# AN EMISSIVITY-BASED LAND SURFACE TEMPERATURE RETRIEVAL ALGORITHM

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### ABSTRACT

Land Surface temperature (LST) is a critical parameter in water and energy circle supporting the global climate research. The traditional optical/thermal remote sensing estimates LST under clear-sky conditions, while the microwave remote sensing provides the all-weather LST estimation capability. In this paper, we derivate a new LST retrieval algorithm based on the emissivity parameterization using the Advanced Microwave Scanning Radiometer - Earth Observation (AMSR-E), considering the atmospheric influence, to tackle the LST retrieval under the non-scattering rain and cloud condition. The new derived LST algorithm has a physical basis and the RMSE is 1.8K with the station validation over boreal forest area at Sodänkylä, Finland.

*Index Terms*—Land Surface Temperature, AMSR-E, Emissivity Estimation

# **1. INTRODUCTION**

Land Surface temperature is a critical parameter in global climate research. For a long time, many investigators have launched researches on the retrieval algorithm of land surface temperature (LST) using the earth observation techniques [McFarland, 1990; Holliger, 1991; Gao, F., 2003], especially using the thermal remote sensed technique in thermal spectrum which achieved accuracy of 1K under clear sky conditions[Wan, 2003]. To some extent, the microwave could penetrate through the cloud, and hardly influenced by atmosphere, while the microwave retrieval capacity of LST is argued when using the relative higher frequency [Wang, J.R., 2007; Savoie, M. H., 2009].

To achieve the land surface temperature under real all weather (no matter rainy or cloudy condition), firstly, an instantaneous emissivity retrieval method has been development to get the intrinsic land surface "effective" emissivity with the MODIS/LST, AMSR-E brightness temperature and microwave atmospheric correction under clear condition [Yubao Oiu, 2008]. Secondly, we have developed an emissivity extrapolation algorithm with multi variable regression method at the "atmosphere transparent" bands (6.9GHz and 10.7GHz). And thirdly, the statistical and simulated (AIEM, bared soil emission model) results of the polarization difference ratio at different frequencies over different land cover have been parameterized. The derived LST retrieval algorithm has been derived and test over two typical areas (one for Southern Asia and another for the north Euro-Asia), the result agree well with the MODIS LST under clear condition with the RMSE 0.65K, while the RMSE for the all-weather is 3 to 4K. A test site over northern boreal forest area of Finland is validated with the mast atmosphere temperature. The validated RMSE of 1.8K shows its applicability.

# 2. EMISSIVITY ESTIMATION

The Moderate Resolution Imaging Spectra - Radiometer (MODIS) and the Advanced Microwave Scanning Radiometer (AMSR-E) – Earth Observation System (EOS) are two sensors on board the Aqua satellite, which provide synchronous earth observation. Instantaneous emissivities over land have been calculated directly from two-weeks (12-08-2006 to 25-08-2006) of global AMSR-E microwave measurements [Yubao Qiu, 2008]. The result is compared to the previous of emissivities [Karbou, 2005].

# 3. EMISSIVITY ANAYSIS UNDER DIFFERENT LAND COVERS

The simulation results of AIEM model (bare soil) [Chen K.S., 2003] also reveal the linear trend (Fig.1, right) between different frequencies. There is some light difference between the intrinsic result from MODIS-based derived emissivity over conifer area (Fig. 1 left),

which needs to be explained by the true forest scenario and the simulation.



Fig 1. the relationship between PDs of the adjacent frequencies over clear-sky conditions (left) and the theoretical result from the AIEM simulation. (The difference between them is to be discussed in near future.)

This relationship is also can be found between the 18.7GHz and 26.5GHz, 10.7GHz and 23.8GHz, and the ratio  $(PD_{23.8GHz}/PD_{18.7GHz})$  of the PDs is found to keep in a stable value when they are considered for a short time series (see Fig. 2).



Ascending Orbit Time Line (from 12-08-2006 to 25-08-2006)

Fig. 2. The time series of PD ratio over the Savanna, all PDs is divided by PD at 23.8GHz

Fig. 2 shows a stable PD ratio value at half month duration over Savanna area, this signal drive us to use the PD ratio as a parameterization method in the LST retrieval algorithm development, avoiding the atmosphere sensitive band when resolving the radiative transfer model.

