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Examining a Vicarious Calibration Method for the TOA Radiance Initialization of KOMPSAT OSMI

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Abstract : A vicarious calibration method was developed for the OSMI sensor calibration. Employing measured aerosol optical thickness by a sunphotometer and a sky radiometer and water leaving radiance by ship measurements as inputs, TOA (top of the atmosphere) radiance at each OSMI band was simulated in conjunction with a radiative transfer model (Rstar5b) by Nakajima and Tanaka (1988).

As a case of examining the accuracy of this method, we simulated TOA radiance based on water leaving radiance measured at NASA/MOBY site and aerosol optical thickness estimated nearby at Lanai, and compared simulated results with SeaWiFS-estimated TOA radiances. The difference falls within about ±5%, suggesting that OMSI sensor can be calibrated with the suggested accuracy. In order to apply this method for the OSMI sensor calibration, ground-based sun photometry and ship measurements were carried out off the east coast of Korean peninsula on May 31, 2000. Simulations of TOA radiance by using these measured data as input to the radiative transfer model show that there are substantial differences between simulated and OSMI-estimated radiances. Such a discrepancy appears to be mainly due to the cloud contamination because satellite image indicates optically thin clouds over the experimental area. Nevertheless results suggest that sensor calibration can be achieved within 5% uncertainty range if there are ground-based measurements of aerosol optical thickness, and water leaving radiances under clear-sky and optically thin atmospheric conditions.

Key Words : Calibration, OSMI, TOA Radiance.

1. Introduction

Geophysical parameters such as ocean color and surface albedo can be retrieved from solar spectral measurements from satellites because the radiation interferes with surface and atmospheric gases while photon is traveling the atmosphere and reflecting from the surface. In particular, for the ocean color remote sensing, water leaving radiance (L_W) can be retrieved from the total radiance measured from the sensor (L_t) by removing the atmospheric contribution. The radiance backscattered from the atmosphere and sea surface is typically larger than the radiance

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scattered out of the water. Because of the dominant influence of atmosphere on the total radiance, exact sensor calibration is important while development of atmospheric algorithm and its validation are also indispensable.

The response characteristics of satellite radiometers vary during the flight, so various methods should be developed to calibrate satellite radiometers. Methods depend on simultaneous satellite measurements with ground-based and aircraft measurements of the reflectance of the earth's surface and the optical properties of the atmosphere. As a case in point, Moderate Resolution Imaging Spectroradiometer (MODIS) employs various methods in comparison of satellite-derived radiances with in-situ measurements obtained from ocean and land surfaces. The reflectance-based method relies on ground-based surface reflectance measurements of a selected target at the time of sensor overpass (Slater *et al.*, 1987). The irradiance-based method (Biggar *et al.*, 1990) employs measurements of the downwelling global and diffuse irradiances to determine the radiance at the top of the atmosphere to avoid the numerous assumptions such as reflectance-based method about the size distribution and composition of aerosols in the atmosphere. The radiance-based method uses the aircraft measured radiances (Thome, 1999). For the SeaWiFS sensor calibration, the instrument and the algorithm are calibrated simultaneously for visible and infrared spectrum. In the visible band, calibrations are made against MOBY (Marine Optical Buoy) measured water leaving radiance (L_w) by adjusting the gains in visible bands until satellite-derived L_w matches up to the MOBY-estimated L_W. Assuming other visible bands are correctly calibrated, it is tested whether the relation between aerosol radiances in two infrared bands equates to the assumed maritime aerosol at the MOBY site.

For the Korean Multi-purpose Satellite (KOMPSAT) Ocean Scanning Multi-Sspectral Imager (OSMI) sensor calibration, we develop a vicarious method that is similar to the reflectance-based method. TOA radiances are simulated to match the OSMI counts, with inputs of measured aerosol optical thickness from a sun photometer and a sky radiometer, and water leaving radiance by ship measurements to the radiative transfer model (Rstar5) developed by Nakajima and Tanaka (1988). Maritime aerosol has been assumed for simulating the TOA radiance.

