ESTIMATION OF AIR TEMPERATURE USING REMOTE SENSING, BASED ON THERMAL DIFFUSIVITY APPROACH

M. ROKHIS KHOMARUD1N[1], AHMAD BEY[2], AND IUUNG RISDlYAVTO[2]

Abstract

The measurement of air temperature usually used thermometer in the meteorology or climate station under Bureau of Meteorology and Geophysics. In Indonesia, there are some limitations in air temperature measurement and then they could not provide the spatial high resolution information. The measurement of air temperature is very important for analyzing the human comfort, photosynthesis, and vegetation growth which we need some details spatial information. However, when data were sparse, the underlying assumptions about the variation among sampled points often differed and the choice of interpolation method and parameters then became critical. Often though data may be too sparse to use any of the interpolation methods, alternate ways to derive spatially representative values of air temperature need to be researched. The data thai could provide spatial information are remote sensing. The objective of this research is to estimate air temperature using remote sensing data (NOAA/AVHRR and LANDSAT/TM), based on thermal diffusivity approach. The steps of this research include the calibration of surface temperature, the determination of amplitude, and the estimation of air temperature. Based on this research, the best equation to calculate surface temperature from NOAA AVHRR is Ulivicri *et at* equation. This equation shows the higher correlation between surface temperatures from NOAA/AVHRR and the observation in the field than the other equation. Physically, this research could estimate air temperature from satellites data, but statistically, this research has not enough significancy to describe the field observation.

Keywords : physical model, temperature, remote sensing.

I. Introduction

Air temperature describes the energy content of air, but not all energy could describe by temperature. For example, the increasing of latent heat flux could not increase air temperature, but decrease it, instead. This is caused by the proportion of sensible heat flux decrease. Sensible heat flux depends on the differences between surface temperature and air temperature, air density, heat capacity, and the aerodynamics resistance. Because the sensible heat flux depends on them, so does the air temperature. The heat transferred from surface temperature to the atmosphere | through the media. This media is called the air. The heat that is transfer through | this media has a specific characteristic. For all the transfer law. Campbells (1977) J called these characteristics with thermal I diffusivity.

The measurement of air temperature usually used thermometer in the | meteorology or climate station under) Bureau of Meteorology and Geophysics, j In Indonesia, there are some limitations of I air temperature measurement and they could not provide the spatial information.

I. LAP AN. Jain I.APAN 70 Pekayon Pasat Rebo Jakarta Timur Tclp'Fax : +62 21 8710065/+62 21 8710274
Email: ayah_a 1 c'«,y.thoo-com.
i. Dcpanemen Cicofisika clan Mctcorologj - IPB Jl. Raya Damiaga - Bogor Telp/Fax: +62 251 623830
Kmail: ahmadbcyfa indo.nei.id and *iA\m^r\^a-\ahoo.com*

For example, in Surabaya, Gresik, and Sidoarjo have only three stations that measure air temperature. So, they could not explain the air temperature in the whole area and the districts. The measurement of air temperature is very important for analyzing the human comfort, photosynthesis, and vegetation growth. For that purpose, we need some details spatial information. The data that could provide spatial information are those derived from remote sensing.

Data from remote sensing are, among others, good for the large area, need small observations, and provide the historical data. Good for large area means that remote sensing data could capture the large area. LANDSAT-TM could capture 185x185 km2 in one picture and NOAA/AVHRR could be 2800 x 2800 km2, or near % of Indonesian areas. If we compare with the manual measurement from climatology station, remote sensing data are more effective. Despite the benefits, remote sensing data have some limitations, that is the condition when the sky is cloudy. For Landsat-TM, the data are not captured daily.

Some research to estimate air temperature from satellite have been developed by Dong (2004) with Neural Network model, Sun *et al.* (2004) with thermodynamics models, and Han *et al.* (2003) with the multiple regression model. Only Sun *et al.* (2004) has physical approach to estimate air temperature. Neural network model and the regression model can only explaine the influence of some parameters to air temperature, but they do not explained physically. The inputs of these models have a lot of things and very complex. Based on the previous study, this research will try to estimate air temperature with little parameters, not complex, and easy to do.

