

# IMPACT OF ATMOSPHERIC WATER VAPOR CONTENT ON LAND SURFACE TEMPERATURE RETRIIVING FROM NOAA/AVHRR DATA

Shin Akatsuka and Yoshifumi Yasuoka  
Institute of Industrial Science, The University of Tokyo  
4-6-1, Komaba, Meguro-ku, Tokyo, JAPAN  
Tel: (81)-3-5452-6415, Fax: (81)-3-5452-6410  
akats@iis.u-tokyo.ac.jp, yyasuoka@iis.u-tokyo.ac.jp

**KEY WORDS:** Atmospheric water vapor, Land surface temperature, NOAA/ AVHRR, GPS

**ABSTRACT:** In retrieving LST from satellite data, the atmospheric correction is a challenging part of preprocessing. In order to avoid the atmospheric correction issue, split window algorithms are usually used for retrieving LST from NOAA/AVHRR data. However, the simple split window algorithms cannot remove the atmospheric effect completely. Therefore, some algorithms incorporating the atmospheric water vapor (AWV) content have been developed. In this study, we examined the impact of AWV content on LST retrieving from AVHRR by comparing the LST which were retrieved by various split window algorithms. In addition, we examined the possibility that the precipitable water (PW) estimated from AVHRR was used as the AWV content parameter in the alternative split window algorithm like the PW derived from GPS data. It was found that the impact of AWV on LST retrieving in urban area was greater than vegetation area and the PW estimated from AVHRR could be used for retrieving LST within 0.5 degree Celsius error in case of AWV content less than  $3.0 \text{ g/m}^2$ .

## 1. INTRODUCTION

Land surface temperature (LST) is a key parameter in many environmental studies, such as urban heat islands, evapotranspiration, global circulation models, and vegetation monitoring, and so on. In retrieving LST from satellite remote sensing data, the atmospheric correction is essential because the difference between top of atmosphere brightness temperature and LST is wide. In order to avoid the atmospheric correction issue, split window algorithms are usually used for retrieving LST from AVHRR data. However, traditional split window algorithms cannot remove the atmospheric effect completely. Therefore, many efforts have been made to incorporate the atmospheric water vapor (AWV) content into the split window equations (Liang, 2004).

The objective of this study is to examine the impact of AWV content on LST retrieving from AVHRR by comparing the LST which are retrieved by traditional split window algorithms and an alternative split window algorithm incorporating AWV content. In addition, it is to examine the possibility that the precipitable water (PW) estimated from AVHRR was used as the AWV content parameter in the alternative split window algorithm as is the case with the PW derived from GPS data.

## 2. DATA

We used three daytime AVHRR images for this study. The AVHRR images were acquired

from Institute of Industrial Science, the University of Tokyo. The AVHRR data were calibrated to reflectance values and brightness temperature, and they were geometrically corrected based on ground control point (GCP) matching by using PaNDA software (Takeuchi et al. 2002).

GPS-derived precipitable water was used as AWV content. GPS-derived PW is the total atmospheric water vapor contained in a vertical inverse cone, whose radius is 40km, from GPS receiver to top of atmosphere. In Japan, GEONET (GPS Earth Observation Network System) has provided us with the GPS-derived PW data set since 1996, and this data set offers the average PW for every three hours. The data set was acquired from GPS/MET JAPAN Homepage ([http://dbx.cr.chiba-u.jp/Gps\\_Met/GpsHome\\_e.html](http://dbx.cr.chiba-u.jp/Gps_Met/GpsHome_e.html)).

The data acquisition time are listed in Table 1.

The study area is Kyusyu district in Japan(Figure 1). There were about one hundred GPS stations in Kyusyu district.

Table 1. Data acquisition time.

DATE	AVHRR	GPS-derived PW
5, May, 1997	05:18(UTC)	3:00 – 6:00 (UTC)
17, May, 1997	04:47(UTC)	3:00 – 6:00 (UTC)
31, May, 1998	05:44(UTC)	3:00 – 6:00 (UTC)

### 3. METHODS

#### 3.1 Estimating LST from AVHRR

We adopted two traditional split window algorithms and an alternative split window algorithm incorporating AWV content for estimating LST from AVHRR. Sobrino’s split window algorithm (Sobrino et al. 1993) and Ulivieri’s (Ulivieri et al. 1994) were used as the traditional split window algorithm, and Sobrino’s (Sobrino et al. 1991) was used as an alternative algorithm. The traditional split window algorithm means that it does not incorporate AWV content into the equation directly, and the alternative algorithm means the algorithm incorporating AWV content into the equation. The abbreviations of the algorithms and their expression are listed in Table 2.

