EVALUATING THERMAL COMFORT IN CITY LIFE BY SATELLITE REMOTE SENSING AND IN-SITU MEASUREMENTS

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Abstract: In this study, we developed a method for calculating WBGT from MTSAT data. First, we chose 10 fixed point observation stations and calculated hourly or 3 hourly WBGT there. Secondly hourly MTSAT data (IR1, IR2, IR3) of the same points were prepared. And we derived formulas expressing relations between these two data by regression analysis for each station point. It was found that the formulas could express the inclination of WBGT, and it would enable making WBGT mapping. But there were also some underestimations and overestimations, so further study should be investigated to derive more accurate formulas.

INTRODUCTION

Heat island is one of the urban problems in recent years. Human's health and thermal comfort are affected by not only the rise of air temperature, but also other factors including humidity, wind speed and solar radiation. In recent years, we have usually used composite temperatures such as discomfort index (DI), effective temperature (ET) and Wet bulb globe temperature (WBGT) for assessing hot environment. Above all, WBGT is widely used to determine the appropriate exposure level to high temperatures and mainly against heat injury.

Now we can use handy measuring instruments to check WBGT, but in order to know about various remote areas, we need values of temperature, humidity, wind speed and radiant heat which are observed in observation stations there for calculating WBGT. There is difficulty to gather all necessary data.

In this study, we tried to develop a method for calculating WBGT from MTSAT data. Multi-functional Transport Satellite (MTSAT) is a Japanese geostationary satellite launched in 2005 and provides hourly data with 5 bands including two thermal infrared bands. Our findings should enable calculating various region's and time's WBGT easily. In addition, comparing WBGT at the same time will become possible at a glance in wide area by making WBGT map from MTSAT data.

METHODOLOGY

Figure.1 shows the framework of this operation.

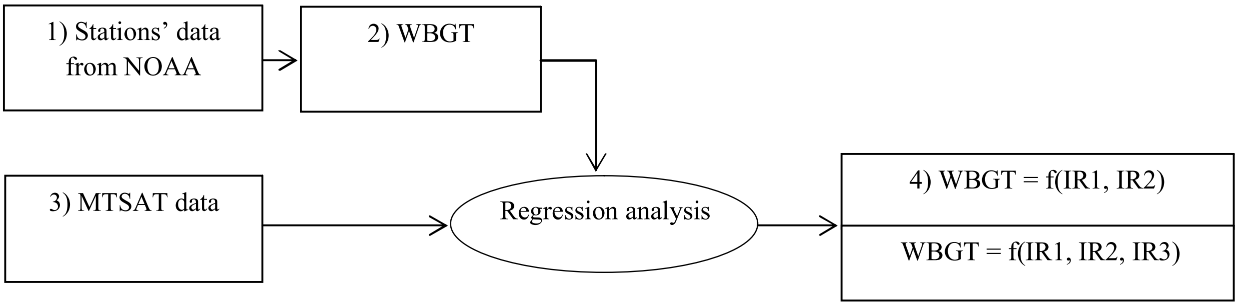

Figure 1 : A flowchart of making relational expression between WBGT and MTSAT data

1.
We chose the following 10 observation stations (Table.1) and prepared the hourly or 3 hourly data of temperature, dew point and atmospheric pressure at each station in 2011. These data are downloaded from Online Climate Data Directory of National Oceanic and Atmospheric Administration (NOAA) (http://lwf.ncdc.noaa.gov/oa/climate/).

Table 1: Stations data

Station	Country	Latitude	Longitude	Data	
SAPPORO	JAPAN	43.06	141.329	hourly	2011/1/1~12/31
TOKYO	JAPAN	35.683	139.767	hourly	2011/1/1~12/31
SEOUL	KOREA,SOUTH	37.567	126.967	3 hourly	2011/1/1~12/31
BUSAN	KOREA,SOUTH	35.1	129.032	3 hourly	2011/1/1~12/31
PYONGYANG	KOREA,NORTH	39.033	125.783	3 hourly	2011/1/1~12/31
WU LU MU QI	CHINA	43.8	87.65	3 hourly	2011/1/1~12/31
TAIBEI	TAIWAN	25.033	121.517	3 hourly	2011/1/1~12/31
BANGKOK	THAILAND	13.7	100.567	3 hourly	2011/1/1~12/31
BANGALORE	INDIA	12.967	77.583	3 hourly	2011/1/1~12/31
PERTH METRO	AUSTRALIA	-31.917	115.867	3 hourly	2011/1/1~12/31

2.
Next we calculated the wet bulb globe temperature (WBGT). WBGT is a composite temperature used to estimate the effect of temperature, humidity, wind speed and solar radiation on humans. It is derived from the following formula. (C.P.Yaglou and D.Minard, 1957)

$$WBGT\ (outdoor) = 0.7Tw + 0.2Tg + 0.1Td$$

Tw: wet-bulb temperature / Tg: globe temperature / Td: dry-bulb temperature

In this study, we used the following simple estimate formula as below, derived with a relation between Tg and Td, "Tg = 1.45Td – 7.09" (Niigata Agricultural Research Institute, Horticultural Research Center, 2004).

$$WBGT = 0.7Tw + 0.4Td - 1.4$$

Following formulas (Table2) were used for calculating WBGT with the data from NOAA (Td : temperature, D : dew point, P : atmospheric pressure).