II. Methods

a. The data and material

Data used in this research are from NOAA/AVHRR, 9 June 2004 until 5 July 2004 which cover Surabaya, Gresik, and Sidoarjo. The observation for surface temperature, air temperature, albedo, and wind speed was conducted in the same time with NOAA/AVHRR acquisitioned. The observation is hourly from 07:00 to 16:00 Western Indonesian Time (WIT) in the different land use. The one hour interval was used for determination amplitude of maximum and minimum temperature difference. The Softwares used in this research are Ermapper 5.5., Arcview 3.2., and Minitab for Windows 11.0 for statistical analyses. The weather in the field was measured using infrared thermometer to measure surface temperature, thermometer with thermocouples sensor, and the albedometer.

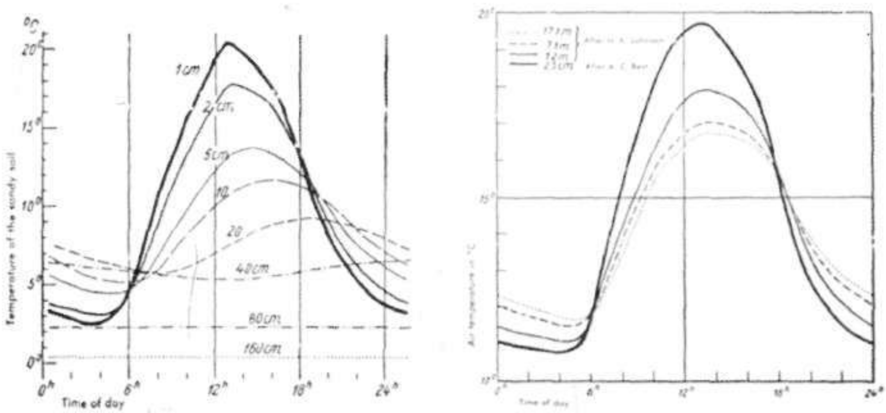
b. Estimation of air temperature

The element from satellite used to estimate air temperature in this research is surface temperature. Physically, surface temperature influences air temperature above the surface. It is because there is heat transfer form surface to the atmosphere. ' The equations used to estimate air temperature based on surface temperature are as follows (Geiger, 1959; Campbell, 1977; Oke, 1978; Arya, 1988; Monteith and Unsworth, 1989):

$$T(0,t) = \overline{T} + A(0)\sin\omega t \quad ....(1)$$

$$T(z,t) = \overline{T} + A(0)\,e^{-z/D}\sin(\omega t - z/D) \quad ....(2)$$

T (0,t) is surface temperature in the specific time (°C), calculated by Ulivieri *et al.* (1994) or Coll *et al.* (1994) or Price (1984). This research will find equations that have the best correlations with the observation.
T (z,t) is temperature at height z and time t.
A(0) is the amplitude (the distance between maximum and minimum surface



(a) (b)

(b)

Figure 1. Temperature pattern (a) below the surface and (b) above the surface

temperatures to the average) (Tmax = r+A(0), and Tmin = T-A(O)); co is the angular frequency of the oscillation $\left(\frac{271}{t}\right)$ (s^{-1}); D is *damping depth depends on thermal diffusivity* (m); $D=\left(\frac{2\kappa}{\omega}\right)^{1/2}$, and K is thermal *diffusivity* ($m^2 s^{-1}$).

The equations above usually are used to estimate temperature at the soil depth. Those equations are also used in this research to estimate air temperature because the temperature above surface have relatively same pattern with temperature in the soil depth (Geiger, 1959). Figure 1 depicts the temperature pattern above and below the surface.

c. Determination of Amplitude and **Thermal diffusivity**

The amplitude of surface temperature has different value in the different surface/landuse. For example, the water surface has smaller amplitude than bare surface. In the water surface, the changes of temperature are slower than that in bare surface because of the characteristics and heat capacity of the surface. In this research, we measure surface and air temperatures at one hour interval. Based on the equation 1, we could make regression between T (0,t) as ordinate with sin *cot* as absis. The slope of this equation is amplitude, A (0). The time of this measurement are 9 June 2004 - 5 July 2004 with one hour interval from 07:00 until 16:00 WIT in the 3 different domination landuse (water, vegetation, and bare land/city). It was assumed that the maximum surface temperatures at Surabaya, Gresik, and Sidoarjo were at 12.00 WIT. •

To know the damping depth value, we need to know the thermal diffusivity value in the air. For that purpose we checked 5 different condition of air. The condition are still and dry air at 30°C, still and moisture air at 30 °C, motionless very stable, motionless neutral, and motionless not stable. For teach result, we calculate, *Mean Square Error* (MSE) and the correlation. The condition of air that have smallest MSE and have highest correlation used to estimate air temperature in Surabaya, Gresik, and Sidoarjo. Table 1 shows thermal diffusivity value and *damping depth* (D) at each condition of air.