2. Methodology

1) Vicarious Calibration

The OSMI channel of the KOMPSAT satellite can be calibrated with a linear relationship converting measured digital counts C to a TOA radiance L_T, i.e.:

$$L_T = \alpha\,(C - Co) \qquad (1)$$

where α is the calibration coefficient and C_o is the count observed at space view (dark count), which corresponds to the zero offset. The obtained radiance is then used for estimating the ocean color by removing the atmospheric effect.

In order to estimate the calibration coefficient for the OSMI sensor, we estimate the calibration coefficient by first simulating OSMI channel radiances with inputs of aerosol optical thickness from a sunphotometer and a sky radiometer, and shipboard upwelling radiance to the Rstar5 radiative transfer model. Then obtained TOA radiances are regressed against OSMI measured counts as in eq. (1). Since the most significant uncertainties are induced from the presence of clouds, we select cloud-free conditions with homogeneous maritime aerosol.

2) Radiative Transfer Model

For the TOA simulations we employ the radiative transfer model (Rstar5 version b) developed by Nakajima and Tanaka (1988) using the transfer scheme of Nakajima and Tanaka (1986) for an atmosphere with plane-parallel geometry and horizontally homogeneous layers. The Rstar5b simulates radiation fields in the atmosphere-land-ocean system at wavelength regime between 0.2 and 200 μm. A plane-parallel atmosphere is divided into several homogeneous sub-layers with assumed underlying ground or ocean surface.

Since Rstar5b model does not include a specific maritime aerosol model despite of 11 different aerosol types presented in Table 1, we use the external mixture of the two aerosol models, i.e., model 8, sea spray and model 10, troposphere aerosol with 5.14 and 1.0 as respective ratios (Nakajima, 2000, personal communication). The reflectance of the sea surface is considered in the Rstar5b, following the theoretical 40-layer model for solar reflection associated with wind-roughened ocean surface as described by Nakajima and Tanaka (1983). For the ocean surface wind we used Special Sensor for Microwave Imager (SSM/I) wind product (Wentz, 1992). Dependence on solar zenith angle, satellite viewing angle, and their azimuth angle difference were also counted in the model.

Table 1. Particle model type of radiative transfer model Rstar 5 (Nakajima and Tanaka, 1988).

Model Number	Aerosol Type	Model Number	Aerosol Type
1	Water	7	Rural
2	Ice	8	Sea Spray
3	Dust-like	9	Urban
4	Soot	10	Tropo
5	Volcanic-ash	11	Yellow Sand
6	75% H2SO4		

3. Input Data

1) Aerosol Optical Thickness

Aerosol optical thickness $\tau_{a\lambda}$ is obtained from direct solar irradiance measurements by a sunphotometer (PREDE PSF-100) at wavelengths centered at 368, 500, 675, and 775 nm and a sky radiometer (PREDE POM-01L) at wavelengths centered at 315, 400, 500, 675, 870, 940, and 1020 nm. It is determined by subtracting optical thickness by Rayleigh scattering ($\tau_{R\lambda}$) and by ozone absorption ($\tau_{o\lambda}$), i.e.:

$$\tau_{a\lambda} = \frac{\ln(F_{o\lambda}/F_{\lambda})}{m} - \tau_{R\lambda} - \tau_{o\lambda} \qquad (2)$$

where $F_{o\lambda}$ is the direct solar radiation assumed to be at the top of the atmosphere and F_{λ} is the measured direct solar radiation at the ground. Relative optical air mass m is obtained by the inverse of cosine of the solar zenith angle. Optical thickness of Rayleigh scattering is calculated using a formula by Hansen and Travis (1974), i.e.:

$$\tau_{R\lambda} = (0.008569\lambda^{-4}(1+0.0113\lambda^{-2}+ 0.00013\lambda^{-4}))p/p_o \qquad (3)$$

where p is atmospheric surface pressure and p_o is the standard atmospheric pressure of 1013.25mb. For the calculation of ozone optical thickness, we use daily mean column ozone amount estimated by Nimbus 7 Total Ozone Mapping Spectrometer (TOMS). Surface pressure is from National Centers for Environmental Prediction (NCEP) reanalysis data.

