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Estimating Surface Temperature from Satellite Data

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Abstract: During last two decades, the extensive requirement of surface temperature (T_s) for environment studies and management of activities of the earth's resources has made the remote sensing an important academic topic. The availability of channels 4 and 5 of Advance Very High Resolution Radiometer (AVHRR) and Thematic Mapper TM 6, made possible for the retrieval of surface temperature (T_s) from satellite data. Various algorithms based on different local conditions do exist to estimate surface Temperature (T_s) from satellite data. The split window technique is used to estimate surface temperature (T_s) from channel 4 and 5 of NOAA-AVHRR, for Sindh Province, Pakistan. The slicing method is used to distinguish research area research. The low temperature is observed for water bodies and high temperature values for bare soil, desert and mountain areas. The results of Surface Temperature (T_s) are also compared with air temperature (T_a) for same period. The difference between T_s and T_a observed as realistic. The estimation of surface temperature (T_s) from satellite data will certainly help in many environmental studies and management activities of the earth.

Key words: Surface temperature, remote sensing, NOAA-AVHRR

INTRODUCTION

Surface temperature (T_s) is the skin temperature of the land surface. It is an important factor controlling most physical, chemical and biological processes of the Earth. The knowledge of Surface Temperature is essential for many environmental studies and management activities of the Earth's resources. It describes the equilibrium between energy supply (radiation balance) and energy consumption (energy balance) as shown in Fig. 1. According to Bastiaansseen 1998, surface temperature is a key parameter of in the energy balance. The evaporation of water from soil and plant surfaces is a component of the surface energy balance and has practical value.

The heat balance equation can be expressed by the following two equations:

$$Rn = R_S^{\downarrow} - R_S^{\uparrow} + R_L^{\downarrow} - R_L^{\uparrow} \qquad \text{(radiation balance)}$$
$$Rn = Go + H + \lambda E \qquad \text{(energy balance)}$$

Where "Rn" is the net radiation, "R_S" is the shortwave (0.3-3 μm) radiation, "R_L" is the longwave (3-10 μm) radiation, "Go" is the soil heat flux, "H" is the sensible heat flux and "λE" is the latent heat flux. The arrows show the direction of the flux entering "↓" or leaving "↑" the system. All units are expressed in [watt.m^{-2}]. The influences of the above balance equations on the surface temperature are described in Fig. 2.

The partition of energy between the terms is largely controlled by the availability of water in the system. Consider a closed canopy of crop, when moisture in not restricted, "λE" reaches maximum, "H" tends to zero and as a result the surface temperature will be very low. This is the case of maximum evapotranspiration. When a crop is suffering from water shortage, it closes its stomata and transpiration is then reduced. Now, more energy is available for the sensible

heat and canopy temperature rises as a result[1]. From this discussion, it can be seen that the surface temperature can be a good indicator of the soil moisture content[2].

The surface temperature (T_s) can also be a good indicator of land cover. Generally speaking, because of soil water extraction by plant roots, plants make water available for evaporation and hence their daytime surface temperature reduces relative to bare soil. In practice, diurnal temperature changes are used in landcover assessment. Fuchs and tanner[3], recognized that the surface skin temperature of crops was informative for growing conditions. As during daylight hour, plants

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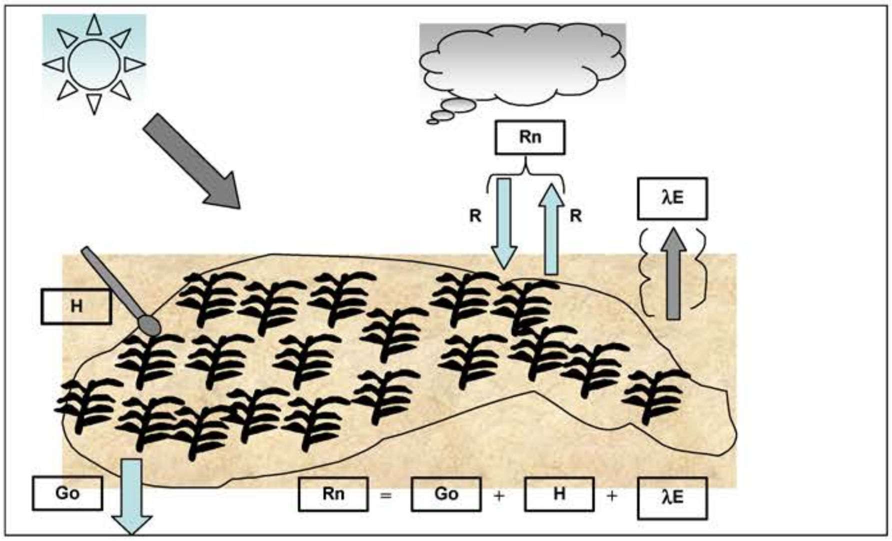

