Effective Band Center Wavelengths for MODIS and VIIRS for Open Ocean Waters

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INTRODUCTION

- The in-band and out-of-band responses refer to sensor spectral response contribution from within and outside the spectral bandwidth of the sensor bands, while total-band refers to the contribution from in-band as well as out-of-band regions (Wang et al., 2001).
- Most ocean color satellite sensors in addition to an in-band contribution, have a significant contribution from out-of-band region. Although the out-of-band effects can be small, it is not uniform over all bands hence can cause biases in derived biogeochemical variables.
- The out-of-band contributions for Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) are relatively well characterized as compared to Visible Infrared Imaging Radiometer Suite (VIIRS).
- The objectives of this study are to analyze the sensor out-of-band effects for MODIS as well as VIIRS, and to determine their effective band center wavelengths using hyperspectral data from MOBY measurements. This study has been documented in our recent conference proceeding paper (Naik and Wang, 2014).

METHODS & DATA

- The hyperspectral normalized water-leaving radiance ($nL_w(\lambda)$) spectra from MOBY were convolved with respect to spectral response functions from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS) sensors to obtain the total-band and in-band averaged radiances as follows:

$$nL_w^{(Total)}(\lambda) = \frac{\int_{All} nL_w(\lambda) RSR(\lambda)\, d\lambda}{\int_{All} RSR(\lambda)\, d\lambda}$$

and

$$nL_w^{(In\text{-}Band)}(\lambda) = \frac{\int_{\pm 1\%} nL_w(\lambda) RSR(\lambda)\, d\lambda}{\int_{\pm 1\%} RSR(\lambda)\, d\lambda}$$

RSR(λ) - sensor spectral response function.

- The out-of-band contribution can be calculated as the ratio of spectrally averaged radiances for total subtract in-band versus in-band as shown below:

$$OOB(\%) = \left(\frac{nL_w^{(Total)}(\lambda)}{nL_w^{(In\text{-}Band)}(\lambda)} - 1 \right) \times 100$$

- In situ data for this study were obtained from the Marine Optical Buoy (MOBY) in the waters off Hawaii (http://coastwatch.noaa.gov/moby/).
- MOBY is deployed in clear oligotrophic oceanic waters (chlorophyll-a is in the range of ~0.01–0.1 mg m^{-3}).
- Hyperspectral $nL_w(\lambda)$ data from MOBY covers wavelengths range from ~340 nm to 750 nm.
- The hyperspectral resolution of $nL_w(\lambda)$ from clear oceanic waters makes MOBY an optimum platform to analyze sensor out-of-band effects.
- Prior to the calculation of the band averages, the spectral response function values are interpolated to the $nL_w(\lambda)$ wavelength resolution.

