Seventh International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Range, Forest and Wetlands Assessment

June 23 - 26, 1981

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

PROBLEMS IN TEMPERATURE ESTIMATION FROM REMOTELY SENSED THERMAL IR DATA

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I. ABSTRACT

Through the comparison between temperatures estimated from remotely sensed data and those actually measured, we discuss causes of discrepancy between them. We apply regression analysis to the data and pay particular attention to regression coefficient which as a shole represents causes for the error. The coefficient obtained by taking ground truth data as independent variables and estimated temperatures as dependent variables tends to be less than 1. Atmospheric effect on the coefficient is studied, being based on a simple model. Vertical temperature profile, another possible cause for the tendency, is also discussed on the basis of laboratory experiments.

II. INTRODUCTION

Remotely sensed thermal infrared (IR) data give us information about temperature of terrain objects.[1] There are several papers dealing with the estimation from the data.[2] The validity of the technique is evaluated by goodness of the coincidence between estimated and actually measured temperatures. Some reported very good coincidence such as within 0.1 C, and some poor one. We examined it for several causes by using regression analysis. We point out causes for the discrepancy between estimated and measured temperatures, and pay particular attention to the regression coefficient which as a whole represents causes for the error. The coefficient obtained by taking ground truth data as independent variables and estimated temperatures as dependent variables has tendency to be less than 1. We discuss the causes for it by using an atmospheric model and laboratory experiments.

III. EXAMPLES OF COMPARISON

The thermal IR data for this study were obtained by an airborne multispectral scanner MSS-BG-I whose spectral band in thermal IR was 10.5 -12.5 um.

As ground truth were used bucket temperatures because we need a lot of measurements for the analysis, and radiometers for them are too expensive, and moreover the temperatures which we really want to know seem to be closer to those obtained by conventional method than to those by radiometers.

We will show examples of the realtion between ground truth and estimated temperatures. Fig. 1 (a) and (b) show the realtion for sea water. In the figure the solid line represents the line on which both temperatures are equal, and the dotted line the regression line.

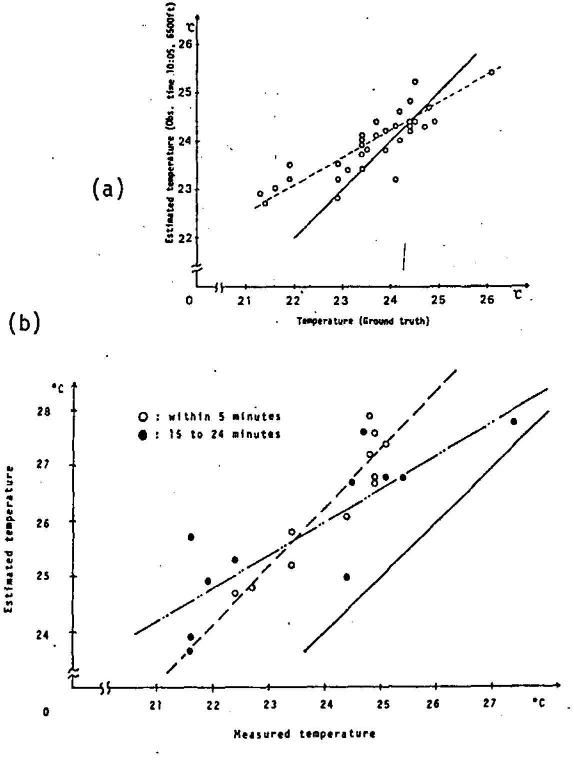


Fig. 1 Ground truth and estimated temperatures

The results of this and some other cases are summarized as follows:

(i) Correlation coefficients between remotely sensed data and ground truth were very high, and were very often statistically significant.
(ii) The inclination of regression line was different from one case to another.
(iii) A tendency was seen that the inclination is less than 1.
(iv) The coincidence in absolute temperature between estimated temperatures and ground truth was not very good.

IV. CAUSES FOR DISCREPANCY

Causes for the discrepancy between the ground truth and estimated temperature are considered as follows: (1) Errors included in the remotely sensed data themselves. (2) Errors included in ground truth. (3) Errors included in the process to obtain the temperature estimate from remotely sensed data. (4) Errors due to effects of atmosphere intervening between remote sensors and terrain objects. (5) Errors due to relative differences between remote sensing and ground truth experiments (in other words, ground truth is not necessarily "truth" from a stand point of remote sensing.)