Fig. 1: The energy balance components

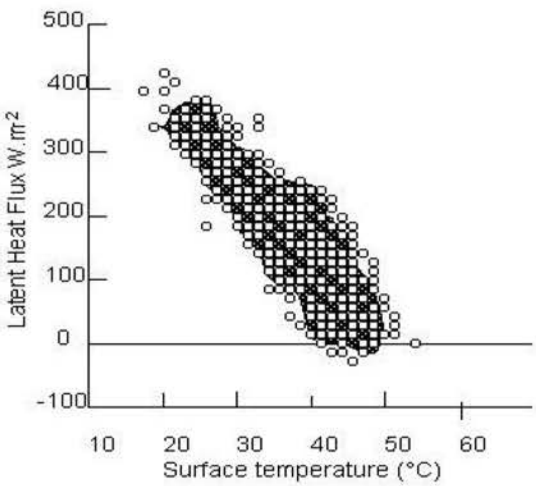

Fig. 2: The relationship between surface temperature (T_s) and Latent heat flux

leaves are cooler than the exposed bare soil because the heat capacity of plant leaves is much lower than the heat capacity of soil.

Remote sensing application: During last two decades, the study of surface temperature (T_s) has become one of the hottest topics in remote sensing. Scientist all over the world, carried out many studies on surface temperature (T_s) and the related ground emissivity from both technological aspects and application to specific areas[4-14]. The main force of deriving the study of surface temperature (T_s) in remote sensing is the extensive application and significant importance of temperature in environmental studies. The achievements of the studies are abundant. Thanks to the availability of thermal sensing data such as channel 4 and 5 of Advanced Very High Resolution Radiometer (AVHRR) data as well as Landsat Thematic Mapper 6 (TM6). Various algorithms have been developed for the remote sensing of surface temperature (Ts), with the development of remote sensing science. These algorithms and methods are based on different considerations and are suitable for different conditions. In this paper, the methodology is presented to estimated surface temperature from satellite data for southern Sindh province Pakistan.

MATERIALS AND METHODS

The NOAA satellite data for ten months (Rabi and Kharif) were received from the United States Geological Survey, EROS Data Centre and the European Space Agency. The satellite system contains AVHRR (Advanced Very High Resolution Radiometer). The AVHRR data set is made up of 5-channel, 10-bit, raw AVHRR data from each daily afternoon pass of NOAA. This global data set is acquired in the form of 10-days composite (Table 1). This also allows cloud free data. Integrated Land and Water Information System (ILWIS,) GIS/RS software developed by ITC Netherlands, with image processing capabilities is used for data processing.

Since the data in the channels are scaled, the following method used to for unscaling the data:

$$\text{Actual} = \frac{(\text{Scaled} - \text{Offset})}{(\text{Scale} - \text{Shift})}$$

The split window technique: Since NOAA-AVHRR acquires data in two spectral bands 4 and 5, within the thermal infrared window region, the atmospheric

Table 1: AVHRR data description and parameter used for unscaling data

Channel	μm	Units	Offset	Scale	Shift
1	0.58-0.68	%	10	10	0
2	0.725-1.10	%	10	10	0
3	3.55-3.93	Kelvin	10	5.602	-160
4	10.3-11.3	Kelvin	10	5.602	-160
5	11.5-12.5	Kelvin	10	5.602	-160

correction in the thermal infrared range was established by split-window technique, being purely developed for plural thermal bands. This technique corrects for atmospheric effects based on different absorption properties of water vapor in two spectral bands[15]. The difference between band 4 and 5 is considered in this approach as an indication for atmospheric heat absorption:

$$T_0^R = T_4 + C_1 (T_4 - T_5) + C_2 \qquad (K)$$

where; T_0^R is the surface radiation temperature, T_4 and T_5 are the temperatures in band 4 & 5 respectively and C_1 and C_2 are empirical coefficients, depend on atmospheric state and spectral emissivities of the surface[16]. The coefficient values C_1=2.78 and C_2=16, were found suitable and used in this research.

