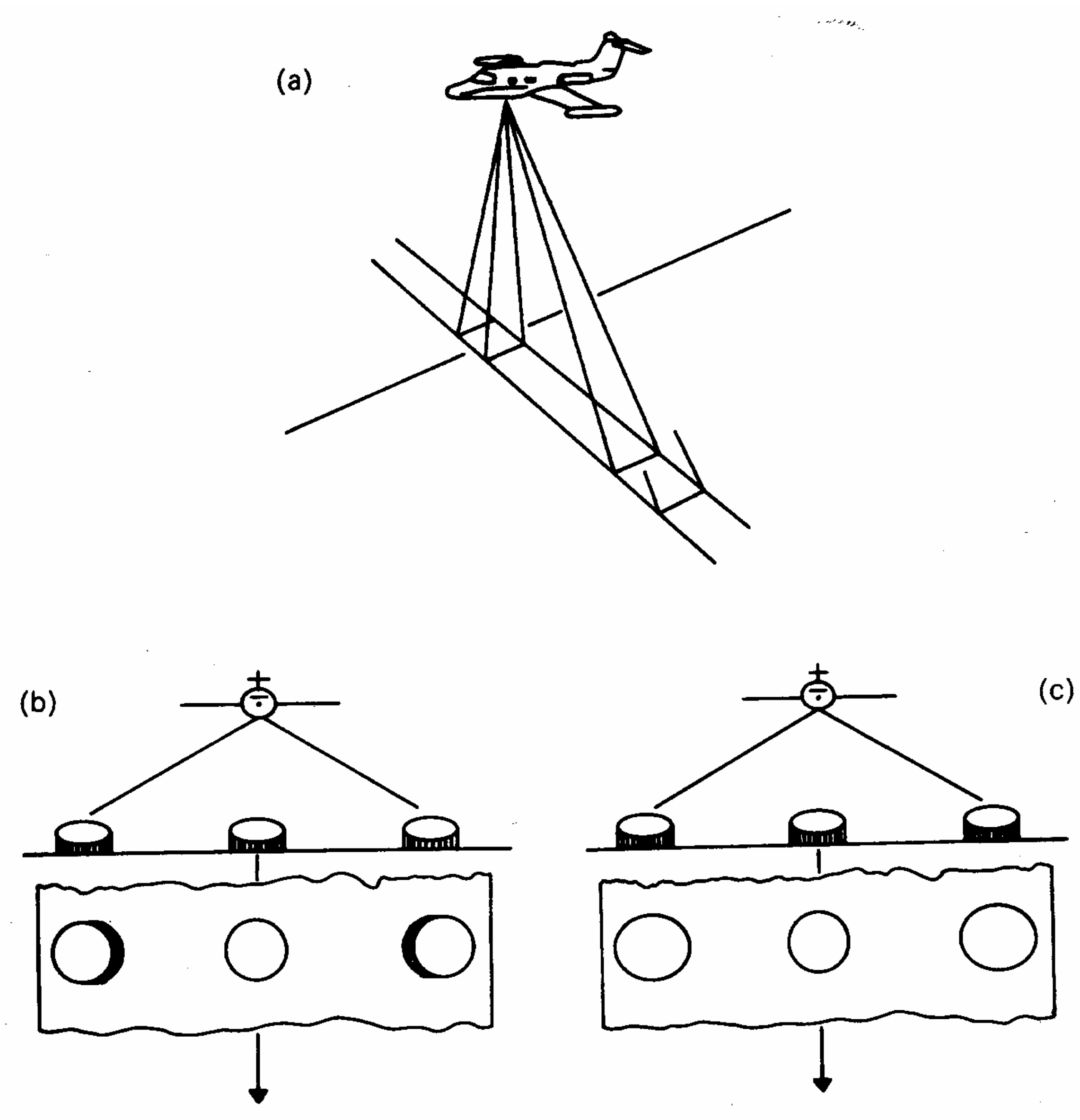

Figure 1: Relief displacement and tangential scale distortion.