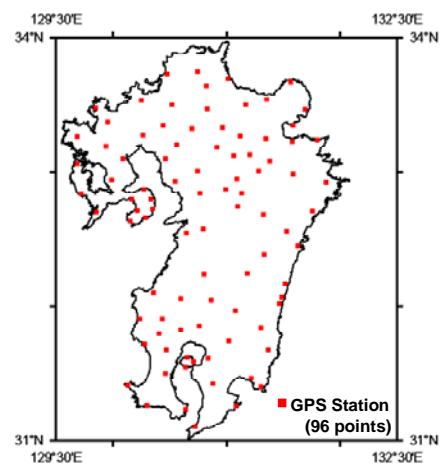


Figure 1. Study area.

Table 2. Split window algorithms.

Author or Group	Abbrev.	Algorithm
Sobrino et al. 1993	S	$LST = T_4 + 1.06(T_4 - T_5) + 0.46(T_4 - T_5)^2 + 53(1 - \epsilon_4) - 53(\epsilon_4 - \epsilon_5)$
Ulivieri et al. 1994	U	$LST = T_4 + 1.8(T_4 - T_5) + 48(1 - \epsilon) - 75\Delta\epsilon$ $\Delta\epsilon = \epsilon_4 - \epsilon_5$ $\epsilon = \frac{\epsilon_4 + \epsilon_5}{2}$
Sobrino et al. 1991	S/w	$LST = T_4 + A(T_4 - T_5) + B$ $A = 0.39W + 1.32 + (1.385W - 0.202)(1 - \epsilon_4) + (1.506W - 10.532)(\epsilon_4 - \epsilon_5)$ $B = \frac{(1 - \epsilon_4)T_4u_1}{\epsilon_4} - \frac{(1 - \epsilon_5)T_5u_2}{\epsilon_5}$ $u_1 = -0.146W + 0.561 + (0.575W - 1.966)(\epsilon_4 - \epsilon_5)$ $u_2 = -0.095W + 0.320 + (0.597W - 1.916)(\epsilon_4 - \epsilon_5)$

( $T_4, T_5$  : Brightness temperature in AVHRR channel 4,5 [K])

$\epsilon_4, \epsilon_5$  : Average of the emissivities for channels 4 and 5 of AVHRR sensor

W : Atmospheric water vapor content [ $g/m^2$ ])

### 3.2 Estimating Surface Emissivity

The algorithms require the surface emissivity for retrieving LST. We estimated surface emissivity map on 17 May 1997, using the algorithm proposed by Sobrino et al. (2001) (Table 3). This algorithm is quite simple and can achieve the comparative accuracy to several other algorithms (Liang, 2004). Then, we used the emissivity map on 17 May 1997 for estimating LST on 5 May 1997 and 31 May 1998.

Table 3. Surface emissivity estimation (Sobrino et al. 2001).

0.2 < NDVI < 0.5	$\varepsilon_4 = 0.968 + 0.021f_v$
	$\varepsilon_5 = 0.974 + 0.015f_v$
	$f_v = \frac{(\text{NDVI} - 0.2)^2}{0.09}$
NDVI < 0.2	$\Delta\varepsilon = \varepsilon_4 - \varepsilon_5 = -0.003 - 0.029\rho_1$
	$\varepsilon = \frac{(\varepsilon_4 + \varepsilon_5)}{2} = 0.98 - 0.042\rho_1$
	$\rho_1 = \text{Channel 1 Reflectance}$
NDVI > 0.5	$\varepsilon_4 = \varepsilon_5 = 0.989$

### 3.3 Estimating AWW content

In using the alternative algorithm, we took advantage of the PW as the AWW content parameter. We estimated AWW content by two methods: GPS-derived PW interpolation method and AVHRR split window method. In GPS-derived PW interpolation method, we used three-hour average GPS-derived PW including satellite over pass time. We estimated AWW content map of Kyusyu district by interpolating these GPS-derived PW point data. The AVHRR split window method is the method using the relationship between AVHRR split window temperature difference and GPS-derived PW. The PW distribution equation in Kyusyu district can be written as

$$\text{PW} = 9.64(T_4 - T_5)^* + 3.33$$

where  $(T_4 - T_5)^*$  is the average  $(T_4 - T_5)$  over box of  $25 \times 25$  pixels centered at the GPS station (Akatsuka and Yasuoka, 2006). We estimated AWW content by these two methods, and then the unit was translated mm into  $\text{g/m}^2$ .

