Implementation of a Solar Spectral Model for the Calibration of the Spaceborne Multispectral Imager (SMI) of DIWATA 1.

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ABSTRACT: DIWATA-1 is a low earth orbit (LEO) microsatellite that hovers 400km above the earth. It was launched from the International Space Station (ISS) and deployed into orbit last April 27, 2016. It is envisioned that a set of multi-spectral satellite images from DIWATA-1 will be collected and processed to monitor changes in vegetation and to oversee oceans' productivity in the Philippines. To meet these objectives, the images should be consistent enough to produce meaningful derivative products. The images taken by the sensor must be corrected to eliminate geometric and radiometric distortions and noises. Spectral extraterrestrial solar irradiance is attenuated while passing through the atmosphere by Rayleigh scattering, ozone, mixed gases, water vapor absorption and aerosol transmission. These conditions make it necessary to apply any correction to the atmosphere's effect. A spectral radiance model was applied to estimate the top-of-atmosphere (TOA) radiance which can be predicted using the field data acquired through an airborne mission. The payload, a Liquid Crystal Tunable Filter (LCTF) camera, was installed for an experimental airborne mission to acquire spectral images. The digital number in each pixel of the image was then converted to radiance by modelling the irradiance at the sensor and obtaining reflectance values of certain types of vegetation. The output provides an at-sensor radiance (airborne) accounting for the effects of the atmosphere and incoming solar irradiance. Initial results from the comparison of the irradiance data using the pyranometer and the model show a root mean square error (RMSE) of 90.67 W/m2/um in band 7 (0.64um) but also yields an RMSE of 980.66 W/m2/um in band 11 (0.75um) for the spectral irradiance, while an RMSE of 124.281 W/m2/um was computed for the broadband irradiance. For the normal operation of DIWATA-1, it is vital to include not only the atmospheric correction of the incoming solar irradiance at ground but the incoming radiance at the sensor (DIWATA-1) as well.

1. INTRODUCTION

The PHL-MICROSAT Program has developed a microsatellite, DIWATA1, which will be utilized to do multi-spectral, high precision earth observation. Apart from this, DIWATA1 envisions to provide significant derivative products for the Filipino people. It was deployed into orbit last April 27, 2016 with an altitude of 400km. The payloads of the DIWATA1 are the following; High Precision Telescope (HPT) for disaster management and resource allocation, Space-borne Multispectral Imager (SMI) with Liquid Tunable Crystal Filter (LCTF) for monitoring changes in vegetation, Wide Field Camera (WFC) for observing cloud patterns as well as weather disturbances and an engineering control instrument, Middle Field Camera (MFC) for locating images captured by the HPT and SMI.

The calibration and validation team, a component of the PHL-MICROSAT Program, is tasked to produce a level 1 product. This product commonly referred as the top-of-atmosphere (TOA) radiance must be free from geometric and radiometric distortions and noises. To pursue its goal, the team has developed a calibration procedure which is exhibited in Figure 1. Part of its procedures is to establish an irradiance model and consequently be used to calculate the calibration parameters (gain and offset) unique to each payload.

The irradiance model used by the team estimates the interaction of the solar radiation with the Earth's atmosphere. Rayleigh scattering, ozone, mixed gases, water vapor absorption and aerosol transmission are considered to atmospherically correct the computed TOA radiance. However, for this paper, only the atmospheric correction of the incoming solar irradiance at ground was shown. Solar radiation reflected by the Earth's surface to DIWATA1 sensor or the path radiance is still being established.