Table 1. Thermal diffusivity value and *damping depth* (D) at each condition of air

No.	Condition of Air	*Thermal diffusivity* (K) **mV**	*Damping Depth (D) (m)*
1.	Still, moisture, 30 °C	22,8 x 10 -°	0,79
2.	Still, dry, 30 °C	25,7 x 10 "b	0,84
3.	Motionless, very stable	0,001	5,23
4.	Motionless, neutral	1	165,52
5.	Motionless, unstable	10	523,42

Source: Monteith and Unsworth (1989) and Seller (1965)

III. Result and Discussion

a. Surface Temperature Calibration

The calibration of Ulivieri *et al*. (1994), Coll *et al*. (1994) and Price (1994) to calculate surface temperature between satellite comparison and surface temperature from observation describes in Figure 2.

Calibration result of the three equations explained that all equations statistically could be used to estimate air temperature but, the equation that have smallest MSE and have higher correlation is Ulivieri *et al.* (1994). Therefore, we can use the equations to estimate the air temperature.

b. Determination of Amplitude

The amplitude is very important element to estimate air temperature. Knowledge of this amplitude makes it easier to estimate air temperature in specific time. Figure 3a and 3b explained the result of determination of amplitude based on observation measurement. Figure 3a is the determination of amplitude in the different land use and Figure 3b explained the determination of amplitude based on surface temperature in specific time. The example is for calculation amplitude at 10:00 WIT.

c. Determination of Damping Depth (D)

Damping depth (D) is also important element to estimate air temperature. Table 2 shows the result of correlation and MSE calculation between estimated and observed air temperature.

The condition of airs that has smallest MSE and has highest correlation in this research is still and moisture air at 30°C. Figure 4 shows the regression between estimated and observed air temperature.

Table 2. Correlation and MSE between estimate air temperature and observation

Condition of Air	**r**	MSE
Still, Moisture, 30 °C	0,607	8,25
Still, Dry, 30 °C	0,608	7,21
Motionless, very stable	0,532	9,37
Motionless, neutral	0,490	17,21
Motionless, unstable	0,489	17,40