Systematic errors in (1) and (2) can be eliminated by calibration. Item (3) includes errors by linear interpolation, and estimation of emissivity of objects or transmittance of atmosphere. Item (4) is discussed later.

Item (5) is broken down into (a) Saptial difference: 1) Difference in positioning when finding ground measuring points in thermal IR images. 2) Difference in measuring area. A pixel of the image covers some area. Ground truth is usually obtained in a smaller area. 3) Vertical profile: Thermal IR images represent only surface temperatures. Ground truth data are generally obtained under the surface. (b) Temporal difference: To get an accurate coincidence in time between remote sensing and ground truth is almost impossible. (c) Difference of instruments: Difference of system characteristics (for example, observation spectral bands and dynamic characteristics) between remote sensors and instruments for ground truth may cause errors.

V. DISCUSSION

A. ATMOSPHERIC MODEL

By assuming that the relation between true temperatures T(K) which ground truth is assumed to represent and estimated temperature Ta is linear within a narrow range of temperature, say 20° to 30°C, we will get the inclination of the line dT_a/dT from a model.

The model we used is quite simple as shown in Fig. 2. In this model atmosphere is described as a thin layer at an effective temperature To and with transmittance τ and emissivity $(1-\tau)$.

We approximate the radiant emittance from a black body at T(K) by αT^β (See Appendix). Let the emissivity of a terrain object be ε (assumed constant over the wave range considered). Then

$$\alpha Ta^\beta = \varepsilon\,\tau(\alpha T^\beta) + (1-\tau)(\alpha To^\beta) \qquad (1)$$

Let

$$(1-\tau)To^\beta = C^\beta = \text{constant} \qquad (2)$$

Eq. (1) can be rewritten as

$$Ta^\beta = \varepsilon\,\tau T^\beta + C^\beta \qquad (3)$$

$$dTa/dT = \varepsilon\,\tau(T/Ta)^{\beta-1} \qquad (4)$$

By using eqs. (1), (3) and (4)

$$dT_a/dT = (\varepsilon\tau)^{1/\beta}[1-(1-\tau)(To/Ta)]^{1-1/\beta} \qquad (5)$$

If we assume that To = Ta, then

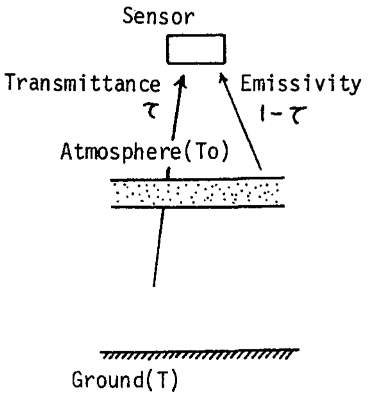
$$dTa/dT = (\varepsilon\tau)^{1/\beta}\,\tau^{1-1/\beta} = \varepsilon^{1/\beta}\,\tau \qquad (6)$$

When T = To with $\varepsilon = 1$, it follows that $T_a = T$.

Therefore for the object such as water which is regarded as black body, the regression line is expected to be one shown by dotted line in Fig. 3.

B. LABORATORY EXPERIMENTS

We tried laboratory experiments using water to know the relation between surface temperature estimated from remotely sensed data and bulk temperature obtained as bucket temperature. In the experiments an infrared radiometer was used to get the surface temperature, and a mercury thermometer or thermocouples submerged into the water to get bulk temperature.



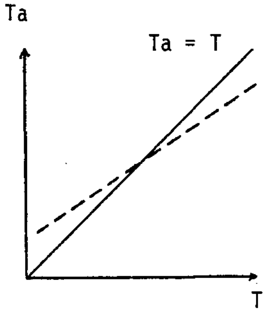


Fig. 2 Atmospheric model
Fig. 3 Ta versus T

Figs. 4 and 5 show the temperature profile and the relation between surface and bulk temperatures, respectively, when the water was stirred (a), and allowed to stand (b). Fig. 6 shows the effect of wind on surface temperature. The bulk temperature was measured at about 15mm under the water surface. Fig. 7 shows a temporal change in the temperature of the surface without (a), (b) and with (c) oil slick since the wind started blowing. Fig. 8 shows the effect of illumination. The illumination was done by an electric bulb (500W) 50 cm above the surface. The temporal changes of the temperature at the surface and at 15mm under the surface are shown. Fig. 9 shows the effect of wind and oil slick on the water surface temperature.