## 4. RESULTS AND DISCUSSION

We examined the impact of AWW content on LST retrieving from AVHRR by comparing the LST at the AMeDAS (Automated Meteorological Data Acquisition System) stations in Kyusyu district. The LST are retrieved by the traditional split window algorithms and the alternative split window algorithm incorporating AWW content. The stations were classified into three categories depending on their location: “urban”, “urban/vegetation”, and “vegetation”. The stations in “urban” category are located in the area whose NDVI values are less than 0.2. The stations in “urban/vegetation” category are located in the area whose NDVI values are between 0.2 and 0.5. The stations in “vegetation” category are located in the area whose NDVI values are more than 0.5.

Figure 2 shows the precipitable water as the AWP content of three categories. Figure 3 shows the LST retrieved from AVHRR by using the algorithms. Figure 4 shows the difference between LST retrieved by the algorithm incorporating AWP content. The atmosphere over the urban area tends to contain more AWP than that over vegetation area, and the difference between AWP content derived from GPS and estimated from AVHRR tends to be larger over the urban than over vegetation area. Therefore, the LST difference due to the different algorithms is greater over the urban area than over vegetation area.

Figure 5 shows the difference between LST retrieved by traditional algorithms and LST retrieved by the alternative algorithm. It is revealed that LST retrieved by Ulivieri's algorithm is closer in value to LST by Sobrino's alternative algorithm incorporating AWP content than LST by Sobrino's traditional split window algorithm. The difference between LST by Ulivieri's and LST by that incorporating AWP content is almost less than 0.5 degree Celsius when AWP content is less than 1.5 g/m<sup>2</sup>, and variation in the difference is small. However, in the case of Sobrino's traditional split window algorithm, the difference from LST by the algorithm incorporating AWP content and the variation are both larger. Therefore, it is suggested that Ulivieri's algorithm more remove the atmospheric effect in retrieving LST from AVHRR than Sobrino's traditional algorithm.

Figure 6 shows the difference between LST incorporating AWP estimated from GPS and LST incorporating AWP from AVHRR in various AWP content. Since the PW can be estimated by AVHRR split window algorithm within the margin of the error, which is 20 % of average GPS-derived PW (Akatsuka and Yasuoka, 2006), we can retrieve LST by using the PW estimated from AVHRR within the only about 0.5 degree C difference from the LST by using the GPS-derived PW, when the AWP content is less than 3.0 g/m<sup>2</sup>. Over Kyusyu area, except for summer, the AWP content is less than 3.0 g/m<sup>2</sup>, the PW estimated from AVHRR can be used for retrieving LST within 0.5 degree C difference from LST incorporating PW derived GPS.

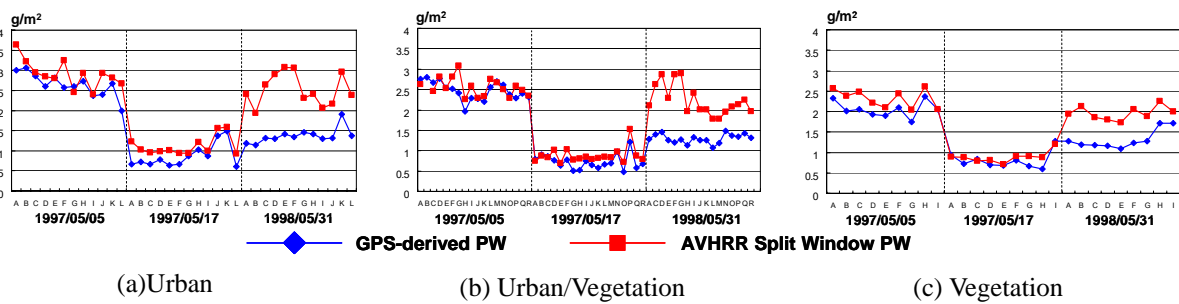


Figure 2. Precipitable water as AWP content.