Table2: Equations used to calculate WBGT

Formula	Variables	Sources
es = 6.1078・10^(7.5T/T+237.3)	es : saturation vapor pressure (hPa) T : temperature (℃)	Sprung (1855)
e = e's - 0.000662・P・(Td-Tw)	e : vapor pressure (hPa) e's : saturation vapor pressure at Tw (hPa) P : atmospheric pressure (hPa) Td : dry-bulb temperature (℃) Tw : wet-bulb temperature (℃)	Tetens (1930)

3.
We prepared MTSAT data below (Table3) of the same points at the almost same times as the stations' data. MTSAT data are downloaded from University of Tokyo MTSAT data processing system (http://webgms.iis.u-tokyo.ac.jp/).

Table3: MTSAT technical specifications

Channel	Wavelength	Spatial Res.
IR1	10.5-11.5 μm	4km
IR2	11.5-12.5 μm	4km
IR3	6.5-7.0 μm	4km
IR4	3.5-4.0 μm	4km
VIS	0.55-0.90 μm	1km

4.
Regression analysis was conducted to derive formulas for WBGT of each station point expressed with IR1 and IR2, and with IR1, IR2 and IR3.

RESULTS AND DISCUSSION

In this paper, we refer to the results about Taibei (Taiwan).
Figures on the next page show the results of regression analysis with IR1 and IR2, and on the one after the next, results of analysis with IR1, IR2 and IR3. Figure2-1 and Figure3-1 show the change of WBGT on 1st day of each month, and Figure2-2 and Figure3-2 show the change in the year expressed by the average WBGT of 1st day of each month. The solid lines are WBGT calculated by data from observation station, and the dotted lines are calculated by MTSAT data with the equations which are the result of the regression analysis.

IR1 and IR2 are both thermal infrared bands, but they are different in absorptivity. IR2 is likely to be absorbed by water vapor. So among the first relational expression, "WBGT = 0.0162 IR1+2.929(IR1-IR2) +12.1974", IR1 can be an indicator of the land surface temperature and (IR1- IR2) can be an indicator of atmospheric water vapor content. It can be said about this formula that the atmospheric water vapor content has much effect on the value of WBGT than thermal energy itself.
The graphs show that the formula can express the inclination of WBGT roughly, and the accuracy is improved in the formula expressed with IR3 besides IR1 and IR2. But there are also some gap between WBGT (station) and WBGT (MTSAT). One of the reasons of it might be effect of cloud. Infrared radiation is hard to through the clouds, so WBGT might be underestimated where there are clouds.

Results (IR1, IR2)

$$WBGT = 2.9452\ IR1 - 2.929\ IR2 + 12.1974$$
$$= 0.0162\ IR1 + 2.929(IR1 - IR2) + 12.1974$$

statistics	
correlation coefficient R	0.647686
decision coefficient R2	0.419497
revised R2	0.41907
standard error	4.657189
number of the observation	2726