Total-band and In-band averaged $nL_w(\lambda)$ – MOBY Site

MODIS

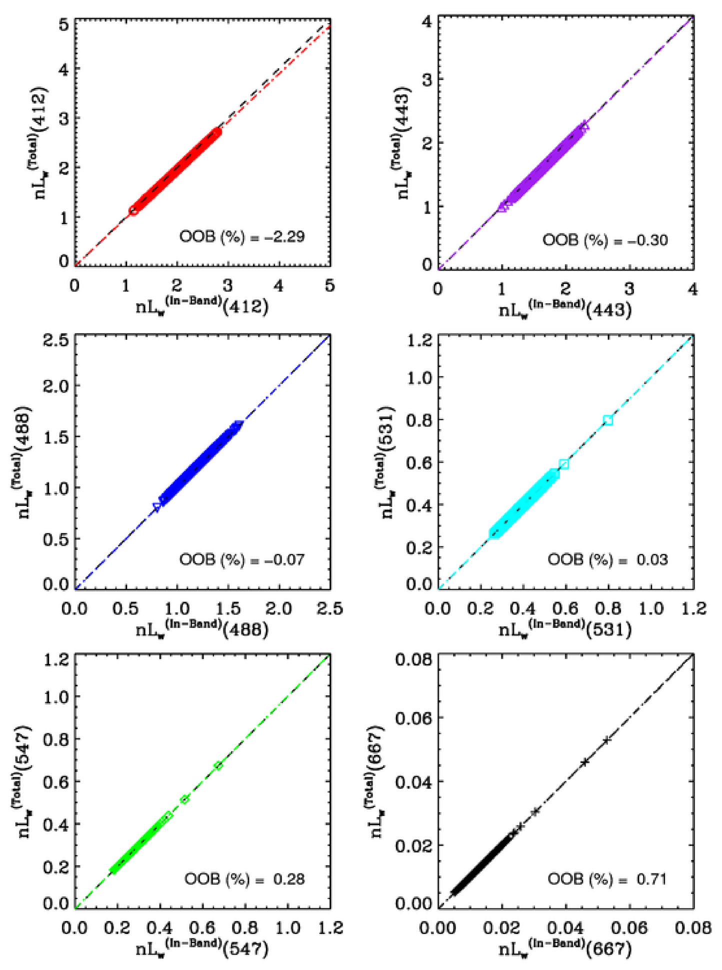

Fig.1 : Total-band and in-band averaged $nL_w(\lambda)$ comparisons at selected MODIS bands. The dotted line is the 1:1 fit.

VIIRS

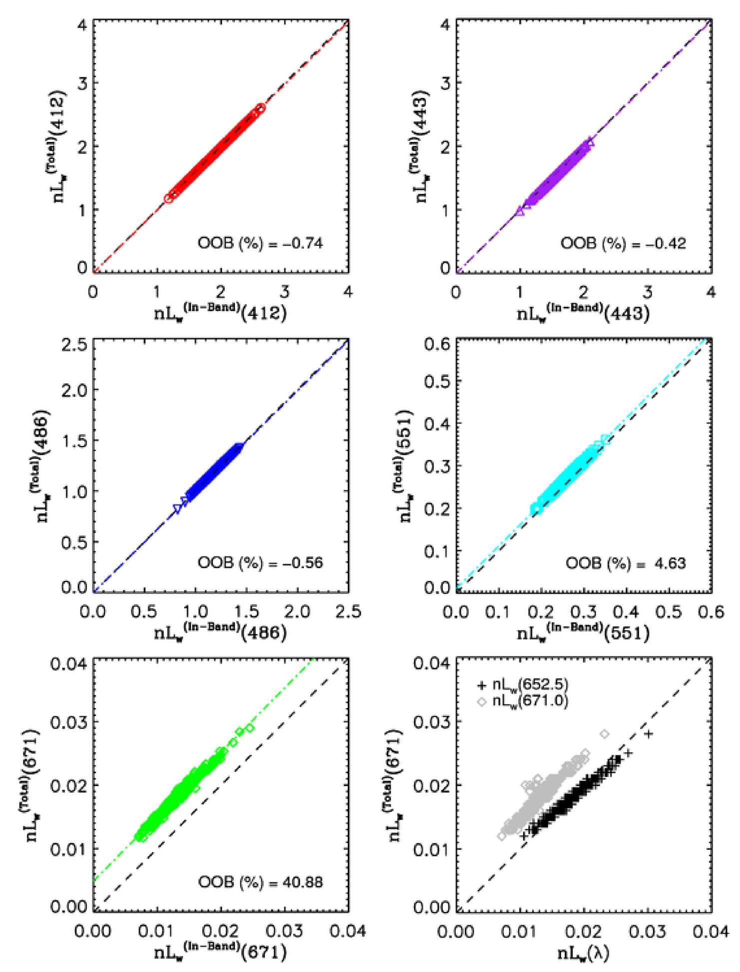

Fig.2 : Total-band and in-band averaged $nL_w(\lambda)$ comparisons at selected VIIRS bands. The dotted line is the 1:1 fit.

- Figures 1 and 2 show the comparisons between total-band and in-band $nL_w(\lambda)$ averaged radiances at the MOBY site (open oceans) for MODIS and VIIRS, respectively.
- For the MOBY site (open oceans) the out-of-band contribution for MODIS is less than ~3% for the bands we have analyzed. While, for VIIRS, the out-of-band contribution is less than ~5% except for band M5 (671 nm).
- The high out-of-band contribution at the band M5 of VIIRS is due to a large leakage (out-of-band spectral distribution) from the blue region of the spectrum.
- In general, the out-of-band response is greater for VIIRS relative to MODIS, except at the blue band.

