Simulated Radiance at sensor using Radiative Transfer Model with Sensor Response Function in MWIR and Validation of Simulated Radiance against MODIS Data

DongHwan Cha (1), DaeYoung Ahn (1), DooChun Seo (1)

1 Korea Aerospace Research Institute
169-84 Gwahak-ro, Yuseong-gu, Daejeon, 34133, Korea
Email: dh.cha@kari.re.kr; ahndy@kari.re.kr; dcivil@kari.re.kr

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ABSTRACT: A precise and globally representative Radiative Transfer Model (RTM) is needed to improve/calibrate for accuracy of radiance received at space-borne Mid-wave infrared (MWIR) observations. The well calibrated radiance can be used in various fields. One of the major application field is surface temperature retrieval. A vendor provide DN to Radiance conversion coefficients are required as a major factor for estimating surface temperature retrieval from MWIR channel data. The conversion coefficients are determined under laboratory setting in pre-launch phase. As the test blackbody is heated up, the emitted blackbody radiance as function of wavelength and temperature based on Planck's law is estimated. The amount of incident energy into MWIR channel sensor is recorded and described as digital number. The relationship between digital numbers and radiance at sensor can be described as conversion coefficients and providing accurate coefficients to users is one of important role as space agency. The vendor provide coefficients determined in lab environments should be calibrated in on-orbit environments. There may be factors can cause vendor provided coefficients errors. First, the unexpected space environments. Second, the geometrical relationship among energy source (solar/moon), an area of interest and satellite position. Third, interruptions related with energy transmittance in MWIR range by atmospheric conditions. Fourth, other source of energy generated by satellite itself for instance. Providing well calibrated DN to Radiance conversion coefficients is the main goal of this study. Therefore, the predicted Top of Atmosphere (TOA) radiance and sensor received radiance in MWIR channel using a Radiative Transfer Model (RTM) is simulated. As preliminary verification process of KOMPSAT data for simulating radiance MWIR channel, The MODIS data is used to validate simulated radiance using MODTRAN is reliable by comparison of the simulated radiance at sensor with the measured radiance at sensor (using DN to Radiance coefficients, SRF) at Lake Tahoe and Salton Sea buoy sites. The MODTRAN input data are consisted of sensor response function, atmospheric profile, line-of-sight geometry, and ground surface properties (surface skin temperature, surface emissivity). The test is carried out by minimizing impediment factors for maximizing radiance base validation accuracy. Such as clear atmospheric conditions, using Night time and nadir angle MWIR channel imagery, and Selecting AOI having homogeneous surroundings for test sites.

1. INTRODUCTION

Remotely sensed imagery of the earth in Mid-Wave Infrared (MWIR) channel were collected for estimating surface temperature in this study. A precise and globally representative Radiative Transfer Model (RTM) is needed to improve/calibrate for accuracy of radiance received at space-borne Mid-wave infrared (MWIR) observations. The emitted radiance from the surface can be estimated by using radiance components calculated from the radiative transfer model. A vendor provide DN to Radiance conversion coefficients are required as a major factor for estimating surface temperature retrieval from MWIR channel data. The conversion coefficients are determined under laboratory setting in pre-launch phase. The conversion coefficients are the crucial factor for user to analyze relationship between The amount of incident energy into MWIR channel sensor and its digitalized number. But the vendor provide coefficients determined in lab environments should be calibrated in on-orbit environments. There may be factors can cause vendor provided coefficients errors. The coefficients were determined only in restricted lab environment and do not reflect on-orbit environment. Followings are the expected factors can cause those errors. First, the unexpected space environments. Second, the geometrical relationship among energy source (solar/moon), an area of interest and satellite position. Third, interruptions related with energy transmittance in MWIR range by atmospheric conditions. Fourth, other source of energy generated by satellite itself for instance. Therefore, DN to Radiance conversion coefficients, which were determined in pre-launch phase, should be monitored and calibrated by reflecting on-orbit situation. The MODTRAN 5.2 (Berk et al.,2008) radiative transfer model with the related data is used to calculate the radiance components. Providing well calibrated DN to Radiance conversion coefficients is the final goal of this study. As preliminary verification process of KOMPSAT-3A data for simulating radiance MWIR channel, The MODIS data is used to validate simulated radiance using MODTRAN is reliable by comparison of the simulated radiance at sensor with the measured radiance at sensor (using DN to Radiance coefficients, SRF) at Lake Tahoe buoy sites and Salton Sea buoy sites.

