IOP Conf. Series: Earth and Environmental Science **17** (2014) 012104 doi:10.1088/1755-1315/17/1/012104

Dynamic monitoring of water petroleum substance using HJ-1/CCD remote sensing data

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Abstract. The experiment data used in this paper include CDOM(Chromophoric dissolved organic matter) absorption coefficient, water apparent optical properties and petroleum pollution concentration ,which were obtained in May 2008, August 2009 and June 2010 respectively at Liaohe Oilfield in Panjin city, Liaoning province of China. A model between CDOM absorption coefficient and petroleum pollution concentration was developed, and then was applied to eight HJ-1CCD remote sense images obtained from 2009 to 2011, to produce multi-period temporal and spatial distribution maps of petroleum concentration in costal waters. Based on these thematic maps, the dynamic monitoring of petroleum pollution concentration distribution was done. The results showed that (1)There was a decreasing trend of petroleum concentration from costal waters to open sea, which manifest itself as an approximately zonal distribution;(2) due to low precipitation in May and June every year, the concentration of petroleum keeps in a relatively high value state; (3) in September, the concentration of petroleum decreases dramatically as pre increases, most of the area below 0.29 mg/L; (4) compared with that in the same period, the concentration of petroleum in April 2010 is apparently higher than in April 2011, and among the images in September from 2009 to 2011,the highest concentration of petroleum appears in 2010, and the lowest in 2009.

1. Introduction

In the last few decades, marine oil spill accidents happen very frequently, this makes a big threat to the open sea and coastal waters environment. Dispersant was usually used to process the polluted waters after the marine oil spill accidents. The processed oil disperses, distributing in the water in the form of micro-particles. Therefore disperse oil still exists in the water, even though there is no floating oil on the surface. It is very essential to monitor the temporal and spatial distribution of the polluted waters by using remote sensing technology. Some studies show that the impact of disperse oil on water absorption coefficient mainly reflected in chromophoric dissolved organic matter (CDOM) light absorption characteristics.

Parameterization of the inherent optical properties of the water colour factor(absorption coefficient and backward scattering) is the precondition of developing all kinds of water colour models. A large number of previous studies have been done on the inherent optical properties of the conventional water colour factors, and a lot of parametric models have been established [1-6]. The study by Huang et al. [2010] showed that the impact of petroleum substance on water absorption coefficient was mainly reflected through CDOM's absorption properties of water [7]. Furthermore, petroleum substance, CDOM and non-pigment particles have similar absorption spectrum, which can be described by a decaying e-exponential function. The model of CDOM absorption coefficient can be parameterized following Bricaud et al. [8].That is,

$$a_i(\lambda)= a_i(\lambda_0)\exp(-S_i(\lambda-\lambda_0)) \quad (1)$$

Where, $a_i(\lambda)$ the corresponding absorption coefficient (m^{-1}) of each wavelength λ; i represents petroleum material, CDOM and non-pigment particles, respectively; $a_i(\lambda_0)$ is absorption coefficient at reference wavelength λ0, in water colour remote sensing λ_0 is usually taken as 440nm; S_i is absorption spectrum slope of the corresponding water colour factor..

The accuracy of equation (1) is determined by $a(\lambda_0)$ and S. Many studies showed that the slope of CDOM optical spectrum S is not related to the concentration of CDOM, but is related to water composition and the choice of reference band, as a result, it is very regional[9-13]. Some studies use remote sensing reflectance to estimate CDOM's $a_i(\lambda_0)$ in estuary area [14-16].Present studies on these two parameters of water petroleum pollution are restricted by the limited number of experiment samples. In this paper, experimental data are used to determine the relationship between the absorption coefficient $a_g(440)$ of CDOM which represents the concentration of CDOM and the concentration of petroleum substances. These data contains CDOM (Chromophoric dissolved organic matter) absorption coefficient, water apparent optical properties and petroleum pollution concentration, which were obtained in May 2008, August 2009 and June 2010 at Liaohe Oilfield in Panjin city, Liaoning province, China. Then, a model to inverse the concentration of petroleum pollution substances in the water was established by using spectral slope S and $a_g(440)$ of CDOM. Finally, the model was applied to the HJ-1/CCD remote sensing data from the year of 2009 to 2011 to monitor the concentration of petroleum pollution substances in the water.

2. Data and Measurement methods

2.1 Experiment description

CDOM is an important part of the dissolved organic matter which exists in all waters. It has two main sources. One is the degradation products of water phytoplankton, the other is dissolved organic matter from land. In this paper the discussion focus mainly on the CDOM with petroleum substances in the water, therefore, the natural sewage were got from Liaohe oilfield sewage treatment factory located in Panjin city, Liaoning province, China in May 2008, August 2009 and June 2010.The sewage water was filtered to remove, organic chlorophyll particles and inorganic suspended sediment particles in order to ensure that the achieved samples contains only water and oil (in the form of CDOM). In the experiment process, "simulation pollution" and "simulation purification" were applied by mixing-ratio, which is using pure water, tap water, river water and sea water as raw materials and making them proportional to the filtered natural sewage water, to obtain water samples of various pollution concentration.