Effective band center wavelengths – MOBY Site

MODIS

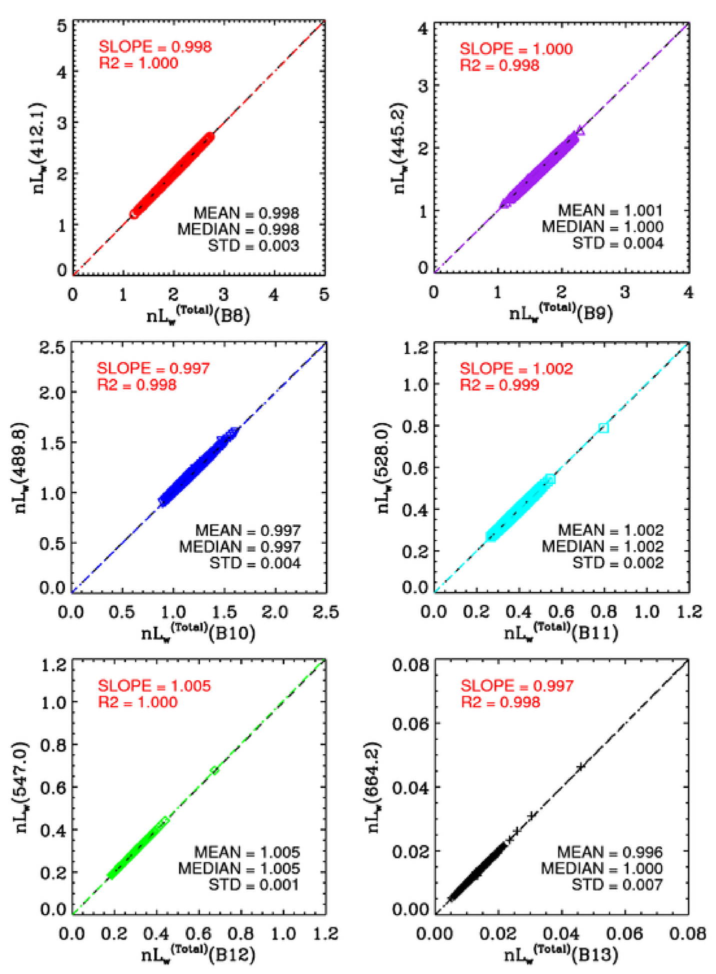

Fig.3 : Effective center wavelengths for selected MODIS bands. The dotted line is the 1:1 fit.