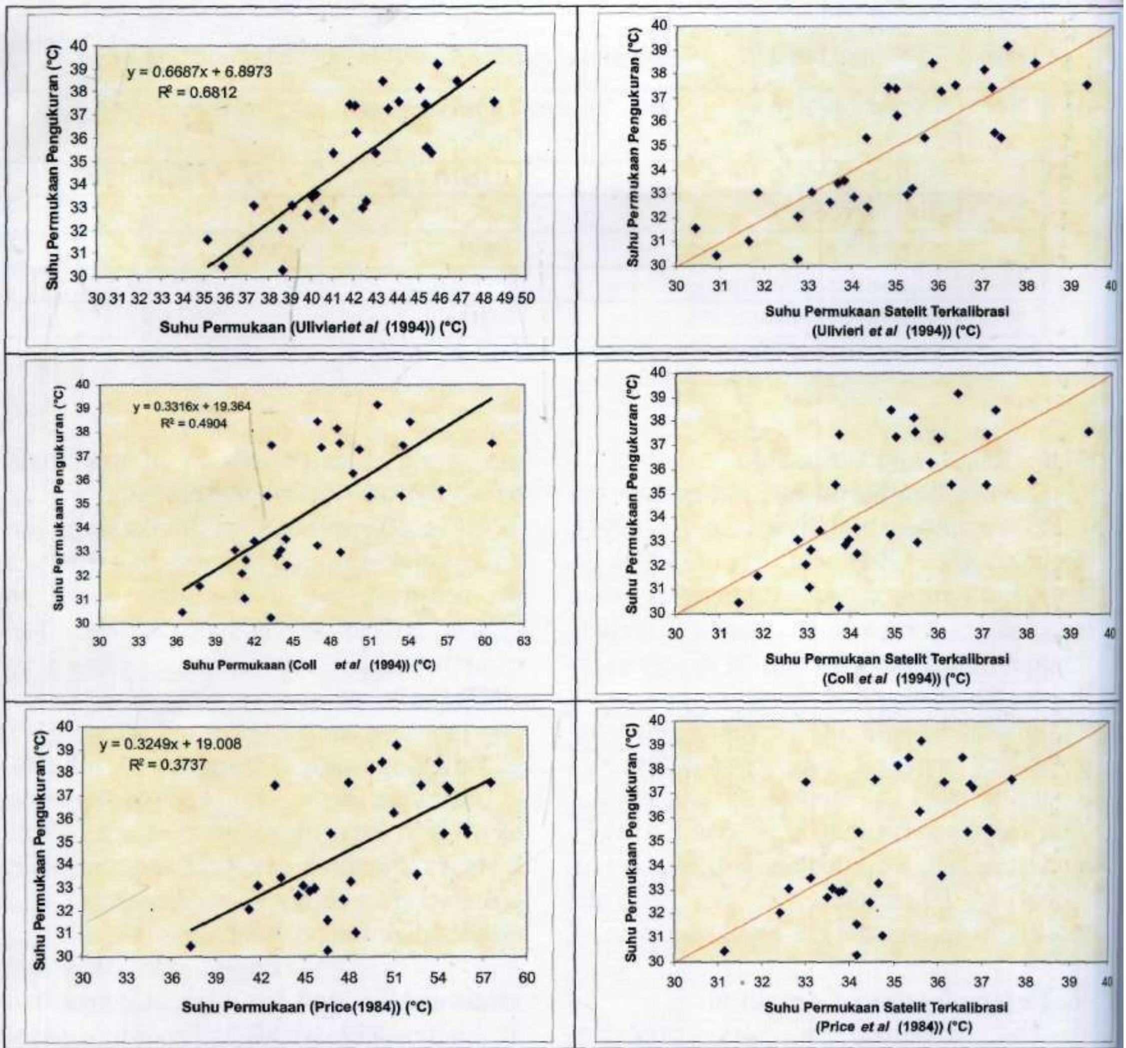


Figure 2. Calibration of surface temperature in the different equation

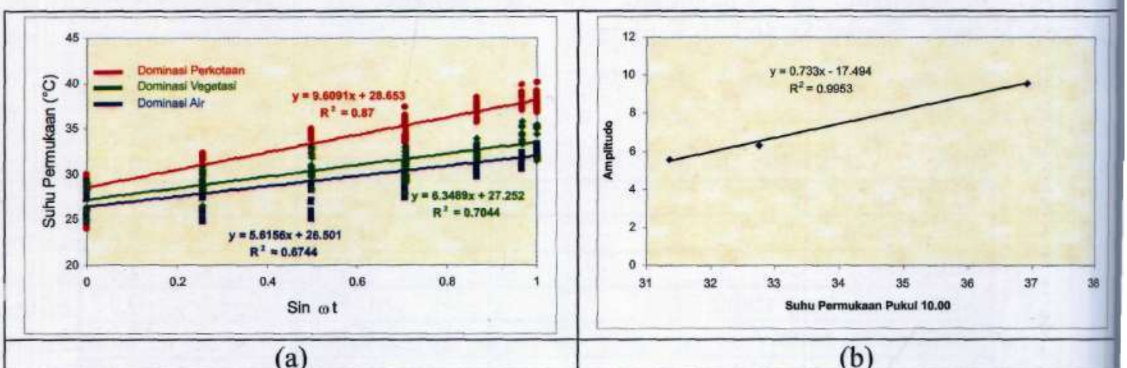


Figure 3. Determination of amplitude

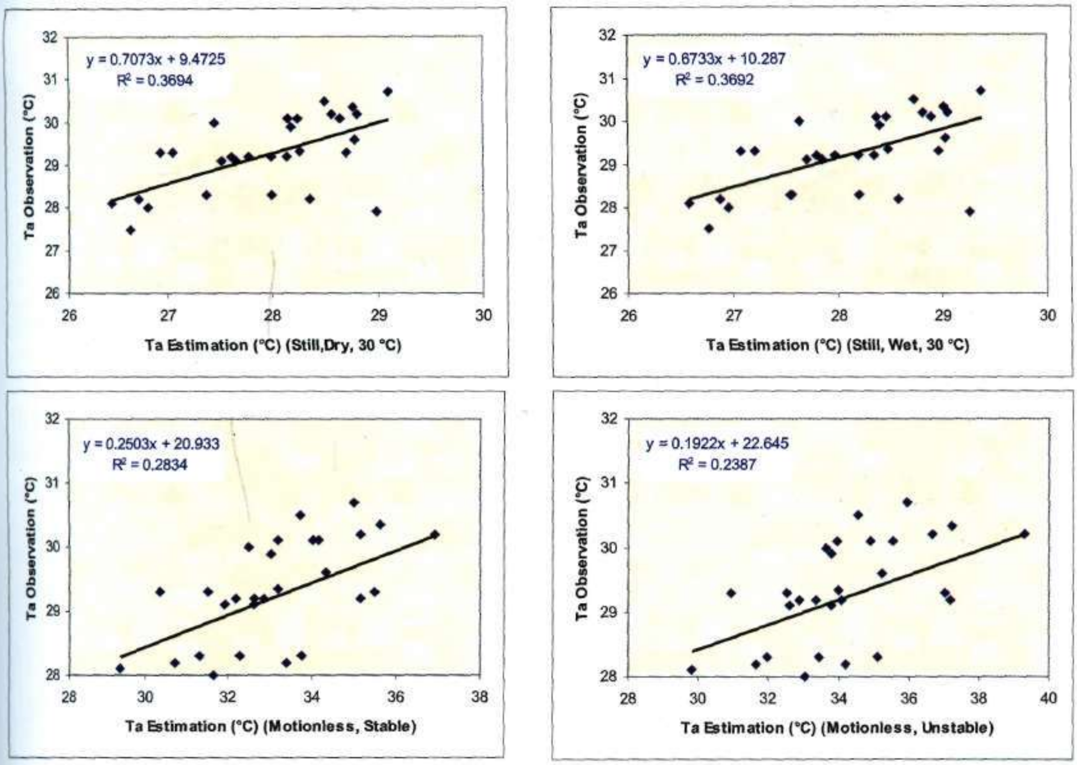


Figure 4. Correlation between air temperature from NOAA AVHRR and the observations

Conclusion

Based on this research the best equation to calculate surface temperature from NOAA/AVHRR is Ulivieri *et al.* equation. These equations have the highest correlation between surface temperatures from NOAA/AVHRR and the observation in the field than the other equations. Physically, this research could estimate air temperature from satellite data. But statistically, this research has not enough significance to describe the field observation. The model describes the field observation only 40 %. The determination coefficients (R2) between air temperature from satellite and observation are not more than 0.4.

References

Arya, S. P. 1988. Introduction to Micrometeorology. Academic Press, Inc. San Diego, California 92101.

Campbells, G. S. 1977. An Introduction to Environment Biophysics. Springier Verlag, New York.

Coll, C, V. Casselles, J. A. Sobrino, and E. Valor. 1994. On the atmospheric dependence of the split-window equation for land surface temperature. *International Journal of Remote Sensing,* 15:105-122.