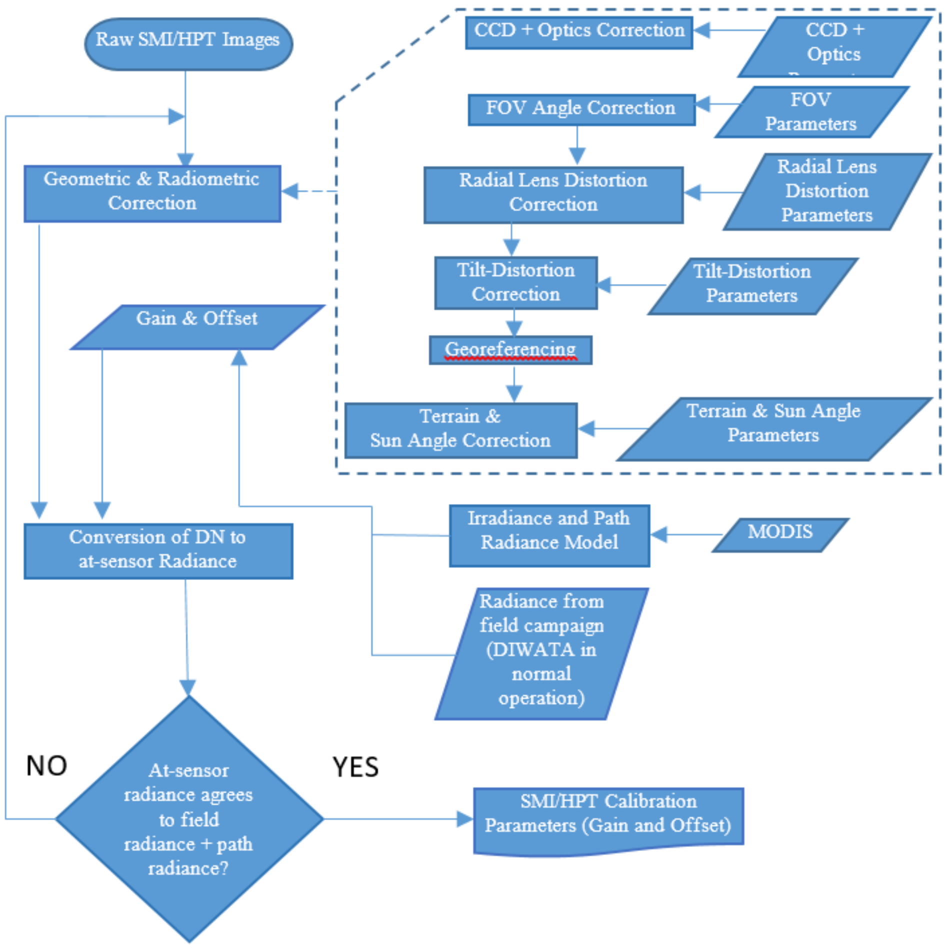

Figure 1. Calibration Method of the SMI & HPT Images

2. METHODOLOGY

2.1 Background Information of the Model

A simple spectral irradiance model has been used to produce terrestrial spectra encompassing different factors such as the slope and aspect of the surfaces, solar zenith angle, atmospheric turbidity, the amount of precipitable water vapour, aerosol optical depth, total ozone column, surface pressure and ground albedo.

The model computes for the total irradiance by adding the calculated direct normal irradiance and diffuse irradiance on inclined surfaces which is represented by

$$I_{T\lambda} = I_{D\lambda} * \cos(z) + I_{S\lambda} \qquad (2\text{-}1)$$

Where $I_{T\lambda}$ is the total irradiance, $I_{D\lambda}$ is the direct normal irradiance, z is the angle of incidence of the direct beam on the tilted surface and $I_{S\lambda}$ is the diffuse irradiance.

For the direct normal irradiance, the formula is given by

$$I_{D\lambda} = I_{o\lambda} * D * T_{r\lambda} * T_{a\lambda} * T_{w\lambda} * T_{o\lambda} * T_{u\lambda} \qquad (2\text{-}2)$$

As seen in Figure 2, the $I_{o\lambda}$ is the extra-terrestrial irradiance at the mean earth-sun distance for wavelength λ; D is the correction factor for the earth-sun distance while the $T_{r\lambda}$, $T_{a\lambda}$, $T_{w\lambda}$, $T_{o\lambda}$ & $T_{u\lambda}$ are the transmittance functions of the atmosphere at wavelength λ for for molecular (Rayleigh) scattering, aerosol attenuation, water vapor absorption, ozone absorption, and uniformly mixed gas absorption, respectively.

Furthermore, the diffuse irradiance on inclined surfaces is divided into three components: (1) the Rayleigh scattering component $I_{R\lambda}$, (2) the aerosol scattering component $I_{A\lambda}$, and (3) the component that accounts for multiple reflection of irradiance between the ground and the air $I_{G\lambda}$. The total scattered irradiance $I_{S\lambda}$ is then given by the sum

$$I_{S\lambda} = I_{R\lambda} + I_{A\lambda} + I_{G\lambda} \tag{2-3}$$

Based on (Bird & Riordan, December 1984), the calculations above are products of the improvements in the methodology by refining the earlier models Leckner, Brine, Iqbal, Justus and Paris. It was based on the comparisons of the results of rigorous radiative transfer codes and measured spectra.