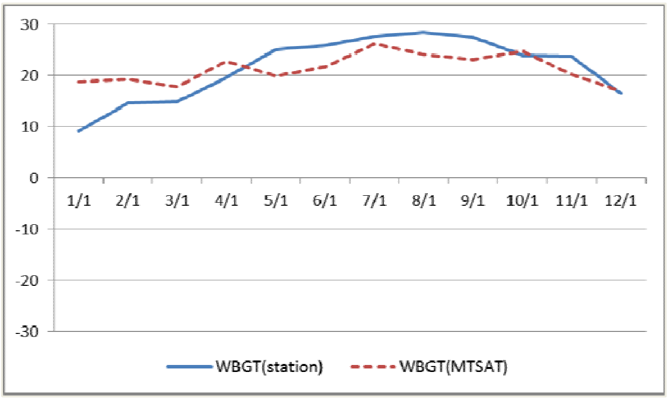

Figure2-2: annual change in WBGT (station/MTSAT) in 2011

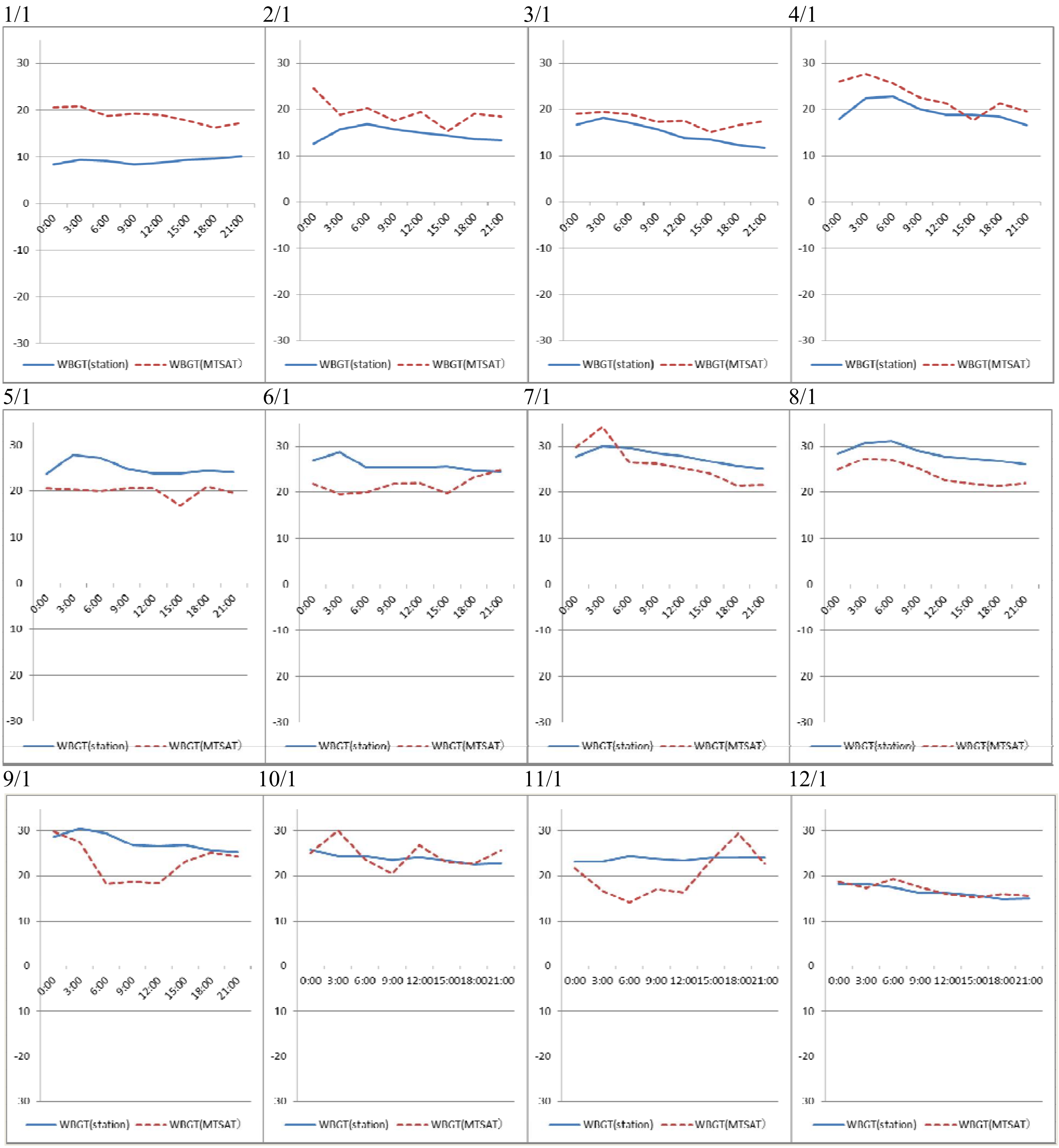

Figure2-1: diurnal change in WBGT (station/MTSAT)

Results (IR1, IR2, IR3)

WBGT =

$$1.6032\ IR1 - 1.426\ IR2 - 0.495\ IR3 + 90.58975$$

statistics	
correlation coefficient R	0.762183
decision coefficient R2	0.580923
revised R2	0.580461
standard error	3.957746
number of the observation	2726