The OSMI consists of four bands in the visible at 412, 443, 490, 555 nm with bandwidth of 20 nm and two bands in the near infrared at 765, 865 nm with bandwidth of 40 nm. The sunphotometer and skyradiometer altogether consist of seven bands at 315, 368, 400, 500, 675, 778, 870 nm whose spectral locations do not match to those of OSMI channels. Because of the discrepancy of spectral bands between OSMI and sunphotometry instruments, the measured optical thickness for a given spectrum is converted into that at the closest OSMI channel wavelength by applying a theoretical relationship of optical thickness between two bands which is also obtained from radiative transfer model simulation.

Fig. 1 shows diagrams of theoretical

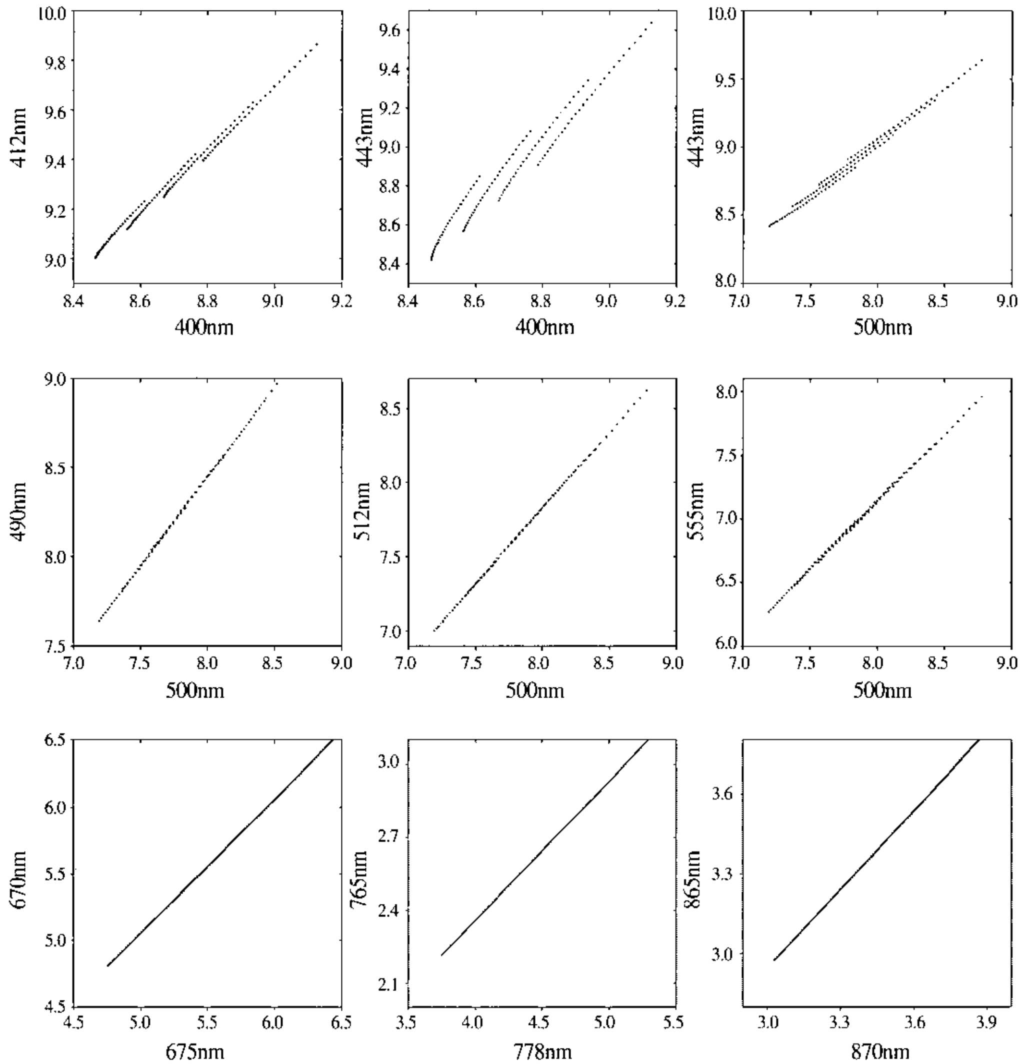

Fig. 1. Relationship of TOA total radiance at spectral bands between photometry instruments and OSMI sensor, obtained from theoretical calculations. Abscissa and ordinate represent the total radiance given in mW cm^{-2} μm sr^{-1} at the sunphotometer and sky radiometer channel wavelength, and at OSMI channel wavelength, respectively.

relationships of TOA radiance between two adjacent channels of OSMI and photometry instruments. Maritime aerosol is assumed. Employing the theoretical relationship given in Fig. 1, optical thickness estimated from sunphotometer and sky radiometer are inserted into the radiative transfer model for calculating TOA radiance at OSMI spectral bands, for the given wind speed.

2) Water leaving radiance (L_W)

The ship measurements of the water leaving radiances are taken simultaneously with sun photometry measurements at the observation site around which the sub-satellite point of the polar orbiting KOMPSAT is located. Detailed information on the instrument and measurements are found in Yoo *et al.* (2000).

4. Results

The clear-sky SeaWiFS-estimated radiances at 25 targets for January 28, 1999 in the East Sea are first simulated in order to test if the proposed methodology reproduces the expected radiances reasonably well. The locations of targets are given in Fig. 2. For the simulation, SeaWiFS associated aerosol thickness and SSM/I-derived wind speed are used for specifying atmospheric condition and surface reflectance respectively, in conjunction with the assumption of prevailed maritime aerosol. For specifying the upwelling radiance as surface boundary condition, nominal values of