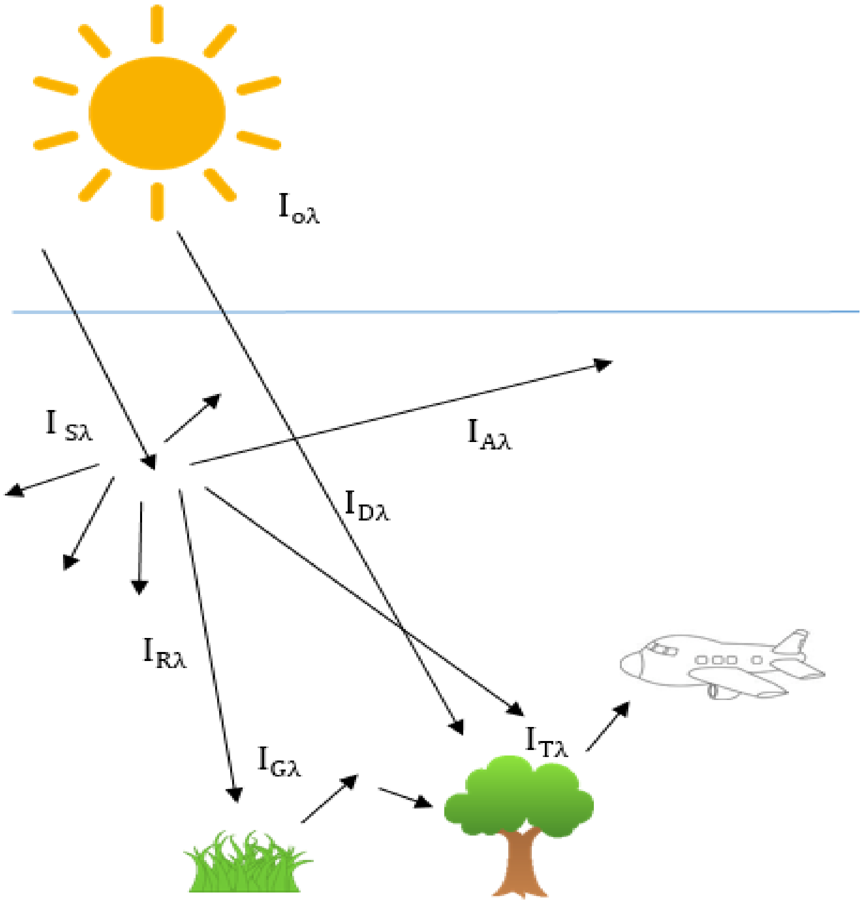

Figure 2. Diagram Representation of Irradiance

2.2 Datasets Used

The datasets used for the derivation of the spectral irradiance are mainly the MODIS Products and Digital Surface Model (DSM). MOD04_L2 (Aerosol), MOD05_L2 (Total Precipitable Water Vapor), MOD07_L2 (Temperature and Water Vapor Profiles) and MCD43A3 (Albedo product) were downloaded from Level 1 and Atmosphere Archive and Distribution System (LAADS Web, https://ladsweb.nascom.nasa.gov/) while the DSM was given by the Phil-LIDAR 1 program.

MODIS products were further extracted using MODIS Conversion Tool Kit which was used as a plugin for ENVI software. Aerosol Optical Depth (AOD) and atmospheric turbidity was obtained from MOD04_L2, total precipitable water vapour and surface pressure from MOD05_L2, total ozone column from MOD07_L2 and ground albedo from MCD43A3 while slope and aspect profile were derived from the DSM using ENVI topographic modeling.

Meanwhile, the field data from a Silicon Pyranometer were used to validate the model. The field campaign was occurred last March 29 – April 2, 2016 in Tarlac, Philippines. However, for the simplification of this paper, only the dataset from March 29 was shown to check the validity of the model.

2.3 Implementation of the Model

Figure 3 demonstrates the process flow for the model implementation and validation. The Silicon Pyranometer yielded a broadband irradiance data, which was filtered using Savitzky-Golay Smoothing Filter and processed afterwards by the pyranometer response curve (Figure 4) to produce its equivalent spectral irradiance. Broadband irradiance is the sum of all integrated area over a specific spectral range in a spectral irradiance. The spectral range used in this experiment is 300nm to 1100nm (spectral range of the silicon Pyranometer) as seen in Figure 4.

Necessary MODIS and DSM products were extracted and used in the model. The available working version of the spectral irradiance model is implemented in a spreadsheet format (http://rredc.nrel.gov/solar/models/spectral/). This was then converted into python for automation and efficiency. Both broadband and spectral irradiances were calculated by the model.

