ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

A novel method for destriping of OCM-2 data and radiometric performance analysis for improved ocean color data products

Rakesh Kumar Singh, Palanisamy Shanmugam *

Ocean Optics and Imaging Laboratory, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600036, India

Received 12 January 2018; received in revised form 21 February 2018; accepted 13 March 2018

Abstract

Despite the capability of Ocean Color Monitor aboard Oceansat-2 satellite to provide frequent, high-spatial resolution, visible and near-infrared images for scientific research on coastal zones and climate data records over the global ocean, the generation of science quality ocean color products from OCM-2 data has been hampered by serious vertical striping artifacts and poor calibration of detectors. These along-track stripes are the results of variations in the relative response of the individual detectors of the OCM-2 CCD array. The random unsystematic stripes and bandings on the scene edges affect both visual interpretation and radiometric integrity of remotely sensed data, contribute to confusion in the aerosol correction process, and multiply and propagate into higher level ocean color products generated by atmospheric correction and bio-optical algorithms. Despite a number of destriping algorithms reported in the literature, complete removal of stripes without residual effects and signal distortion in both low- and high-level products is still challenging. Here, a new operational algorithm has been developed that employs an inverted gaussian function to estimate error fraction parameters, which are uncorrelated and vary in spatial, spectral and temporal domains. The algorithm is tested on a large number of OCM-2 scenes from Arabian Sea and Bay of Bengal waters contaminated with severe stripes. The destriping effectiveness of this approach is then evaluated by means of various qualitative and quantitative analyses, and by comparison with the results of the previously reported method. Clearly, the present method is more effective in terms of removing the stripe noise while preserving the radiometric integrity of the destriped OCM-2 data. Furthermore, a preliminary time-dependent calibration of the OCM-2 sensor is performed with several match-up in-situ data to evaluate its radiometric performance for ocean color applications. OCM-2 derived water-leaving radiance products obtained after calibration show a good consistency with in-situ and MODIS-Aqua observations, with errors less than the validated uncertainties of ±5% and ±35% endorsed for the remote-sensing measurements of water-leaving radiance and retrieval of chlorophyll concentrations respectively. The calibration results show a declining trend in detector sensitivity of the OCM-2 sensor, with a maximum effect in the shortwave spectrum, which provides evidence of sensor degradation and its profound effect on the striping artifacts in the OCM-2 data products.

Keywords: Remote sensing; OCM-2 sensor; Data quality; Destriping; Calibration; Coastal waters

1. Introduction

The Ocean Color Monitor (OCM) was successfully launched aboard the OCEANSAT-2 satellite on September 23, 2009. The OCM-2 sensor enables monitoring of the ocean, land, and atmosphere in eight spectral bands ranging from the visible to the near-infrared at a spatial resolution of 360 m × 250 m (Table 1). Owing to its high spatial resolution, an increasing community of research scientists and coastal zone managers is actively involved in making use of the OCM-2 data for understanding the coastal ocean

* Corresponding author.
E-mail address: pshanmugam@iitm.ac.in (P. Shanmugam).

https://doi.org/10.1016/j.asr.2018.03.021
0273-1177/

Please cite this article in press as: Singh, R.K., Shanmugam, P. A novel method for destriping of OCM-2 data and radiometric performance analysis for improved ocean color data products. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.03.021

Table 1
Specifications and features of OCM-2 sensor (Chauhan and Navalgund, 2009).

Parameters		Specifications
Instantaneous Geometric Field of View (m)		360 × 250
Swath Width (km)		1420
Number of Spectral Bands		8
Spectral Range (nm)		402–885
Spectral Bands (nm)		B1: 404–424
		B2: 431–451
		B3: 476–496
		B4: 500–520
		B5: 546–566
		B6: 610–630
		B7: 725–755
		B8: 845–885
Quantisation Bits		12
Along-track steering		± 20°
Targeted error budget	Chlorophyll-*a*	<30%
	Vertical diffuse attenuation coefficient (K_d)	<20%
	Total suspended matter	<20%
	Aerosol Optical Depth (at 865 nm)	<20%

processes, dynamic interactions involved between land, ocean, and atmosphere, and achieving specific goals like Potential Fishing Zone (PFZ) identification, primary productivity assessment, algal bloom detection and substrate mapping of optically shallow coral reefs and other benthic ecosystems (Chauhan and Navalgund, 2009; Navalgund, 2008). Unfortunately, visible and NIR data, provided by the OCM instrument, are characterized by an irregular pattern of sharp, random stripes over the entire image. If uncorrected, these stripes can lead to incorrect retrievals of aerosol (atmospheric) correction parameters and biogeophysical products such as water-leaving radiance and chlorophyll-*a* (*Chl-a*) concentration (Lyon, 2009).