The thermodynamic temperature of the surface T_0 requires the correction of emissivity, which can be estimated empirically from NDVI as;

$$\epsilon_0 = 1.009 + 0.047 * \ln(NDVI)$$

Normalized Difference Vegetation Index (NDVI) estimated from AVHRR channels 1 and 2 after atmosphere corrections and the values for NDVI are in practice between 1 (high biomass) and -1 (water).

$$NDVI = \frac{(rnir - red)}{(rnir + red)}$$

rnir, is the measured surface reflectance in the near infrared band.
red, is the measured surface reflectance visible band

Finally, by using non-linearity between temperature and radiation, Surface Temperature (T_s) calculated from T_0^R and ϵ_0. Mathematically expressed as;.

$$T_s = \sqrt{\frac{(T_0^R)^4}{\varepsilon_0}} \qquad (K)$$

RESULTS AND DISCUSSION

The minimum values of surface temperature (T_s) for all months were obtained from water bodies i.e. Mancher and Keenjar Lakes (Table 2). The maximum values of T_s are observed from desert area (Thar Desert), bare soil and mountain areas (Dadu Districts). The median values of surface temperature (T_s) represent the vegetation in the basin.

Table 2: Results of surface temperature (T_s) estimated from satellite data

Month	Min	Max °K	Med	Mean	Std
Apr-95	298.0	337.0	312.0	316.0	20.4
May-95	301.0	346.0	310.0	318.0	28.3
Jun-95	293.0	343.5	318.0	314.0	15.7
Aug-95	291.0	33.9	309.0	311.0	28.7
Sep-95	281.0	336.2	310.0	309.0	16.3
Oct-95	293.0	341.7	309.0	317.0	09.4
Nov-95	279.0	327.0	303.0	304.0	25.0
Dec-95	276.0	324.0	300.0	298.0	25.0
Feb-96	288.0	332.0	310.0	310.0	13.0
Mar-96	282.0	335.0	316.0	314.0	17.1

Table 3: Surface temperature (Ts) estimate from satellite data and observed air temperature (Ta)

Months	T_s (°K)	T_s (°C)	T_a (°C)
Apr-95	316.0	43.0	32.74
May-95	318.0	45.0	37.68
Jun-95	314.0	41.0	36.80
Aug-95	311.0	38.0	33.11
Sep-95	309.0	36.0	33.26
Oct-95	317.0	44.0	33.67
Nov-95	304.0	31.0	27.20
Dec-95	298.0	25.0	22.23
Feb-96	310.0	37.0	27.00
Mar-96	314.0	41.0	34.00

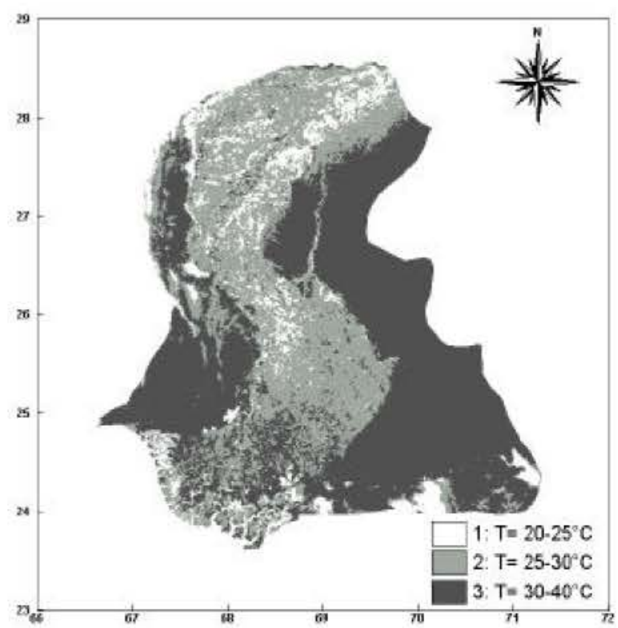

Fig. 3: Study area as imaged by the stellite NOAA AVHRR, showing surface temperature (Ts) for the

In Fig. 3, the satellite image for the 1995 of surface temperature (T_s) estimation is presented. Since the T_s

estimation from satellite data, gives results on pixel by pixel basis, therefore slicing method is used to distinguish Ts in three categories. The T_s between 20-25°C observed for water bodies and irrigated agriculture, T_s between 25-30°C is experimented for the basin (Vegetation) and Ts between 30-40°C is practice for bare soil, desert and mountain areas (Fig. 3).

The local surface temperature data was unavailable, however the results were compared with air temperature (T_a) data for the same period (Table 3). The difference of 5-10°C observed between surface temperature (T_s) and air temperature (T_a).

The main object of this study is to test the methodology for the retrieval of surface temperature (T_s) from satellite data. The NOAA-AVHRR satellite data for ten months were used in contest. The slicing is used to distinguish study area in three major temperature zones. The low temperature is observed for water bodies, medium temperature for basin (vegetation) and high temperature for non agriculture areas i.e. bare soil, desert and mountain areas. The results of surface temperature (T_s) are compared with air temperature (T_a). The Ta was found 5-10°C cooler than T_s, which is realistic. The results of this study are show that Satellite data can provide regionally and globally representative values for surface temperature (T_s), which is not possible from ground observations.

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