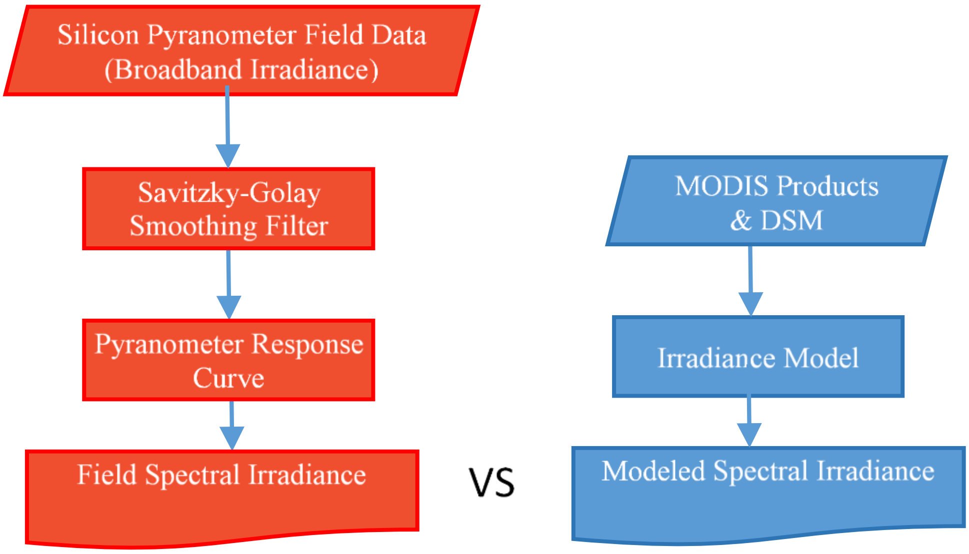

Figure 3. Process Flow of Model Implementation and Validation

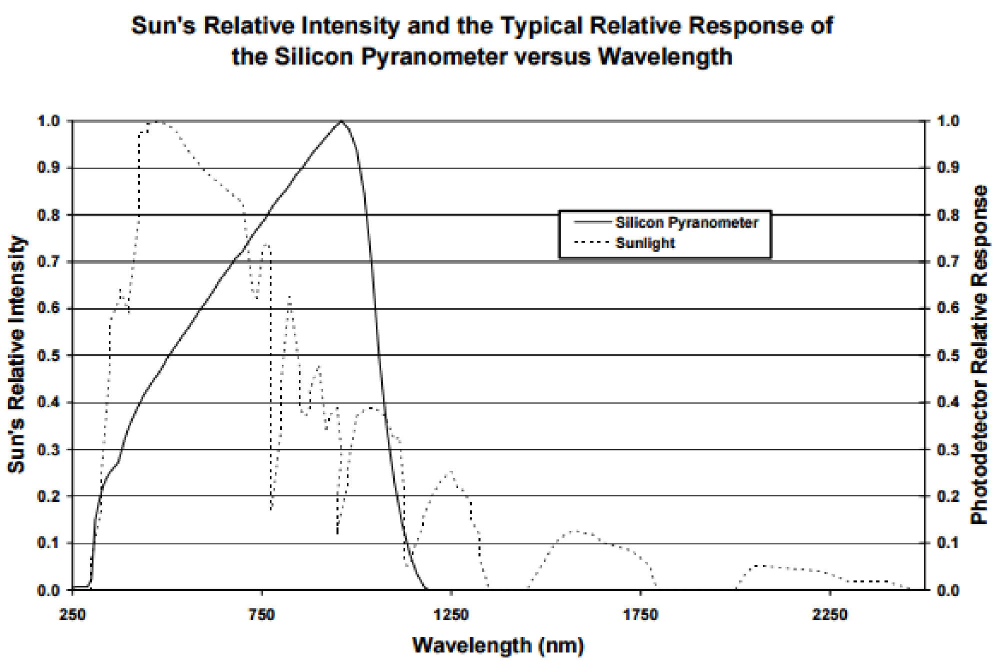

Figure 4. Silicon Pyranometer Response Curve

3. RESULTS AND DISCUSSION

3.1 Raw and Filtered Broadband Irradiance Comparison

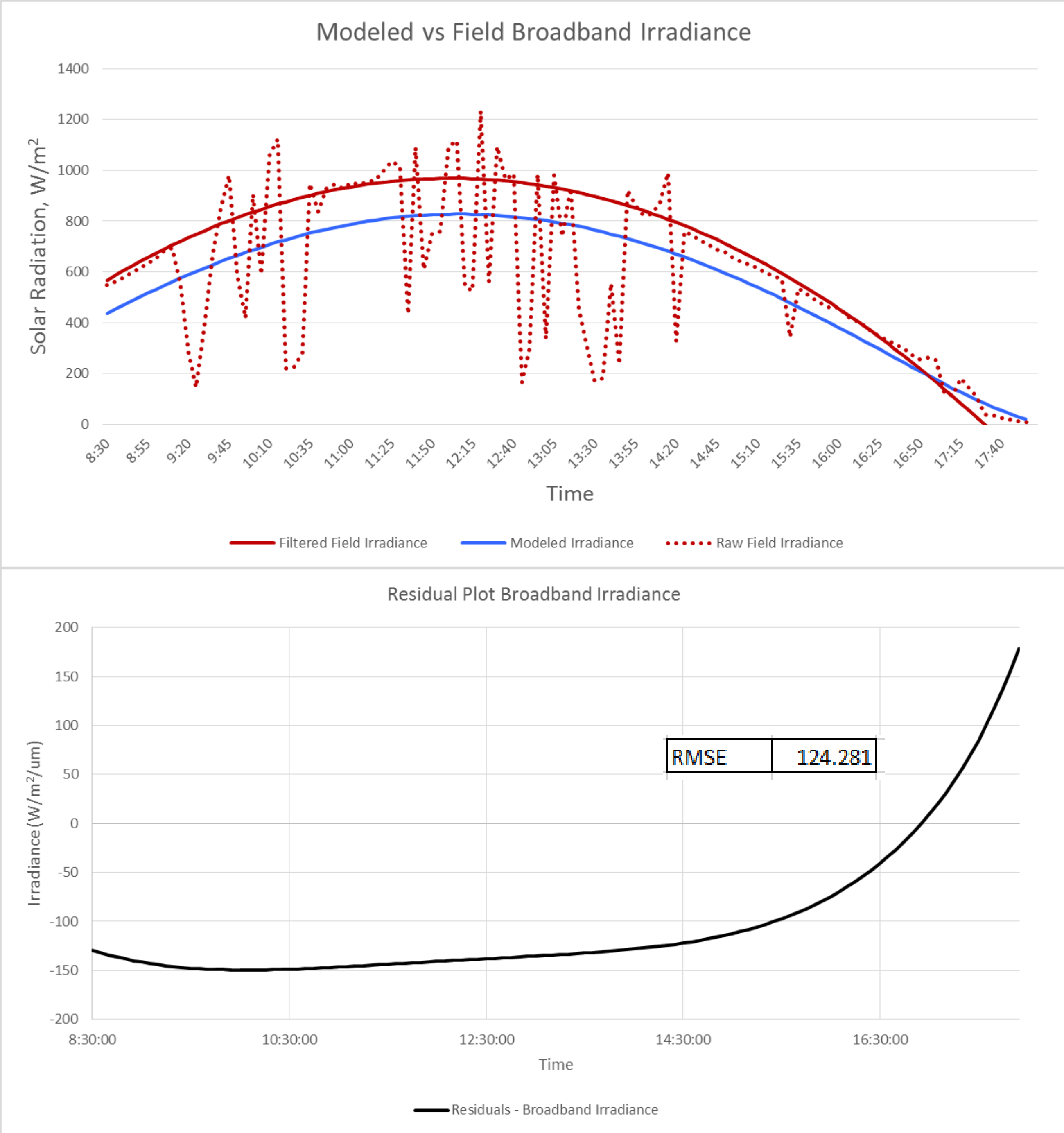

Figure 5. Modeled vs Field Broadband Irradiance (Raw and Filtered)

As perceived in Figure 5, broadband irradiance yielded from the pyranometer portrays a noisy output. This is true on actual scenarios where clouds are usually present. The dip demonstrates the presence of a cloud cover during that time period. To properly validate the model, the researcher used a filter to simulate a cloudless atmosphere. It is apparent to affirm that the field broadband irradiance validated the modeled broadband irradiance due to a low value RMSE of 124.281 W/m2/um.