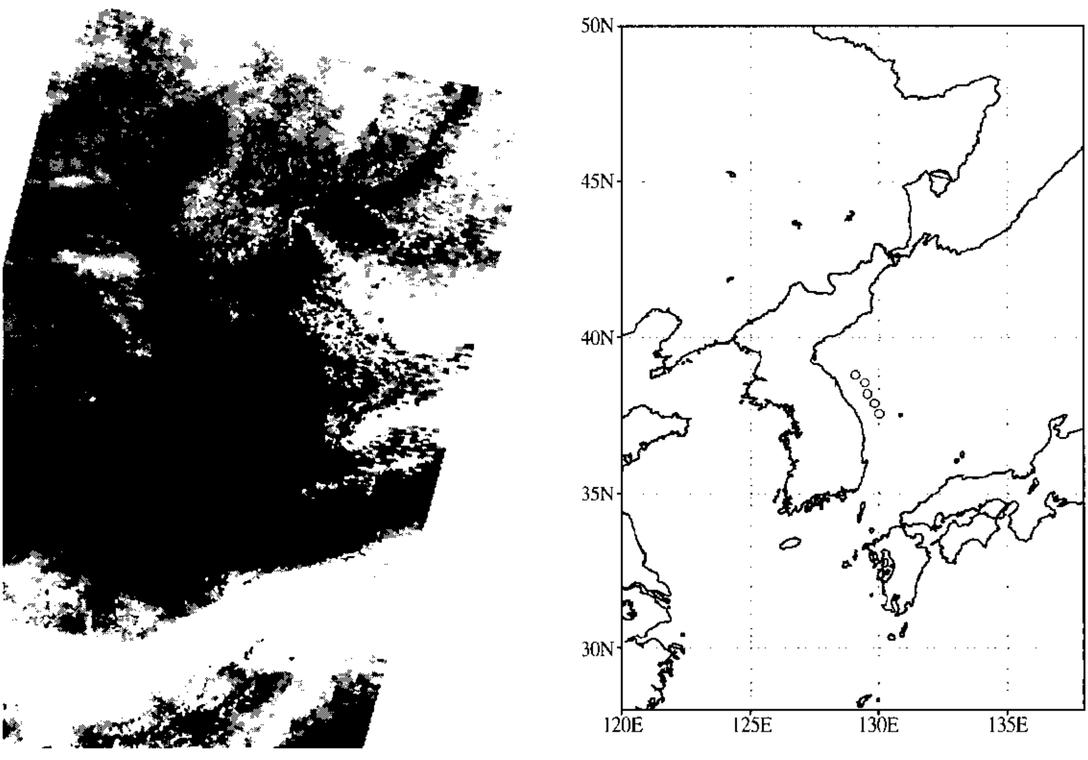

Fig. 2. Locations of 25 SeaWiFS targets used for radiance simulation, along with SeaWiFS image for January 28, 1999. Each circle in the right panel consists of five target points.

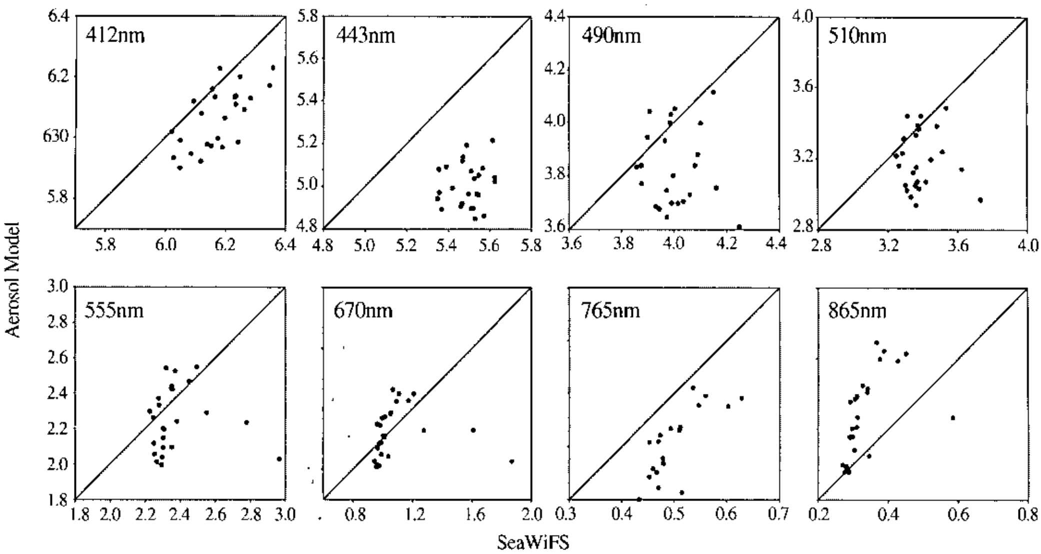

Fig. 3. Total radiances at the top of the atmosphere at 25 SeaWiFS targets in the East Sea. The ordinate and abscissa represent the model-simulated and SeaWiFS-estimated radiance in mW cm^{-2} μm sr^{-1}, respectively.

contribution ratio to the TOA signal from below the sea surface are used (Sturm, 1981).

The result presented in Fig. 3 shows that both are in general agreement although simulated total radiances are smaller than those from the SeaWiFS measurements in the visible bands while opposite behaviors are found in the near-infrared bands. The bias errors are about 510%, which may be attributed to input errors from nominal values of water leaving radiances multiplied by atmospheric transmittance and SeaWiFS-processed aerosol optical thickness. Nonetheless reasonably well-matching patterns suggest that the proposed vicarious method can be used for calibrating the OSMI sensor.