#### 4. ALGORITHM DERIVATION

The brightness temperature is represented by,

$$T_{B_{\nu_{p}}} = e_{\nu_{p}} \cdot T_{s} \cdot t_{a} + T_{\nu_{u}}$$
$$+ T_{\nu_{d}} \cdot (1 - e_{\nu_{p}}) \cdot t_{a} + T_{CB} \cdot (1 - e_{\nu_{p}}) \cdot t_{a}^{2}$$
(1)

where,  $T_{B_{V_p}}$  is the brightness temperature,  $e_{v_p}$  is the surface emissivity,  $t_a$  is the atmosphere transmissivity,  $T_s$  is the land surface temperature,  $T_{v_p} / T_{v_p}$  are the up-welling/down-welling contribution of the atmosphere, and  $T_{CB}$  is the cosmic background.

Considering the radiative transfer equations at 18.7GHz and 36.5GHz, we get,

$$T_{b187} = T_s \cdot \varepsilon_{187} \cdot t_{a187} + T_{u187} + (T_{d187} + T_c) \cdot (1 - \varepsilon_{187}) t_{a187}$$
(2)

$$T_{b_{23,8}} = T_s \cdot \varepsilon_{23,8} \cdot t_{a_{23,8}} + T_{u_{23,8}} + (T_{d_{23,8}} + T_c) \cdot (1 - \varepsilon_{23,8}) t_{a_{23,8}}$$
(3)

The emissivities over land surface are relative high (almost more than 0.9), the reflection of the down-welling  $(T_{dx} + T_c) \cdot (1 - \varepsilon_x) t_{ax}$  can be ignored. We can get,

$$T_{b18.7} = T_{s} \cdot \varepsilon_{18.7} \cdot t_{a18.7} + T_{u18.7}$$
(4)

$$T_{b23.8} = T_{s} \cdot \varepsilon_{23.8} \cdot t_{a23.8} + T_{u23.8}$$
(5)

then equation (4) and (5) are transferred to,

$$T_{s} = \frac{(T_{b18.7} - T_{b23.8}) - (T_{u18.7} - T_{u23.8})}{\varepsilon_{18.7} \cdot t_{a18.7} - \varepsilon_{23.8} \cdot t_{a23.8}}$$
(7)

According to the assumption,  $T_{\nu_u} = T_{\nu_d} = T_a \cdot (1 - t_{a_v})$ , where the  $T_a$  is the effective atmosphere temperature, then we get,

$$\frac{\mathrm{T}_{u18.7}}{\mathrm{T}_{u23.8}} = \frac{1 - t_{a18.7}}{1 - t_{a23.8}} \tag{8}$$

Thus, the  $T_a$  is eliminated via equation (8)

Then we get,

$$\mathbf{T}_{u18.7} - \mathbf{T}_{u23.8} = \mathbf{T}_{u18.7} \cdot t_{a23.8} - \mathbf{T}_{u23.8} \cdot t_{a18.7} \tag{9}$$

The follow equation can be derived Via equation (4) and (5),

$$T_{u_{187}} \cdot t_{a_{23.8}} - T_{u_{23.8}} \cdot t_{a_{187}} = \mathbf{T}_{b_{187}} \cdot t_{a_{23.8}} - \mathbf{T}_{b_{23.8}} \cdot t_{a_{187}}$$
$$- (\varepsilon_{187} - \varepsilon_{23.8}) \cdot \mathbf{T}_{s} \cdot t_{a_{187}} \cdot t_{a_{23.8}}$$
(10)

Combined equation (9) and (10), we get,

$$T_{u18.7} - T_{u23.8} = T_{b18.7} \cdot t_{a23.8} - T_{b23.8} \cdot t_{a18.7} - (\varepsilon_{18.7} - \varepsilon_{23.8}) \cdot T_{s} \cdot t_{a18.7} \cdot t_{a23.8}$$
(11)

Then, we get the retrieval algorithm from equation (7) and (11),

$$T_{s} = \frac{(T_{b18.7} - T_{b23.8}) - (T_{b18.7} \cdot t_{a23.8} - T_{b23.8} \cdot t_{a18.7}) + (\varepsilon_{18.7} - \varepsilon_{23.8}) \cdot T_{s} \cdot t_{a18.7} \cdot t_{a23.8}}{\varepsilon_{18.7} \cdot t_{a18.7} - \varepsilon_{23.8} \cdot t_{a23.8}}$$
(12)