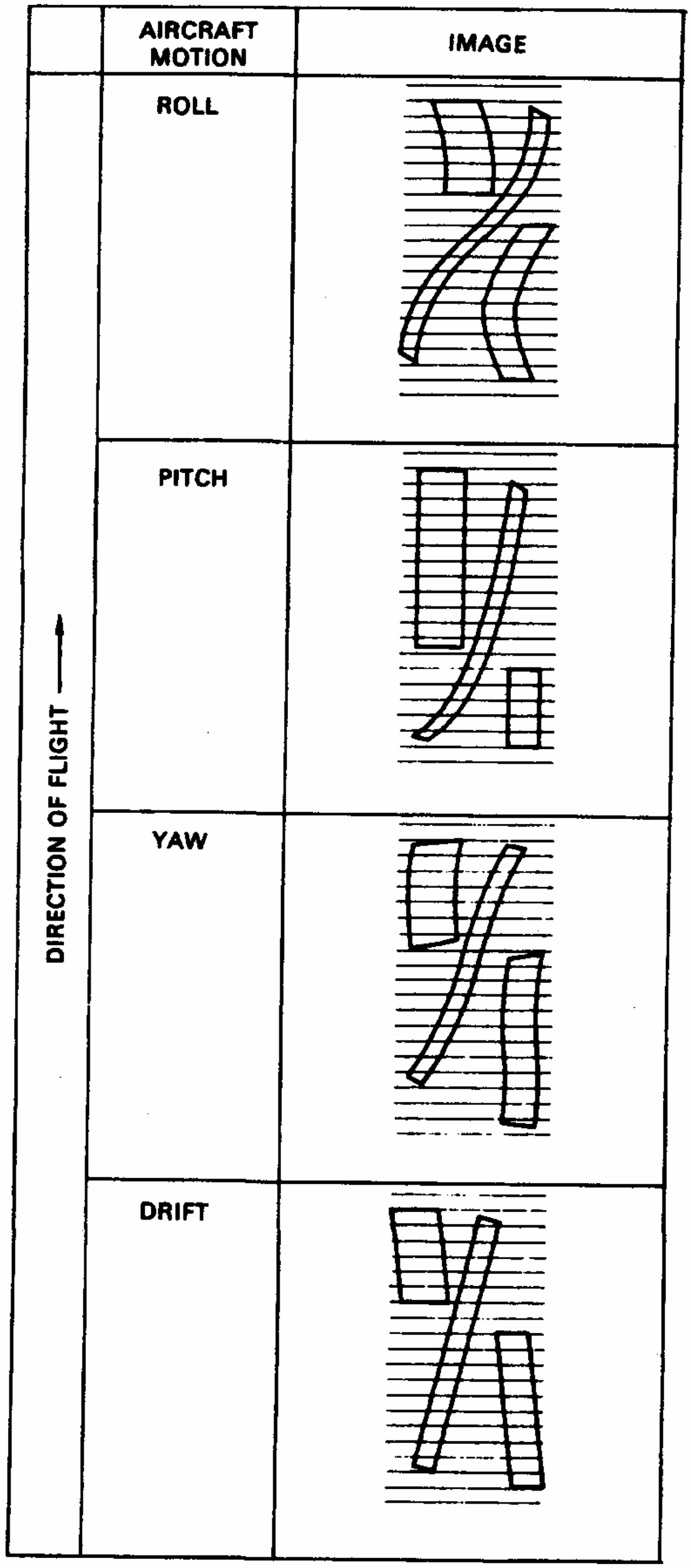

Figure 2: Geometric errors caused by aircraft instability

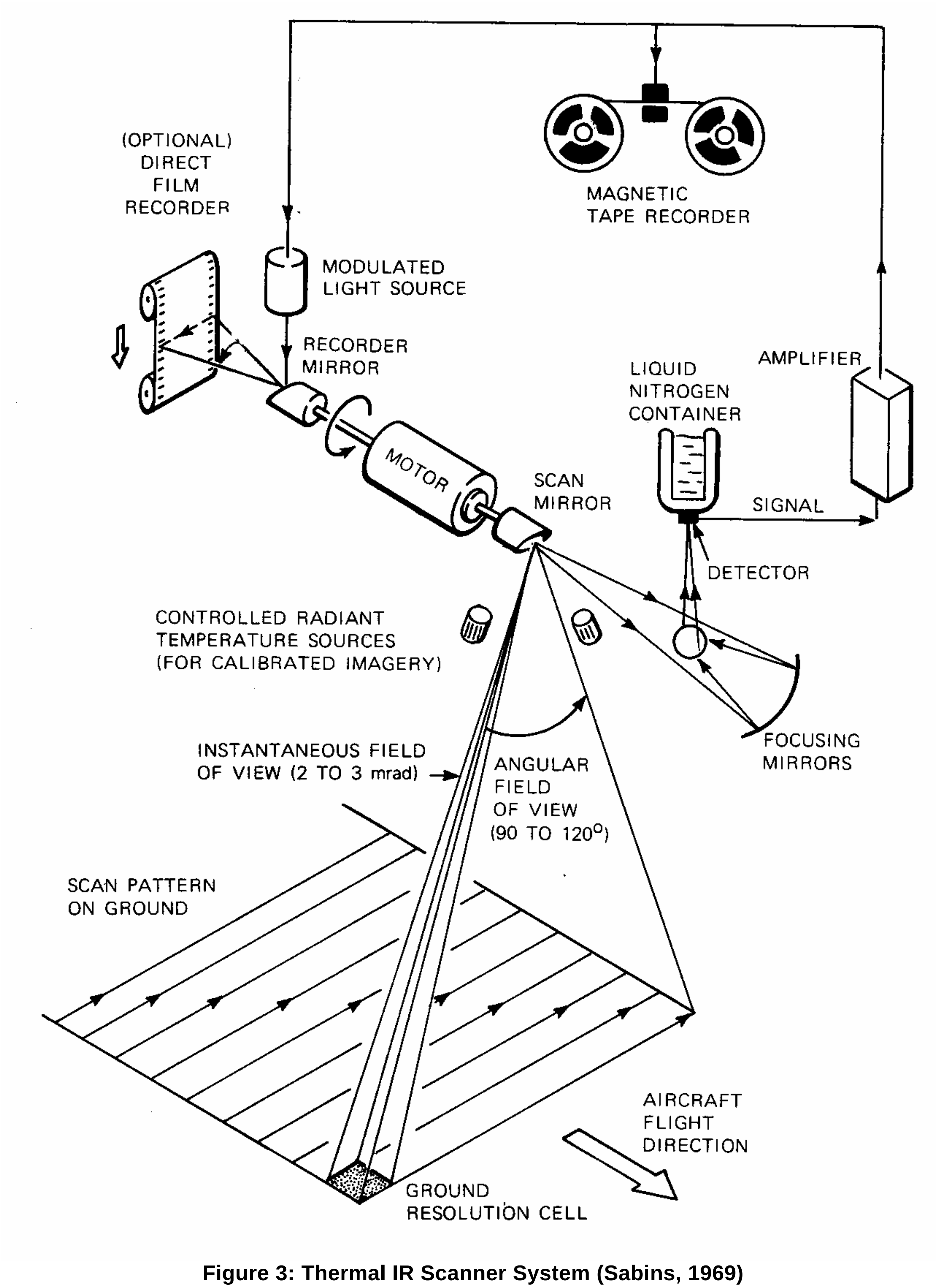