In order to further test the feasibility of the vicarious method for calibrating OSMI sensor, SeaWiFS-estimated TOA radiances are simulated with the measured water leaving radiance and optical thickness. The surface measurements at the MOBY site (20° 49.7′ N, 157° 11.4′ W) deployed in the west of the Hawaii Islands consist of water leaving radiance see Fig. 4 for the location of the MOBY site. The primary purpose of MOBY site is to measure visible and near-infrared radiation entering into and emanating from the sea surface by running radiometry instruments in the spectral range from 380 to 900 nm with approximately 2~4 nm spectral resolution. For the aerosol optical thickness we use sunphotometer-derived value at Lanai (20° 49′ N, 156° 59′ W) which is about 100 km apart from the MOBY site.

Results are given in Fig. 5. The comparison shows a very good agreement despite of the general underestimation of simulated radiance throughout the channels. The difference appears to be within about 5% of the signal, suggesting that the sensor calibration can be achieved within about 5% error limit for a given ground-based measurements under the clear-sky conditions and thus the proposed vicarious calibration method can be used for the OSMI sensor calibration.

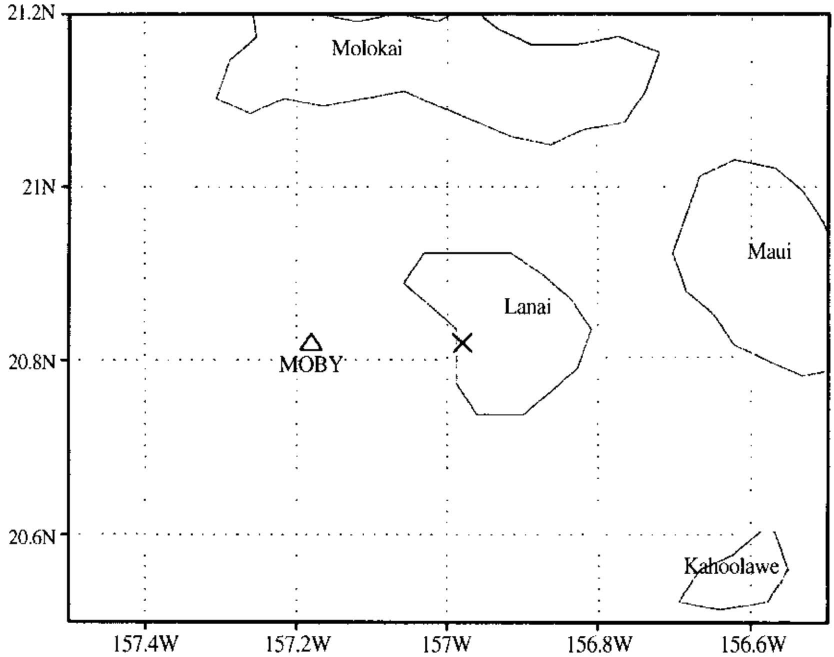

Fig. 4. Locations of MOBY site and a ground-based sunphotometer site, Lanai.

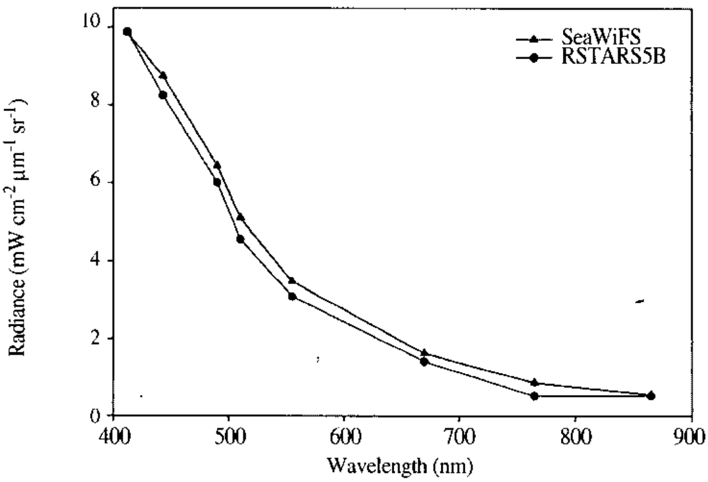

Fig. 5. TOA total radiance from SeaWiFS measurements (triangle) and Rstar5 model simulation (circle) for September 26, 1998 at the MOBY site.