3.2 Modeled vs Field Spectral Irradiance Per Band

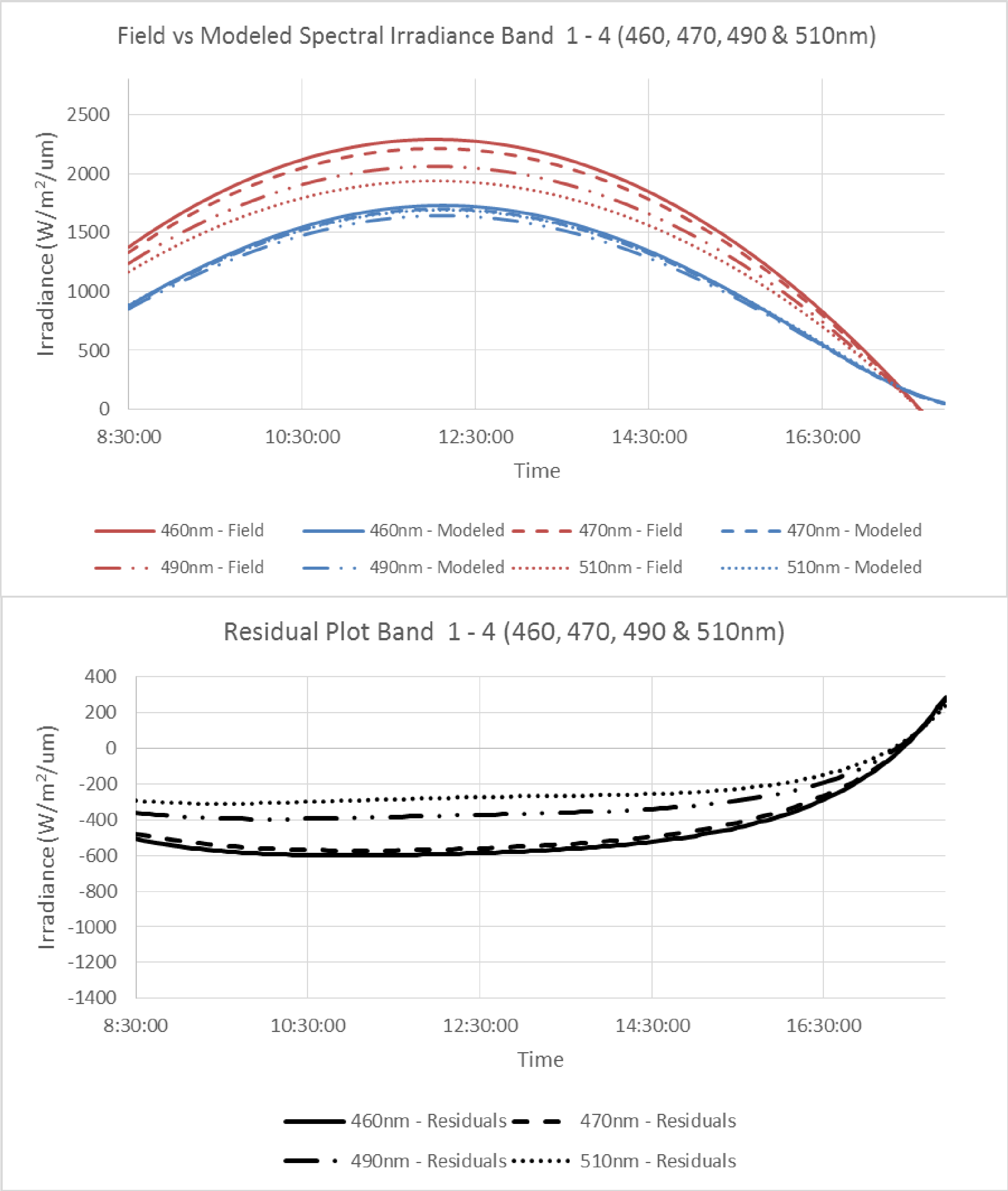

Figure 6. Modeled vs Field Spectral Irradiance (Band 1 -4)