VI. CONCLUSION

Through the comparison between estimated temperatures from thermal IR data and ground truth, we pointed out causes for the discrepancy between them, and discussed one of the problems by using an atmospheric model and laboratory experiments. To determine T_0 in the model and to examine reproductibility of these results in various cases are the subjects for the future study. The results shown above indicate that it is not meaningful to pursue absolute and precise measurement of temperature for terrain objects by means of remote sensing. We have studied this problem to evaluate the feasibility of the technique.

The data we used in this study were supplied by Japan Research Committee of Environmental Remote Sensing (JACERS).

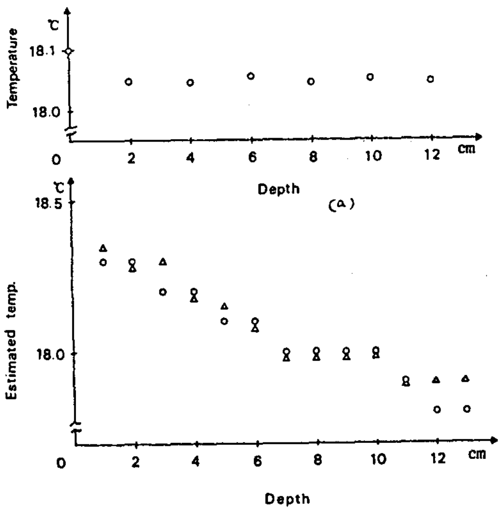


Fig. 4 Vertical temperature profile, (a) stirred and (b) allowed to stand

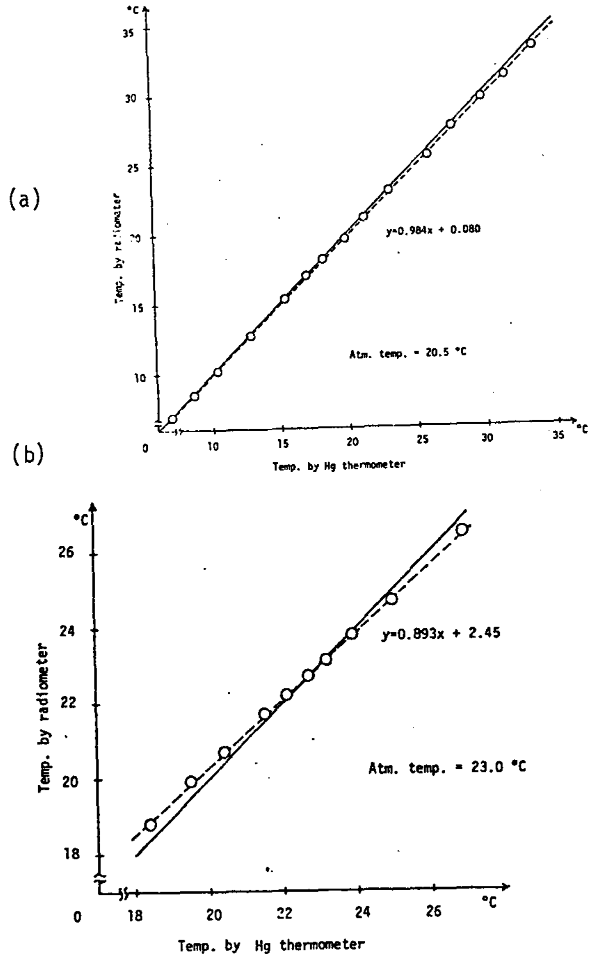


Fig. 5 Surface and bulk temperatures, (a) stirred and (b) allowed to stand

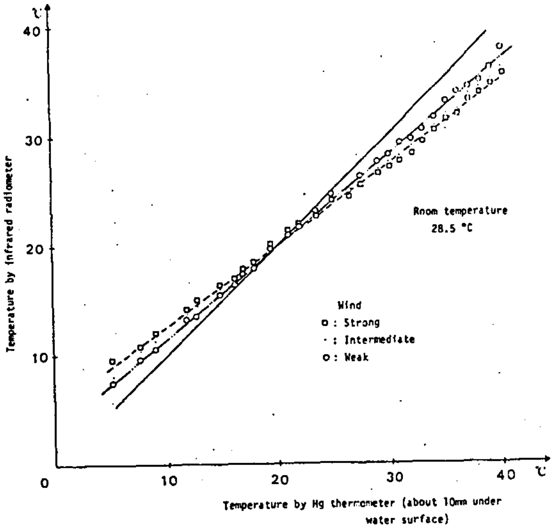


Fig. 6 Effect of wind

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APPENDIX

We approximate the radiant emittance from the black body at T(K) by αT^{β}. We determine the exponent factor for a narrow range of temperature by regression analysis between log(t) and log[q(T)] (Fig. 10), where T is the absolute temperature, and q(T) is given by

