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Developing MODIS-based retrieval models of suspended particulate matter concentration in Dongting Lake, China

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ABSTRACT

To case-II waters, suspended particulate matter (SPM) is one of the dominant water constituents, SPM concentration (C_{SPM}) is a key parameter describing water quality, and developing remote sensing-based C_{SPM} retrieval models is foundation for obtaining its spatiotemporal distributions. This study aimed to develop moderate resolution imaging spectroradiometer (MODIS)-based C_{SPM} empirical retrieval models in Dongting Lake, China. The 95 C_{SPM} measurements on 31 August 2012 and 14 June 2013 and their corresponding MODIS Terra images were used to calibrate models, and the model calibration results showed that the 250 m MODIS red band obtained better fitting accuracies than the near infrared band; the quadratic and exponential models of single red band explained 75% (estimated standard errors (SE) = 6.19 mg/l) and 71% (SE = 6.54 mg/l) of the variation of C_{SPM}; and the quadratic and exponential models of red minus shortwave infrared (SWIR) band at 1240 and 1640 nm explained 72–73% (SE = 6.43–6.48 mg/l) and 68–69% (SE = 6.83–6.96 mg/l) of the variations of C_{SPM}, respectively. The quadratic and exponential models of red band and red minus SWIR band were applied to the MODIS Terra image on 16 September 2013 to estimate C_{SPM} values. By comparing the estimated C_{SPM} values on 16 September 2013 and the measured ones on 17 September 2013 at 40 sampling points for model validations, the results indicated that there exited significantly strong correlations between the measured and estimated C_{SPM} values at a significance level of 0.05 for all models, and the exponential model of red minus SWIR band at 1240 nm achieved the best estimation result within all models. Such result provided foundation for obtaining the spatiotemporal distribution information of C_{SPM} from MODIS images in Dongting Lake, which will be helpful for understanding, managing and protecting this ecosystem.

Introduction

Suspended particulate matter (SPM, including organic and inorganic matter) is one of the main constituents of case-II waters, and it greatly affects water quality and aquatic ecosystems, such as transporting nutrients and contaminants, declining water clarity and reducing light transmission through water column (Kirk, 1994; Davies-Colley and Smith, 2001; Cigizoglu and Kisi, 2006; Giardino et al., 2010; He et al., 2013; Long and Pavelsky, 2013; Xing et al., 2013). SPM concentration (C_{SPM}) is an important parameter describing water quality (Zhang et al., 2003; Pozdnyakov et al., 2005; Uddin et al., 2012), and obtaining its spatiotemporal distribution information is thus necessary for understanding, managing and protecting aquatic ecosystems.

Remote sensing techniques have been widely applied to obtain the spatiotemporal information of C_{SPM} since the first Landsat satellite's launch in 1972. Moderate resolution imaging spectroradiometer (MODIS) is a key instrument aboard the Terra and Aqua satellites of the National Aeronautics and Space Administration (NASA). With their advantages of medium spatial resolution, daily coverage, high sensitivity and cost-free distribution (Li and Li, 2004; Miller and McKee, 2004), MODIS images have been frequently employed to retrieve C_{SPM} values during the past decade (Table 1). Furthermore, the two MODIS sensors have collected more than 10-year massive data of the Earth's surface, and such an image archive provides great opportunity to monitor and analyse the

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Table 1
Some published regression models of suspended particulate matter concentration (C_{SPM}, mg/l) based on moderate resolution imaging spectroradiometer (MODIS). $R_{rs}(\lambda)$ is the remote sensing reflectance at the wavelength of λ nm, $L_w(\lambda)$ is the water-leaving radiance at λ nm; R^2 is the determination coefficient of calibrated model, *SE* is estimated standard error, *n* is the number of sampling, and * means that the value was estimated from related literature.