Applying the tested method for calibrating the OSMI sensor, ground-based measurements of solar irradiance using one sunphotometer and one sky radiometer were conducted at Mukho on the east coast of Korean peninsula on May 31, 2000. Along with sun photometry measurements, upwelling radiances were simultaneously measured at one ocean location 20 km off the Mukho coast while an

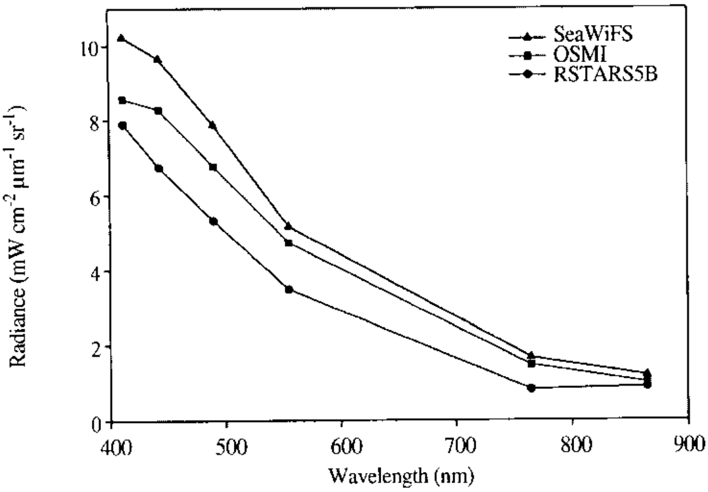

Fig. 6. TOA total radiance from OSMI (square), SeaWiFS (triangle) estimation, and model simulation (circle) for May 31, 2000 on the east coastal ocean near Mukho, Kangwon Do.

OSMI overpass was made. The OSMI radiance was obtained after intercalibrating against SeaWiFS (Kim and Lee, 2000).

Obtained results are presented in Fig. 6. In this diagram, the observation times were 11:48 for OSMI and 12:59 May 31, 2000 for SeaWiFS, The comparison of OSMI radiance with SeaWiFS radiance is not straightforward because there are intrinsic differences in solar and satellite geometry due to the different equatorial crossing time, so caution must be exercised before drawing any conclusions from Fig. 6. In contrast to the good agreement between model-simulated and SeaWiFS-estimated radiance given in Fig. 5, the simulation result shows a substantial bias to lower value in comparison to OSMI values. In the aftermath of the experiment, satellite image analysis suggests that there existed optically thin clouds during the satellite overpass. Thus, the large discrepancy existing between the OSMI-estimated and model simulated radiances appears to be attributed to the cloud contamination. The lights scattered by the ice particles or water droplets should have caused hazy conditions found in the image analysis. Thus, absolutely clear days should be chosen for the successful sensor calibration using in-situ measurements.

5. Conclusions

For the calibration of the OSMI sensor, TOA radiance was simulated using a radiative transfer model, with measured aerosol optical thickness and upwelling radiance as inputs. The method has been tested against SeaWiFS-estimated radiance by employing observation data at the MOBY site. The result indicates that ocean color sensor calibration can be achieved within about 5% error range for a given clear-sky condition.

In order to apply the developed methodology for calibrating OSMI sensor, sunphotometer and sky radiometer measurements were performed at Mukho on the east coast of the Korean peninsula, along with the measurement of upwelling radiance from below ocean surface at one location

20km off the Mukho coast while KOMPSAT overpass was made. However, experiment was not satisfied because of the cloud contamination. Clear-sky condition and homogeneous airmass are prerequisite for the accurate calibration.

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