$$q(T) = \int_{\lambda_1}^{\lambda_2} \nu(\lambda) W_{\lambda}(T) d\lambda$$

and

$$W_{\lambda}(T) = C_1 \lambda^{-5} [\exp(C_2/T)-1]^{-1} .$$

The inclination of the regression line determines the factor. Table 1 shows the factors for several spectral bands and different shapes of filters $\nu(\lambda)$, rectangular, sinusoidal and Butterworth.

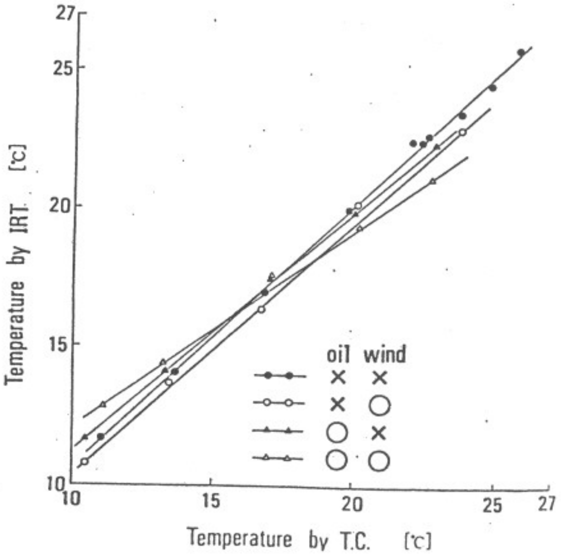

Fig. 9 Effect of wind and oil

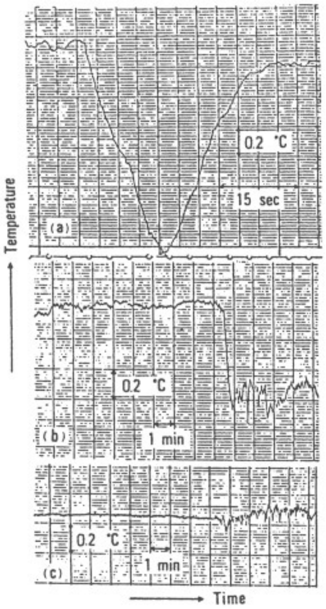

Fig. 7 Temporal change of surface temperature due to wind

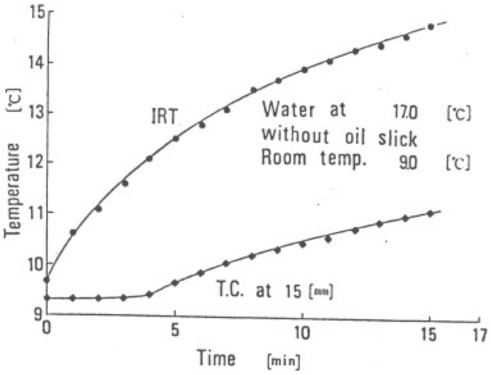

Fig. 8 Effect of Illumination

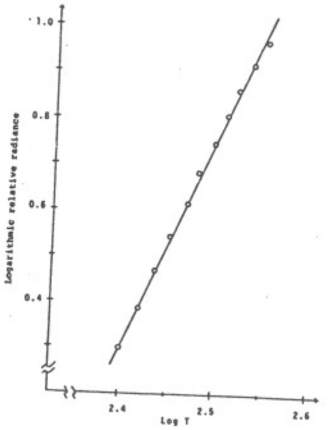

Fig. 10 Log q(T) vs log(T)

Table 1 Exponent factors

P / Wavelength (μm)	A	B	C
	⊓	⌒	⊓
8 -14	4.59	4.52	4.57
9.5-12	4.56	4.54	4.58
10.5-12.5	4.27	4.26	4.27
4.3- 5.5	9.64	9.71	9.65
4.5- 4.9	10.2	10.2	10.2
2.1- 2.4	20.9	21.1	20.6

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