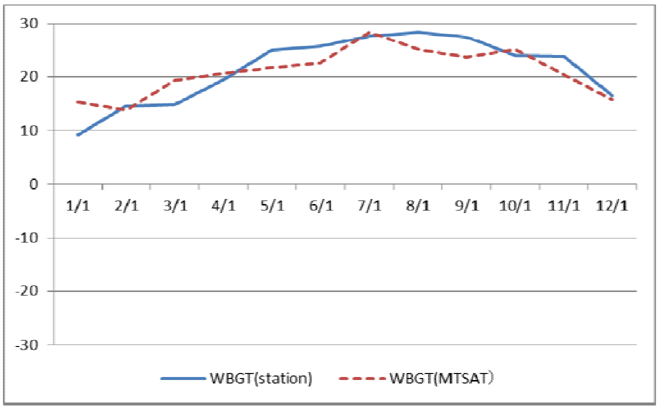

Figure 3-2: annual change in WBGT (station/MTSAT) in 2011

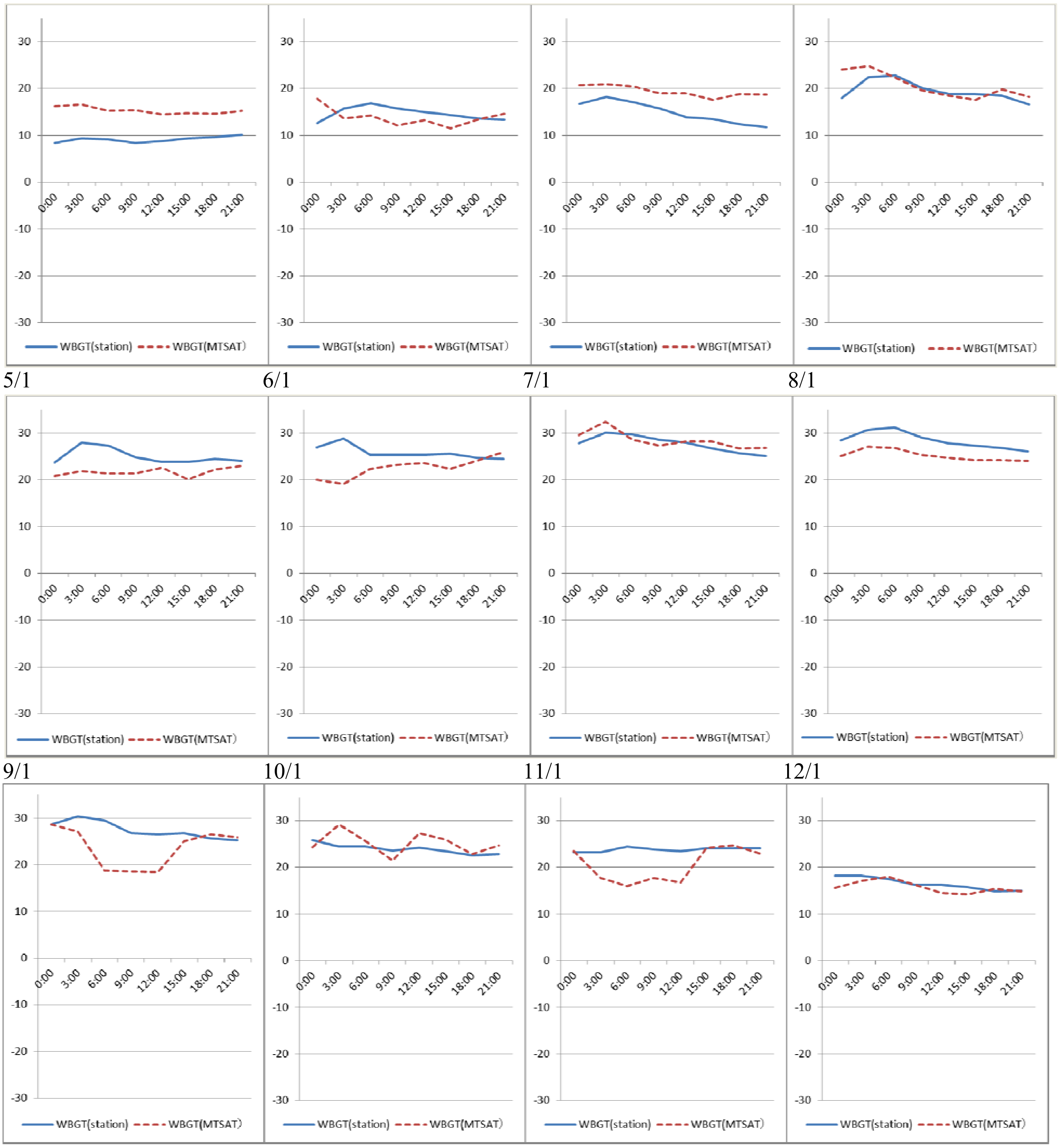

Figure3-1: diurnal change in WBGT (station/MTSAT)

CONCLUDING REMARKS

This study demonstrated a method for evaluating thermal comfort by calculating wet bulb globe temperature (WBGT) using data from Multi-functional Transport Satellite (MTSAT). Regression analyses were carried out using WBGT calculated with fixed point observation data and MTSAT data, and relational expressions were derived between WBGT and IR1, IR2 and IR3. The formulas could express the inclination of WBGT, and the accuracy was improved in the formula expressed with IR3 besides IR1 and IR2. But there were also some underestimations and overestimations, so further study should be investigated to derive more accurate formulas. Next we will add more data and take effect of cloud into account.

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