OCM-2 has push-broom facility in conjunction with a dedicated viewing window for each spectral band which eliminates the requirement of rotating mirror mechanism (as with the MODerate-resolution Imaging Spectroradiometer, MODIS) and consequently avoids the generation of horizontal banding as commonly observed in MODIS and Visible Infrared Imaging Radiometric Suite (VIIRS) images (Eplee et al., 2012; Rakwatin et al., 2007). The charge coupled device (CCD) array with 3730 detectors for each of its eight spectral channels is placed across-track and scans the scene using all the detectors at the same time. Because OCM-2 relies on the push-broom technique, where a whole image line is recorded using a CCD array placed across-track, detector-to-detector sensitivity variation and detector-to-detector stripes are inevitably caused by imperfect calibration of the relative gain and offset of each detector. These are non-periodic stripes observed across the swath with variable effects with respect to space, time and wavelength. Visible, random stripes and bandings also occur around the scene edges, particularly in homogeneous clear-ocean water regions, possibly because of the interference of other factors such as source spectral distribution and polarization or random noise in the internal calibration system (Bouali and Ladjal, 2011; Simpson and Yhann, 1994). In all cases, the presence of stripes perturbs the qualitative analysis of images, affects radiometric integrity of remotely sensed data, contributes to confusion in the aerosol (atmospheric) correction process and thus introduces strong biases in the high-level ocean color products including water-leaving radiance and *Chl-a* concentration (Carfantan and Idier, 2010; Lyon, 2009).

A number of methods for the removal of striping noise have been reported in the literature, but most of them are designed based on either a filtering or a statistical approach to deal with periodic or horizontal striping effects (Bouali and Ladjal, 2011; Mikelsons et al., 2014). These methods include digital filtering, moment matching, histogram matching, and radiometric equalization. The digital filtering methods which employ finite impulse response filter (Chen et al., 2003; Simpson et al., 1998), selective and adaptive filter (Liu and Morgan, 2006) or wavelet-based filter method (Torres and Infante, 2001) intend to reduce periodic striping on small images. Unfortunately, the frequency components that are identified and inevitably filtered out by these methods contain not only the stripes but useful information about surface features on the observed image, which eventually introduces blurring and ringing artifacts that reduce the radiometric accuracy of data for quantitative analyses (Bouali and Ladjal, 2011). To overcome these limitations, statistical methods such as moment matching and histogram matching have been proposed that focus on the statistical properties of signals measured by individual detectors. The moment matching technique removes stripes by assuming that changes in spatial variability defined by the mean and standard deviation of the data acquired by each detector are very small or negligible over certain length scale (Chang et al., 2007; Gadallah et al., 2000; Horn and Woodham, 1978; Xie et al., 2011). This assumption becomes rapidly invalid if in-water features and surface blooms are small to be imaged by the detectors within a given sweep, thus the moment matching technique is not useful for coastal ocean color applications. In contrast, the histogram matching technique is a refinement based on the same probability density functions of the data acquired by each detector and is considered to be more robust in terms of dealing with nonlinear detector responses and removing the striping effect in areas of relative homogeneity, which means that this technique may remain ineffective on small-size images or the feature rich images and is scene dependent (Rakwatin et al., 2007; Wegener, 1990). The radiometric equalization technique is limited by its performance over the inhomogeneous areas with the striping entity varying with time (Algazi and Ford, 1981; Corsini et al., 2000).

One recent work by Mikelsons et al. (2014) which is primarily based on the work of Bouali and Ignatov (2014) attempted to remove the systematic noise (banding noise) on the ocean color reflective bands of the MODIS-Aqua sensor which uses a whisk-broom technique to scan the swath. These striping artifacts are present at a specific