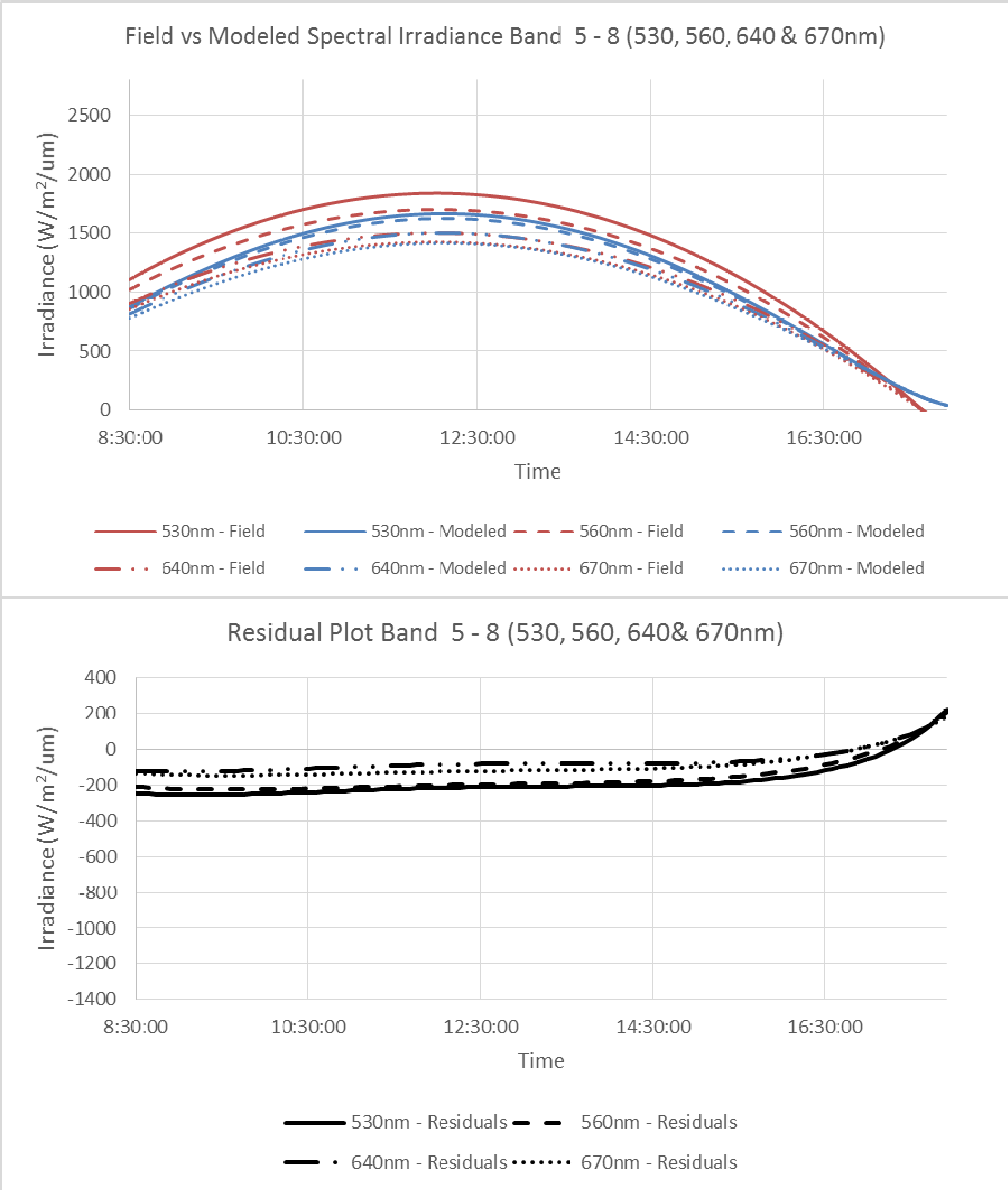

Figure 7. Field vs Modeled Spectral Irradiance (Band 5 -8)