Dong, J. J. 2004. Evaluation of thermal-water stress of forest in southern Quebec from satellite images. Universite Laval Faculte De Forestrie Et De Geomatique. Canada.

Geiger, R.. 1959. The Climate Near The Ground. Harvard University Press. Cambridge, Massachusetts.

Han, K-S, A. A. Viau, and F. Anctil. 2003. High-resolution forest fire weather index computations using satellite remote sensing. Can. J. For. Res., 33:1134-1143.

Monteith, J. L and M. H. Unsworth. 1989. Principles of Environmental Physics 2nd edn. Chapman and Hall, Inc. New York, NY.

Okc, T. R. 1978. Boundary Layer Climate. A Halsted Press Book John Wiley & Sons. New York, NY.

Price, J. C. 1984. Land surface temperature measurements from the split-window channels of the NOAA-7 AVHRR. Journal of Geophysical Research, 89.

Sun, J.-F. Wang. R.-H. Zhang, R. R. Gillies, Y. Xue and Y.-C. Bo. 2004. Air Temperature Retrieval From Remote Sensing Data Based On Thermodynamics. Theor. Appl. Climatol, 80:37-48.

Ulivieri, C, M. M. Castronouvo, R. Francioni, and A. Cardillo. 1994. A split-window algorithm for estimating land surface temperature from satellites. Advances in Space Research, 14(3):59-65.