2. DATA AND METHODS

The MODIS Level-1B calibrated radiance data set covers from 0.4 micron to 14.4 micron regions of the spectral range. The resolution of channels 1 and 2 is 250 meter, channels 3 to 7 are 500 meter, and the rest are 1km resolution. The MODIS AQUA data to estimate received radiance at sensor and Lake Tahoe and Salton Sea buoy sites to get reference surface temperature as one of components for simulating radiance using RTM.

Table 1. Date & Time and Location of Test Site

	Lake Tahoe	**Salton Sea**
	MYD021KM(MODIS aqua)	
Date and Time (UTC)	2018-06-20-09:15	2018-06-13-09:15
Location (Lat/Long)	39.155/-120.72	33.225/-115.824

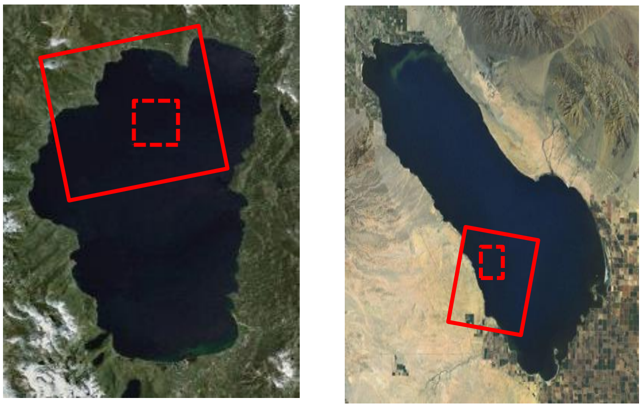

Fig 1. Test Site 1 on Lake Tahoe (Left), Test Site 2 on Salton Sea (Right)

Total Two-time data were evaluated and the work flow are described as below (Fig.2)

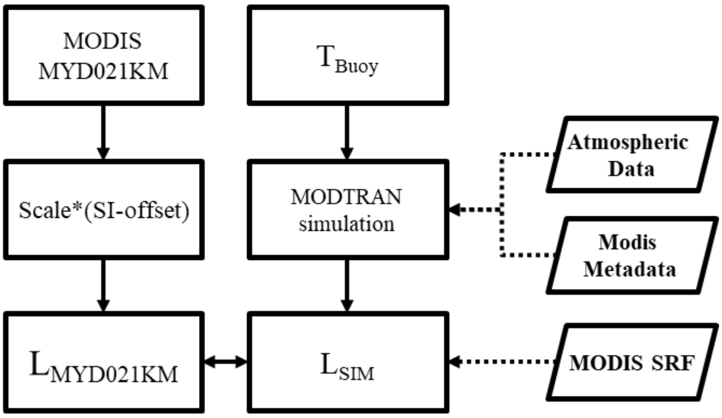

Fig 2. Cross-validation work flow between Simulated radiance and sensor received radiance at MODIS sensor.

There are three components for estimating Top of Atmosphere (TOA) radiance. The top of atmosphere radiance includes contributions from the surface emission, the atmospheric up-welling radiance and atmospheric down-welling radiance reflected by the surface of the Earth. those three major components are simulated by RTM in MODTRAN simulation section on the work-flow chart. Under clear sky conditions, the basis of radiative transfer equation for a given wavelength can be written as below;

$$\mathbf{L_{TOA}} = [\boldsymbol{\varepsilon_\lambda B_\lambda(LST)} + (\mathbf{1} - \boldsymbol{\varepsilon_\lambda})\boldsymbol{L_\lambda^{atm\downarrow}}]\boldsymbol{\tau_\lambda} + \boldsymbol{L_\lambda^{atm\uparrow}} \quad (1)$$

Where ε_λ is the surface emissivity of AOI $B_\lambda(LST)$ is the radiance emitted by a blackbody at temperature (Planck function), $L_\lambda^{atm\downarrow}$ is the down-welling radiance, τ_λ is the total transmittance of the atmosphere and $L_\lambda^{atm\uparrow}$ is the up-welling radiance. In the MODTRAN simulation step, LANDSAT "ATMOCORR" web-service data (Atmospheric correction parameter calculator, http://atmcorr.gsfc.nasa.gov/) was applied for atmospheric data, and MODIS aqua metadata file was used for line-of-sight geometry among space-borne sensor, location of AOI and energy source. In addition, The Spectral Response Function (SRF), which characterizes the sensitivity of each spectral channel, was for reflecting the relationship between input radiance at sensor and recorded digital number of MWIR imagery. The following sensor response function can be described as below;

$$\mathbf{L_{obs}} = \frac{\int_{\lambda 1}^{\lambda 2} L_\lambda * SRF_\lambda d\lambda}{\int_{\lambda 1}^{\lambda 2} SRF_\lambda d\lambda} \quad (2)$$

Where SRF is the normalized value from 0 to 1 to represent sensitivity of a band at wavelength, L_λ is the total radiance incident into sensor (W/m^2/sr/µm).