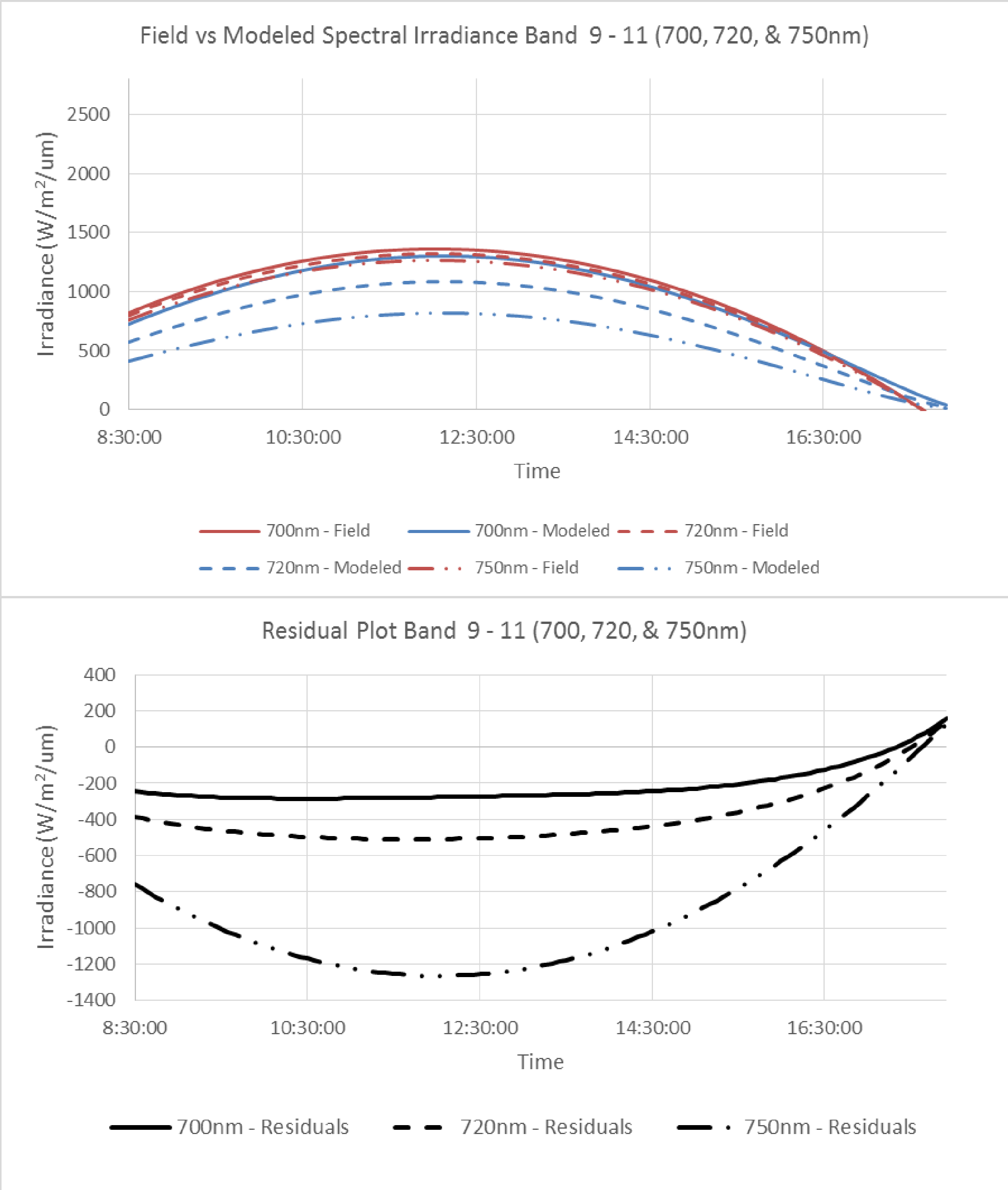

Figure 8. Field vs Modeled Spectral Irradiance (Band 9 -11)

Table 1. Summary of RMSE of Field and Modeled Spectral Irradiances from Band 1 - 11

Wavelength	*460nm*	*470nm*	*490nm*	*510nm*	*530nm*	*560nm*
RMSE	505.2564	478.9618	332.1358	253.2259	203.0659	182.0256
Wavelength	*640nm*	*670nm*	*700nm*	*720nm*	*750nm*	
RMSE	90.67547	115.161	238.0732	419.0258	980.6648	

Based on the Figures 6, 7 and 8, errors were more defined in the extreme bands compared to the inner bands. Accordingly, an RMSE of 90.67 W/m2/um in band 7 (0.64um) was produced but also yielded an RMSE of 980.66 W/m2/um in band 11 (0.75um).

4. CONCLUSIONS

The model implementation and validation presented in this paper provides a different result for broadband and spectral irradiances. The field irradiance confirmed the validity of the model when compared in terms of the broadband irradiance. However, when compared in terms of spectral irradiance, the model gave an impression of unsuitability due to high RMSE in most of the bands, specifically on the extreme side of the spectral range.

Nevertheless, it is imperative to check the type of the pyranometer used and its limitations. Based on (Alados-Arboledas, Batlles & Olmo, 1995), photovoltaic radiation sensors, such as the silicon pyranometer, have fast time responses necessary for measuring rapid solar radiation changes when clouds move in front of the sun. This explains the noisy output of the field irradiance. Also, the paper noted that using such kind of pyranometers as radiation sensors poses problems associated with the limited and non-uniform spectral response of silicon cells which can be detected in Figure 4. This clarifies the high RMSE when interpreted in terms of the spectral irradiance.

It would be of interest for future studies to compare the model to the output of a more spectral sensitive thermopile Pyranometer and check if the modeled spectral irradiance comes close to the field spectral irradiance.

ACKNOWLEDGEMENTS

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