According to equation (4) or (5), we get the polarization difference ratio,

$$\frac{\Delta T_{b187}}{\Delta T_{b23.8}} = \frac{\Delta \varepsilon_{187} \cdot t_{a187}}{\Delta \varepsilon_{23.8} \cdot t_{a23.8}}$$
(13)

Then the final algorithm equation can be derived using equation (12) and (13),

$$T_{s} = \frac{\frac{(T_{b18.7} - T_{b23.8})}{t_{a18.7}} - (T_{b18.7} \cdot \frac{\Delta \varepsilon_{18.7} \cdot \Delta T_{b23.8}}{\Delta \varepsilon_{23.8} \cdot \Delta T_{b18.7}} - T_{b23.8}) + (\varepsilon_{18.7} - \varepsilon_{23.8}) \cdot T_{s} \cdot t_{a23.8}}{\varepsilon_{18.7} - \varepsilon_{23.8} \cdot \Delta T_{b18.7}}$$
(14)

The resolution of equation (14) needs the atmosphere

transmissivity  $t_{a18.7}$  and  $t_{a23.8}$ , so we add two frequencies: 10.7GHz and 36.5GHz, then the four equation group have four atmosphere transmissivity and one land surface temperature. The low frequency has less atmosphere influence, so we assume the transmissivity 10.7GHz atmosphere to be ~1.0. Thus we get four functions and four unknowns with an easy parameterization polarization ratio  $\Delta \varepsilon_x / \Delta \varepsilon_y$  (see above section).

### 5. TEST AND VALIDATION

The above algorithm are called LST parameterization algorithm in this paper, we keep the emissivity estimation from 12-08-2006 to 25-08-2006 as an example.

We choose the clear-sky condition by substitute the emissivity into the equation group. The parameterization PD ratios are listed in Table 1 under different land covers.

Table 1 the PD ratio under different land covers (	(IGBP -based)	)
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Land	PD10.7	PD10.7	PD18.7	PD18.7
1	19	1 35	1 38	1.0
2	1.7	2.0	1.15	1.4
3	2.25	5.0	1.4	2.7
4	1.6	1.95	1.05	1.25
5	1.8	2.0	1.3	1.4
6	1.75	2.05	1.20	1.45
7	2.25	2.25	1.5	1.55
8	1.75	1.9	1.25	1.4
9	2.1	2.3	1.4	1.5
10	2.0	2.2	1.4	1.45
11	2.0	2.25	1.4	1.5
12	1.9	1.55	1.4	1.1
13	2.1	2.3	1.4	1.5
14	1.95	1.65	1.4	1.25
15	2.05	2.2	1.4	1.5
16	1.44	1.8	1.05	1.3

The clear-sky result are listed as following,



250 262.1 274.3 286.4 298.6 310.7 322.9 335

Fig. 3. the comparison of the retrieved result of this method (top) and MODIS LST (bottom).

The result over china area against MODIS LST is showed in Fig 4.



Fig 4. AMSR-E-based LST estimation using the parameterization algorithm against MODIS LST

From Fig 3 and 4, the derived algorithm can get a LST estimation with the RMSE from  $2.6 \sim 4.0$ K.



Fig 5. The LST retrieval algorithm over the rainy and cloudy areas (comparison of MODIS LST, top and AMSR-E derived - bottom)

Another validation is using the 2m atmosphere station observation under the cloud cover area.

This result shows the AMSR-E global retrieval ability of LST, even over the rainy and cloud environment (Fig 5).

We also run this algorithm over boreal forest area over northern Finland.



Fig 6. validation of the cloudy area algorithm using the directly divided by 18.7GHz and the parameterization method.

The test result shows that the parameterization algorithm can get reasonable retrievals. The Fig 6 shows a better result when compared with the direct method Tb/emissivity (18.7GHz), achieving a RMSE 1.3219 over a time series record at Sodänkylä, Finland.

### CONCLUSIONS

This paper present a new develop algorithm for the LST retrieval algorithm, which could be used under the cloud and rainy conditions. The algorithm has a physical-based derivation, with the 23.8 GHz for the water vapor absorption correction and 36.5GHz for the liquid water vapor correction. The result shows the locally and short-time validity.

While, more work is need in the 1) algorithm validation over a large area and long time series. 2) The assumption error analysis.

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