Table 2. Cross-validation Results between Simulated Radiance and Temperature and Reference Data (MODIS Radiance Product and Measured Temperature at Buoy Sites)

Target	**$L_{MYD021KM}$** $(W/m^2/sr/\mu m)$	**L_{obs}** $(W/m^2/sr/\mu m)$	**Error (%)**	**LST (°C)**	**T_{obs} (°C)**	**Error (°C)**
Salton20180613	0.6536	0.6363	**2.64**	28.1	28.8752	**0.78**
Tahoe20180620	0.3507	0.3403	**2.97**	14.1	14.9056	**0.81**

Where $L_{MYD021KM}$ is MODIS Radiance product that we want to use as a compassion data with Simulated Radiance at sensor (L_{obs}). Those two radiances have less than 3 % differences respectively for Salton Sea and Lake Tahoe. The corresponding temperature values calculated by inverse Planck function are very similar (less than 1°C). The inversion of the radiative transfer equation according to the following expression;

$$\mathbf{B}_\lambda(\boldsymbol{LST}) = \frac{L_{TOA} - L_\lambda^{atm\uparrow} - \tau_\lambda(1-\varepsilon_\lambda)L_\lambda^{atm\downarrow}}{\tau_\lambda \varepsilon_\lambda} \quad (3)$$

3. CONCLUSION AND DISCUSSION

As preliminary verification for KOMPSAT-3A MWIR data, the cross-validation was carried out by comparison between simulated value (TOA Radiance and Temperature) using RTM with MODTRAN 5.2 and reference data (MODIS aqua radiance product and measure buoy water surface temperature). The radiance differences are less than 3% and the corresponding temperatures are less than 1°C in Salton Sea and Lake Tahoe test sites respectively. Four expected factors are need to be improved/modified for KOMPSAT-3A MWIR data for further study. First, MODIS channel used for this study covers very narrow and has multi-channels but the KOMPSAT-3A covers 3.3µm~5.2µm with a single MWIR channel. The atmospheric data needs to be considered very carefully for Radiative Transfer Model (RTM) since it has wider range in MWIR range compared to MODIS data relatively. Since KOMPSAT-3A has wider range channel in MWIR, the conventional computation represents a single radiance at certain wavelength cannot be represent the incident radiance energy at sensor. The integrated all the incident radiance from whole cover range from 3.3µm to 5.2µm should be considered for KOMPSAT-3A channel. Seconds, the brightness temperature from the integrated radiance at from 3.3µm to 5.2µm cannot be solved analytically using the inverse Planks function. Therefore, as an approximation, a polynomial function to retrieve the brightness temperature from the integrated radiance from 3.3µm to 5.2µm need to be used for the calculation. Third, this study only carried out two test sites. Sufficient tests in many cases are required for calibrating initial vender-provided DN to Radiance conversion coefficients. Fourth, estimation of spectral emissivity values in MWIR channel is also crucial work for the further study.

4. REFERENCES

Berk, A., Anderson, G. P., Acharya, P. K., & MODTRAN, E. S. 2008. 5.2. 0.0 User's Manual Air Force Res. Lab., Space Veh. Directorate, Air Force Materiel Command, Bedford, MA, USA, 01731-3010.

Guillevic, P., Göttsche, F., Nickeson, J., Hulley, G., Ghent, D., Yu, Y., ... & Román, M. 2017. Land surface temperature product validation best practice protocol. Version 1.0. Best Practice for Satellite-Derived Land Product Validation, 60.

Jiménez-Muñoz, J. C., & Sobrino, J. A. 2003. A generalized single-channel method for retrieving land surface temperature from remote sensing data. Journal of Geophysical Research: Atmospheres, 108(D22).

Kim, Yongseung., Malakar, Nabin., Hulley, Glynn., Hook, Simon., 2019. Surface Temperature Retrieval from MASTER Mid-wave Infrared Single Channel Data Using Radiative Transfer Model. 10.7780/kjrs.2019.35.1.10.