2.2 Measurement of CDOM absorption coefficient

CDOM absorption coefficient measurement refers to ocean optical research technique, see references [12].

2.3 Measurement of petroleum substances concentration in the water

The concentration of petroleum pollution was measured by JK-951multi-function infrared oil instrument with the method of infrared spectrometry (GB16488-96)[13]. The basic procedure is: extracting water petroleum material with carbon tetrachloride, measuring the total extract, then adsorbing the extract solution with magnesium silicate, to remove materials with polarity such as animal and vegetable oil, then determining petroleum content. Both the total extract and petroleum content were calculated by the absorbance A2930, A2960 and A3030 at wave number bands of 2930 cm^{-1} (CH_2 group C-H key in the stretching vibration), 2960 cm^{-1} (CH_3 groups of C-H key stretching vibration) and 3030 cm^{-1} (aromatic ring C-H key stretching vibration).

2.4 Measurement of water spectrum
Water spectral was measured in Above-Water Method with ASD FieldSpec3 spectroradiometer manufactured by American company ASD and 30% reflectivity standard plate was used. Measuring method see references [17].

3. Results and Analysis

3.1 Inverse model
Existing ratio test showed that[17], With the increasing of the concentration of petroleum material, ag (440) increased linearly, the correlation coefficient is larger than 0.83, which makes it feasible to inverse petroleum material concentration by using CDOM optical absorption characteristic parameters ag (440). Ag (440) are commonly used to characterize the concentration of CDOM, S mainly depends on the composition of CDOM, therefore, it is necessary to take both parameters into account in order to improve the accuracy of inverse model of water petroleum substances based on CDOM optical absorption properties.

Table 1 shows all types of relations between S * ag (440) and petroleum substances concentration. it can be found in these relations, power relations has the highest R^2=0.7418, R^2 is less than 0.7 for all the other relations. Therefore, the power relation model was selected as Inverse model of water petroleum pollution based on the CDOM absorption spectral characteristics, that is,

$$y = 127.566x^{1.3288} \tag{2}$$

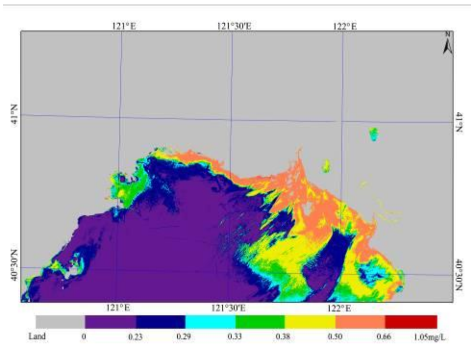
Where y is the concentration of petroleum pollution in the water(mg/L),x is S* ag(440),ag (440) and S are defined as usual, S=0.010892.

Table 1. The relation mode between light absorption characteristics of CDOM and the concentration of petroleum substance (the number of samples =28)

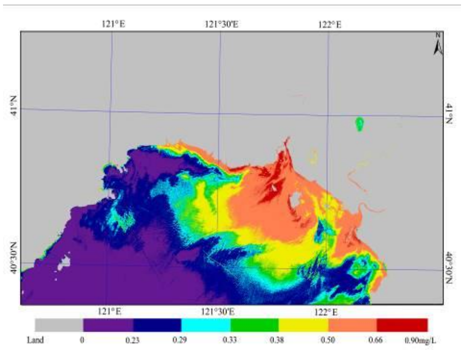
Model Type	Power	liner	logarithm	index
Expression	$y = 127.566x^{1.3288}$	y = 240.64x - 0.5815	y =5.7608Ln(x) + 27.858	y = 1.4527e40.796x
R^2	0.7418	0.6974	0.618	0.6989

The estimated value was calculated by formula (2) by inserting petroleum material content and the absorption coefficient of CDOM at ag (440), measured in May 2008 and August 2009 in natural river. The analysis results show that the relative error of the model is 7%, indicating that the accuracy of model in inversing petroleum substance concentration in the water is relatively high. This provides a new method to estimate petroleum substance pollution in the water by using remote sensing technique.

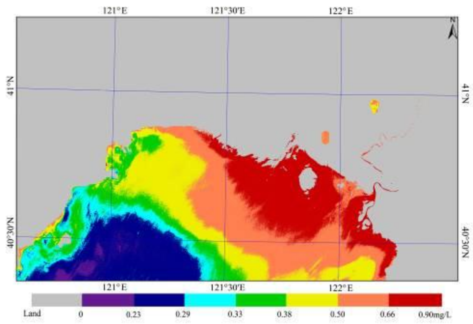
3.2 Thematic map
The model established in this paper was applied to eight images of HJ-1/CCD data, taken from 2009 to 2011, and the temporal and spatial distribution maps of offshore water petroleum material concentration were made (Figure. 1 (a) ~ (h)). These maps show that, (1) there is a decreasing trend of petroleum concentration from costal waters to open sea, which presents a zonal distribution in certain extent; (2) due to low precipitation in May and June every year, the concentration of petroleum keeps in a relatively high value state; (3) in September, the concentration of petroleum decreases obviously as precipitation increases, of which the values in most areas are below 0.29 mg/L; (4) compared to the same period, the concentration of petroleum in April 2010 is apparently higher than that in April 2011, and among the images in September from 2009 to 2011,the highest concentration of petroleum appears in 2010, and the lowest appears in 2009.