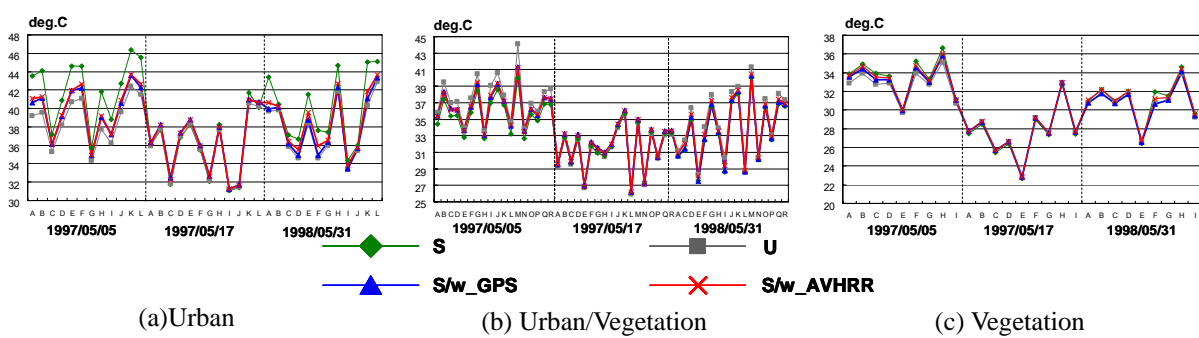


Figure 3. LST difference between split window algorithms.

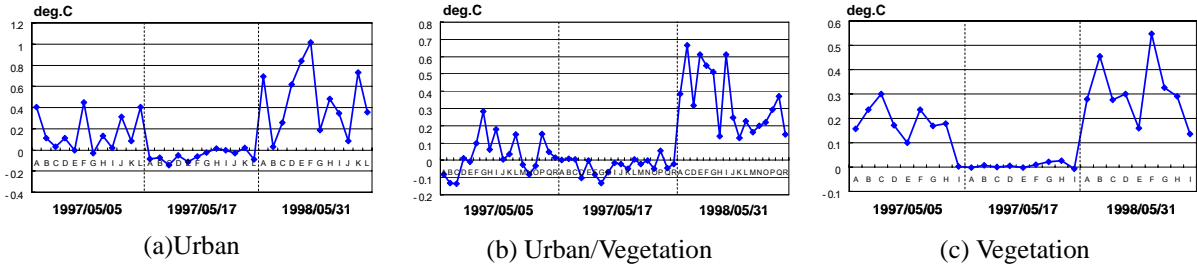


Figure 4. Difference between LST retrieved by the algorithm incorporating AWW content ( $LST_{AVHRR} - LST_{GPS}$ ). ( $LST_{GPS}$  : LST retrieved by S/w algorithm incorporating  $AWV_{GPS}$ ,  $LST_{AVHRR}$ : LST retrieved by S/w algorithm incorporating  $AWV_{AVHRR}$ )

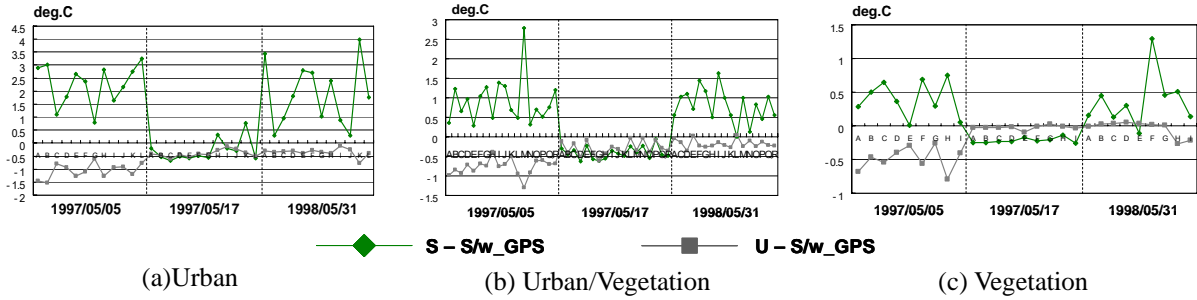


Figure 5. Difference between LST retrieved by traditional algorithms and LST retrieved by the alternative algorithm