Figure 3: Thermal IR Scanner System (Sabins, 1969)

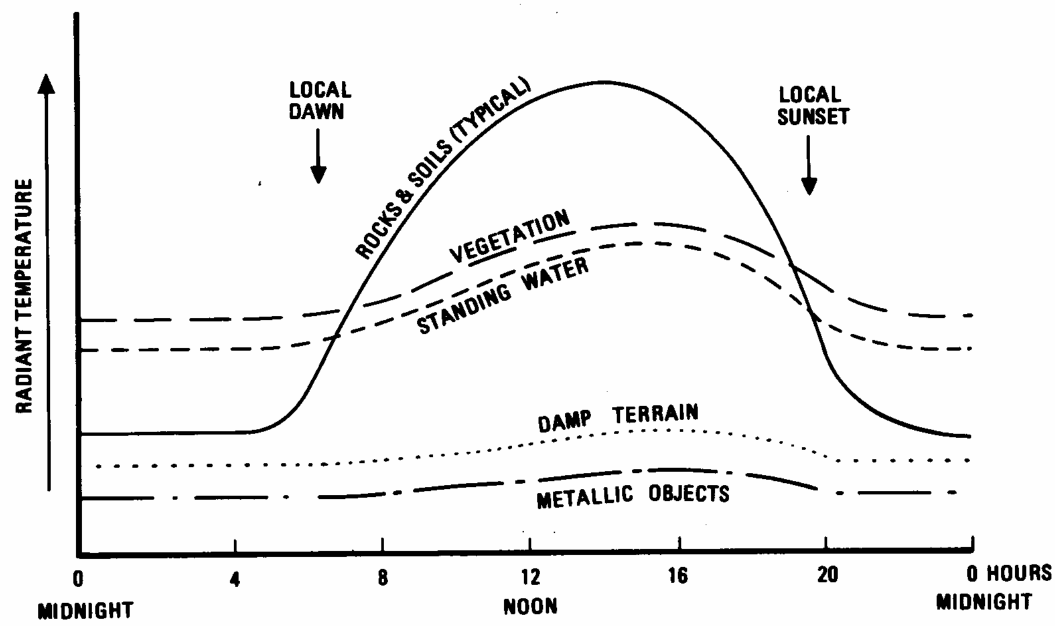

Figure 4: Diurnal Radiant Temperature Curves (Diagram for Typical material)