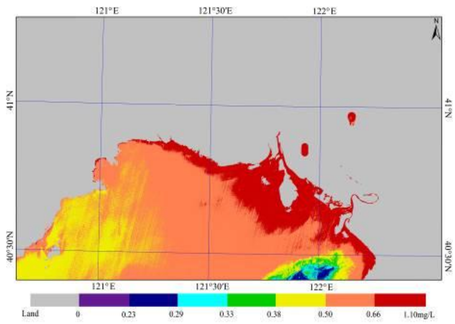
(a) On September 15, 2009 HJ1A/CCD1



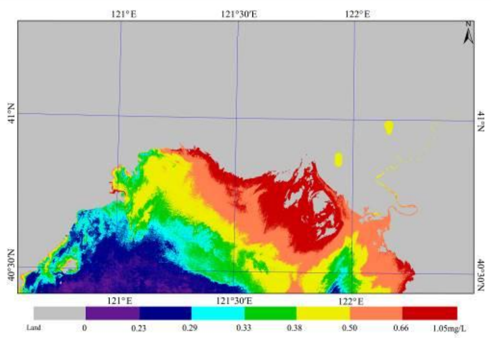
(b) On October 14, 2009 HJ1B/CCD1



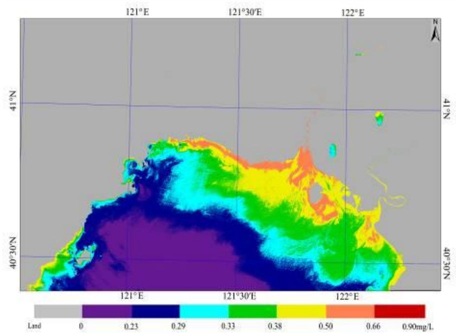
(c) On April 3, 2010 HJ1B/CCD1



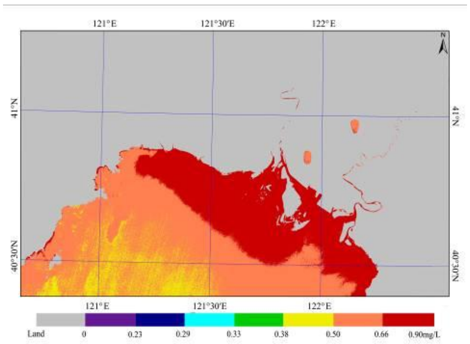
(d) On June 24, 2010 HJ1B/CCD1



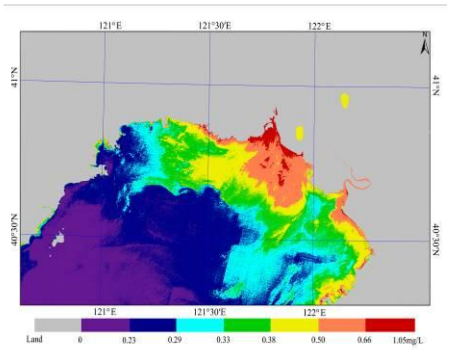
(e) On September 28, 2010 HJ1A/CCD1



(f) On April 13, 2011HJ1B/CCD2



(g) On May 15, 2011HJ1B-CCD1



(h) On September 6, 2011HJ1B/CCD1

Figure 1. The distribution of petroleum substance pollution spatially in Liaodong gulf

4. Conclusion

Based on the experiment, a model that uses optical parameters to inverse the concentration of petroleum substance in the water was established, which provides a new method in monitoring water petroleum substance. The model achieved a satisfying result in monitoring water petroleum substance content for 3 consecutive years. The research results help to promote fundamental and applied studies of colour remote sensing, and promote water inherent optical properties theory research, and provide a reliable theoretical and data basis for optical radiation transmission calculation of petroleum polluted water. The purpose of this research results can also provide technical methods for water petroleum pollution monitoring, as well as basis for oilfield environmental effect evaluation.

The effect of petroleum substance on water absorption coefficient mainly reflect through yellow substance(Chromophoric dissolved organic matter: CDOM).Both of them have similar absorption spectrum, in order to improve the accuracy of water petroleum content inversion by remote sensing, the method of distinguishing between these two must be developed. This is also our next step of research.

Acknowledgments

This work was funded by National Natural Science Foundation of China under contract No. 41271364, Key Projects in the National Science & Technology Pillar Program under contract No. 2012BAH32B01-4, Liaoning Excellent Talents in University under contract No. LR2011019, National Oceanic Public Good Project under contract No. 201005025-04.

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