Author(s)	Model	R^2	*n*	C_{SPM} range	Location
Wu et al. (2013)	$C_{SPM} = 0.0365\exp(63.2(R_{rs}(645) - R_{rs}(1240)))$	0.76	42	0–141.9	Poyang Lake, China
Cui et al. (2013)	$C_{SPM} = 1.063\exp(27.859R_{rs}(645))$	0.91	54	0–141.9	Poyang Lake, China
Feng et al. (2012)	$C_{SPM} = 0.6786\exp(34.366(R_{rs}(645) - R_{rs}(\text{nearest}1240)))$	0.87	38	3–200	Poyang Lake, China
Ondrusek et al. (2012)	$C_{SPM} = 3.8813L_w(645)^3 - 13.822L_w(645)^2 + 19.61L_w(645)$	0.79	35	4.5–14.9	Chesapeake Bay, United States
	$C_{SPM} = 4.0955 + 5.2893L_w(645)$	0.83			
Jiang and Liu (2011)	$C_{SPM} = 1365.5(R_{rs}(470) + R_{rs}(555))^2 - 369.08(R_{rs}(470) + R_{rs}(555)) + 27.216$	0.81	27	0–40*	Poyang Lake, China
	$C_{SPM} = 50228R_{rs}(645)^{3.5938}$	0.74	18	0–100*	
	$C_{SPM} = 78764R_{rs}(645)^{3.6279}$	0.81	18	0–210*	
Chen et al. (2011a)	$\log_{10}(R_{rs}(859))/\log_{10}(R_{rs}(645)) = -0.1325\log_{10}(C_{SPM})^2 + 0.7429\log_{10}(C_{SPM}) + 0.6768$	0.86	32	1.29–208	Apalachicola Bay, United States
Chen et al. (2011b)	$\log_{10}(R_{rs}(859))/\log_{10}(R_{rs}(645)) = 0.4339\log_{10}(C_{SPM}) + 0.8288$	0.80	25	1.29–208	Apalachicola Bay, United States
Zhao et al. (2011)	$C_{SPM} = 2.12\exp(45.92R_{rs}(645))$	0.78	63	0–87.8	Mobile Bay estuary, Alabama
Tarrant et al. (2010)	$C_{SPM} = 0.0213(R_{rs}(645) - R_{rs}(859)) + 0.232$	0.82	105	0.30–13.4	Roosevelt, Bartlett Pleasant Lake, United States
Zhang et al. (2010)	$\ln(C_{SPM}) = 0.015(R_{rs}(645) + 0.003(R_{rs}(645)^2 - 0.282$	0.87	166	4.32–311.4	Taihu Lake, China
	$\ln(C_{SPM}) = 166.960/(R_{rs}(470) - R_{rs}(645)) - 2.192$	0.79			
	$\ln(C_{SPM}) = -16.997R_{rs}(470)/R_{rs}(645) + 3.326(R_{rs}(470)/R_{rs}(645))^2 + 23.681$	0.87			
	$\ln(C_{SPM}) = -29.707(R_{rs}(470) - R_{rs}(645))/(R_{rs}(470) + R_{rs}(645)) + 41.886(R_{rs}(470) - R_{rs}(645))/(R_{rs}(470) + R_{rs}(645))^2 + 11.358$	0.87			
Wang and Lu (2010)	$\ln(C_{SPM}) = 0.262(R_{rs}(859) - R_{rs}(1240)) + 4.117$	0.78	35	74–881	Lower Yangtze River, China
Wang et al. (2010b)	$C_{SPM} = 60.24(R_{rs}(859) - R_{rs}(1240)) - 23.03$	0.73	153	74–881	Middle and Lower Yangtze River, China
Wang et al. (2010a)	$\log_{10}(C_{SPM}) = 1.5144\log_{10}(R_{rs}(859))/\log_{10}(R_{rs}(645)) - 0.5755$	0.72	16	1–64*	Apalachicola Bay, United States
	$\log_{10}(C_{SPM}) = 0.1497\exp(1.5859\log_{10}(R_{rs}(859))/\log_{10}(R_{rs}(645)))$	0.61	11		
Chen et al. (2009)	$\log_{10}(R_{rs}(859))/\log_{10}(R_{rs}(645)) = -0.1356\log_{10}(C_{SPM})^2 + 0.7402\log_{10}(C_{SPM}) + 0.6836$	0.85	25	1.29–208	Apalachicola Bay, United States
Jiang et al. (2009)	$\log_{10}(C_{SPM}) = 0.3568\ln(R_{rs}(859)) + 3.3431$	0.81*	56	0–170*	Taihu Lake, China
Doxaran et al. (2009)	$C_{SPM} = 12.996\exp(R_{rs}(859)/(0.189R_{rs}(645)))$	0.89	204	0–2250	Gironde Estuary, France
Wu and Cui (2008)	$C_{SPM} = 86236.23R_{rs}(645)^3 - 15858.70R_{rs}(645)^2 + 1005.29R_{rs}(645) - 15.67$	0.92	42	0–142	Poyang Lake, China
Liu and Rossiter (2008)	$C_{SPM} = 7167R_{rs}(645) - 42$	0.91	25	15.6–518.8	Poyang Lake, China
Kutser et al. (2007)	$C_{SPM} = 349.83R_{rs}(645) + 2.9663$	0.86	11	2–8*	Muuga and Sillamäe Port, Estonia
Liu et al. (2006)	$\ln(C_{SPM}) = 2.495(R_{rs}(645) - R_{rs}(859))/(R_{rs}(645) + R_{rs}(859)) + 1.810$	0.72	41	23.4–61.2	Middle Yangtze River, China
Sipelgas et al. (2006)	$C_{SPM} = 110.3R_{rs}(645) + 2$	0.58	48	3–10*	Pakri Bay, Finland
Hu et al. (2004)	$C_{SPM} = 0.00522\exp(1002(R_{rs}(645) - R_{rs}(859)))$	0.90	31	2–11	Tampa Bay, United States
Miller and McKee (2004)	$C_{SPM} = -1.91 + 1140.25R_{rs}(645)$	0.89	52	0–60*	Lake Pontchartrain, Mississippi River Delta and Mississippi Sound, United States

Source: Modified based on Wu et al. (2013).