VIIRS

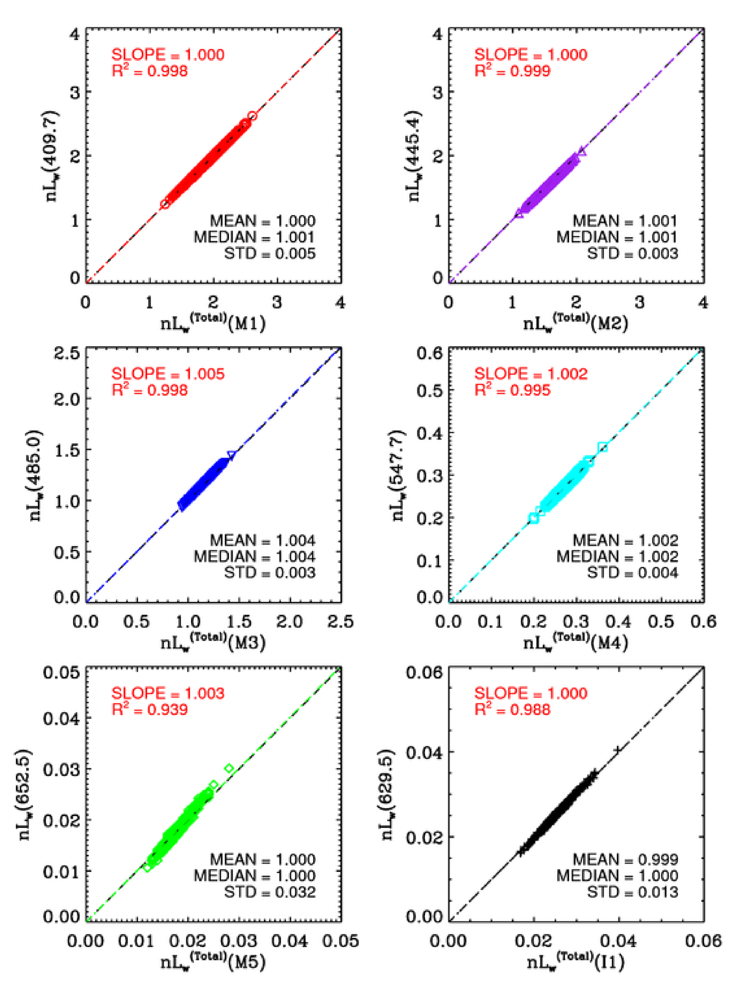

Fig.4 : Effective center wavelengths for selected VIIRS bands. The dotted line is the 1:1 fit.

Table 1. The ratio between $nL_w(\lambda)$ at the nominal band center and total-band averaged $nL_w(\lambda)$, and the effective band center wavelengths for MODIS and VIIRS.

MODIS			VIIRS		
Nominal Center Wavelength (nm)	nL_w(nominal)/ nL_w(Total)	Effective Center Wavelength (nm)	Nominal Center Wavelength (nm)	nL_w(nominal) / nL_w(Total)	Effective Center Wavelength (nm)
412 (B8)	0.994	412.1	410 (M1)	1.022	409.7
443 (B9)	1.034	445.0	443 (M2)	0.959	445.4
488 (B10)	0.977	489.8	486 (M3)	1.072	485.0
531 (B11)	1.012	528.0	551 (M4)	1.078	547.7
551 (B12)	1.005	547.0	671 (M5)	1.399	652.5
667 (B13)	0.977	664.2	635 (I1)	1.070	629.5

- The significant out-of-band response that we noticed can cause an increase in the observed radiance above the measurement for the nominal center band.
- The ratio of the radiance at nominal center wavelength to total-band averaged radiances gives an estimate for out-of-band response on the derived $nL_w(\lambda)$ at nominal center wavelengths (Table 1). Ratio values greater than 1 indicate an underestimation, while ratio values less than 1 show an overestimation relative to the total-band averaged $nL_w(\lambda)$.
- For MODIS, except for bands 412 and 488 nm, all the other bands are biased low, whereas for VIIRS all the bands are biased low except for 443 nm (M2). The largest bias is seen in the VIIRS M5 band, consistent with the results from the total-band and in-band comparisons.
- We determined the effective band center wavelengths for MODIS and VIIRS by comparing the total-band averaged $nL_w(\lambda)$ to $nL_w(\lambda)$ at the individual wavelength measured by in situ radiometers at the MOBY site. In essence, the individual wavelengths are adjusted until the slope equals 1 between $nL_w(\lambda)$ radiance at the individual wavelengths and the corresponding total-band averaged values (Fig. 3 and Fig. 4).
- Figures 3, 4, and Table 1 show the effective band center wavelengths for MODIS and VIIRS determined using the scheme described in methods.
- The effective band center wavelengths are within ±6 nm of the nominal center wavelengths for both MODIS and VIIRS, except for the VIIRS M5 band.

CONCLUSIONS

- From the results of the out-of-band correction, we show that there was up to ~5% out-of-band response (except for VIIRS M5 band with much large effect).
- This results in significant contribution from outside the nominal center wavelength of the sensor wavebands. A significant out-of-band response can cause an increase in the observed radiance above the measurement for the nominal center band.
- The effective band center wavelengths are significantly different from the nominal center wavelengths for both MODIS and VIIRS for some bands. It is noted that the effective band center wavelengths in Table 1 represent the center band wavelengths of MODIS and VIIRS-measured $nL_w(\lambda)$ for open ocean waters.

References:

[1] M. Wang, B. A. Franz, R. A. Barnes, and C. R. McClain, "Effects of spectral bandpass on SeaWiFS-retrieved near-surface optical properties of the ocean," *Appl. Opt.*, vol. 40, pp. 342–348, 2001.

[2] P. Naik and M. Wang, Evaluation of in situ radiometric data processing for calibration and validation of satellite ocean color remote sensing, SPIE Ocean Sensing and Monitoring VI, May 6-7, 2014, Baltimore, Maryland.

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