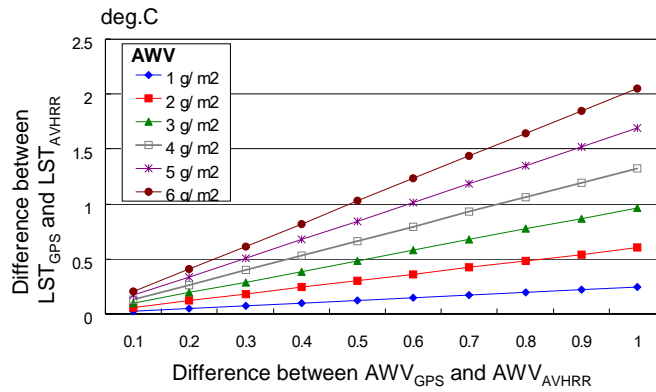


Figure 6. Difference between  $LST_{GPS}$  and  $LST_{AVHRR}$  in various AWW content. ( $\epsilon_4 = \epsilon_5 = 1$ ) ( $AWV_{GPS}$  : AWW content retrieved from GPS(GPS-derived PW),  $AWV_{AVHRR}$  : AWW content retrieved AVHRR split window,  $LST_{GPS}$  : LST retrieved by S/w algorithm incorporating  $AWV_{GPS}$ ,  $LST_{AVHRR}$ : LST retrieved by S/w algorithm incorporating  $AWV_{AVHRR}$ )

## 5. CONCLUSION

In this study, we examined the impact of AWW content on LST retrieving from NOAA/AVHRR by comparing the LST which are estimated by the traditional split window algorithms and the alternative algorithm incorporating AWW content. It was revealed that the impact of AWW on LST retrieving in urban area was greater than vegetation area because the atmosphere over urban area contains more AWW than that over vegetation area. In addition, it was found that if AWW content is less than about  $1.5 \text{ g/m}^2$ , LST estimated by Ulivieri's algorithm differ from the LST estimated by algorithm incorporating AWW content by only about 0.5 degree Celsius. Therefore, if we can tolerate 0.5 degree C difference, we can use the Ulivieri's algorithm in the season when the AWW content is low. On the other hand, LST estimated by Sobrino's algorithm differ from the LST estimated by algorithm incorporating

AWV content by 0.5 degree C, only when the AWV content is less than about 1.0 g/m<sup>2</sup>. When the AWV content is over 1.0 g/m<sup>2</sup>, the LST difference between Sobrino's algorithm and the alternative algorithm is much greater than the difference between Ulivieri's and the alternative. Therefore, it is suggested that Ulivieri's algorithm more remove the atmospheric effect in retrieving LST from AVHRR. Finally, we can use the PW estimated from AVHRR for retrieving LST within 0.5 degree C error in case of AWV content less than 3.0 g/m<sup>2</sup>. We can acquire GPS-derived PW data set only from 1996, but NOAA/AVHRR can be acquired from 1980's. Therefore, the PW from AVHRR is useful for retrieving LST before 1996, when AWV content is less than 3.0 g/m<sup>2</sup>.

## **ACKNOWLEDGEMENT**

The data set of GPS-derived PW for this study was made by the GPS/MET Japan project financially supported by the Ministry of Education, Sports, Culture, Science and Technology of Japan.

## **REFERENCE**

- Akatsuka, S. and Yasuoka, Y., 2006. Estimation of precipitable water distribution over land using NOAA/AVHRR and GPS. Proceedings of the 40<sup>th</sup> Conference of the Remote Sensing Society of Japan. pp.127-128.
- Liang, S. 2004. Quantitative Remote Sensing of Land Surfaces. John Wiley & Sons, Inc, New Jersey, pp.534.
- Sobrino, J. A., Coll, C. and Caselles, V., 1991. Atmospheric corrections for land surface temperature using AVHRR channel 4 and 5. Remote Sensing of Environment. 38, pp.19-34.
- Sobrino, J. A., Caselles, V. and Coll, C., 1993. Theoretical split window algorithms for determining the actual surface temperature. Il Nuovo Cimento. 16(3), pp.219-236.
- Sobrino, J. A., Raissouni, N., and Li, Z. L. 2001. A comparative study of land surface Emissivity retrieval from NOAA data. Remote Sensing of Environment. 75, pp.256-266.
- Takeuchi, W., Nemoto, T., Ochi, S. and Yasuoka, Y., 2002. Development of AVHRR data processing system on WWW. J. Japan Society of Photogrammetry and Remote Sensing, 41(3), pp.23-27.
- Ulivieri, C., Castronuovo, M., Francioni, R., and Cardillo, A., 1994. A split window algorithm for estimating land surface temperature from satellites. Adv. Space Res. 14(3), pp.59-65.