ANALYSIS ON THE KEY TECHNIQUES OF CONSTRUCTING VIRTUAL SATELLITE CONSTELLATION

Xufeng Xing(1), Shiyi-Xie (1), Miaofen Huang (1), Weijian Luo (1), Junjie Yang (1)

[1] Guangdong Ocean University, No. 1 Haida Road, Mazhang District, Zhanjiang, 524088, China
Email: 4918585@qq.com; huangmf@gdou.edu.cn; hmf808@163.com;lwjluo@sina.com;
junjie_y@foxmail.com

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ABSTRACT: Mariculture areas often locate in the case II water areas such as shallow sea, beaches and harbor. According to the practical production requirements, long-term and high dynamic monitoring of these parameters need to be proceeded meanwhile the spatial and temporal resolution is 3 to 5 days and 50 to 100 m respectively. The high spatial resolution remote sensing data sources are a good way to solve the problem of spatial resolution requirements. If the remote sensing satellites carrying with medium or high spatial resolution sensors can constitute a virtual constellation oriented the goal, the problem of temporal resolution can be solved. The concept was put forword that can combined the high spatial resolution of sensors to build high temporal resolution virtual constellation to meet the specific demands of high temporal and spatial resolution environment parameter information in the mariculture areas. The key technology were analysed when the high temporal resolution virtual constellation was built from the satellite sensors with the high spatial resolution, They include the relative calibration between multi-source sensors (for example, removal of stripe, relative radiation calibration), atmospheric correction of the no ocean color sensor over a wide range, standardization of remote sensing inversion product on mariculture environment parameters. Firstly, the problem of the multi-source sensors integrated application as follows, (1) the inside difference between sensors; (2) low signal to noise ratio of high spatial resolution sensors;(3) the difference between sensors in band width and the characteristics of the radiation; (4) the difference of atmospheric aerosol, surface roughness, change of the water body during disparate passing. The solution of these problems can be solved by that the high spatial resolution sensors are applied to the quantitative relative calibration technique of regional water and atmospheric correction work. Only after conducted a quantitative remove stripe to the high spatial resolution multi-source sensors, proceeded the relative radiation calibration and atmospheric correction can ensure get the high precision of apparent optical water quantity and make the data comparable between sensors. Secondly, Chinese mariculture zones majorly are located in Case II water body. The current study of atmospheric correction algorithm in Case II water body is essentially based on water colour sensor. However it is used land satellite sensors with high spatial resolution, its band width has obvious different with ocean colour sensors. On the other hand, the sensors' signal to noise ratio are be often low, and the water signal just occupies a small part of remote sensor received signals. In order to highlight the water body radiation information, studying an effective method of atmospheric correction become particularly important. Finally, the spectral ranges of the choice of multi-source sensor are different, but they are overall similar, for example, they all have the waveband of 520-590nm, 600-690nm and 770-860nm. The purpose can be achieve that inversion product of the parameters are not influenced by the response differences between sensors' band spectrum from proceeding fine-tuning for different sensors' inversion model.

1. INTRODUCTION

Mariculture areas refer to waters, which are often located in Case-II water areas such as shallow sea, beaches and harbor, used for artificial breeding for fish, shrimps, crabs, shellfish, algae, etc (Zhang, 2016). Due to great effects of land, mariculture environmental parameters such as phytoplankton biomass, suspended sediment, transparency and water temperature change greatly in temporal and spatial scales, which not only influences mariculture managers deciding where to set as the mariculture area and how large the scale of breeding is, but also affects aquatic product farmers making scientific arrangement of production measures and achieving economic benefits. According to the practical production requirements, long-term and high dynamic monitoring of mariculture environmental parameters need to be proceeded meanwhile the temporal and spatial resolution is 3 to 5 days and 50 to 100 m respectively. Satellite remote sensing is an effective way to implement long-term and high dynamic monitoring of these parameters (Huang, 2011).

In the field of remote sensing satellite, time resolution and spatial resolution are commonly contradictory, namely high spatial resolution sensors generally have low time resolution. Current mariculture study using remote sensing monitoring of environmental parameters mainly use lower spatial resolution marine satellites or meteorological satellites data, but there solutions is too low to meet the demand for mariculture production (Fan, 2013). Relatively speaking, 50~100m is a high spatial resolution for conventional marine satellite sensors, and 3~5d is a high temporal resolution for conventional land satellite sensors. Therefore, if several satellites, which all carry high spatial resolution sensors, are constituted as a virtual constellation for mariculture environmental parameters monitoring, it is of great significance for making a scientific plan and design of marine resources, arranging mariculture production rationally and raising the mariculture level; further, some key technical breakthroughs can promote the application of land satellite remote sensing data in ocean research.

Owing to the above, to meet the demands of mariculture, the land satellites, which have higher spatial resolution compared with marine satellites, are selected to constitute virtual satellite constellation. As there are many problems such as the diversity of band widths and radiation characteristics among multi-resource remote sensors, the different variations of properties of atmospheric aerosols and water sat different transit time, etc., this paper attempts to analyze and discuss some relative issues, including (1) Quantitative relative calibration of application of multi-source sensors in regional waters; (2)Atmospheric correction techniques of broad-band non-ocean color multi-source sensor over coastal Case II turbid waters.

2. CONSTITUTION OF VIRTUAL SATELLITE CONSTELLATION

2.1 Common Land Satellites

With the development of remote sensing, human can observe the Earth more comprehensively than ever before and the data of land satellites images are exponentially increasing. Up to present, more than 500 Earth observation satellites have been launched globally, a dozen successfully-launched Chinese land satellites included. Concerning the feasibility of business operation in the future, we select 12 land satellites launched by China and 5 international common medium and high spatial resolution land satellites, combined with hyper spectral marine satellite sensors EOS/MODIS and ENVISAT/MERIS, to constitute as multi-source sensors to meet the actual needs of mariculture production and management.

Table 1 and Table 2 respectively show the technical parameters of Chinese and international land satellites selected, and Figure 3 shows the technical parameters of selected marine satellites.

Table 1 Technical Parameters of Sensors on Land Satellites Launched by China

Satellites/Sensors	Wave band（nm）	Spatial resolution	Orbital period/Revisit period (day)
BJ-1/Multispectral CCD	530~605 630~690 774~900	32m	Programmable，2-3
BJ-2/Multispectral CCD	530~605 630~690 774~900	4m	Programmable，2-3
GF-1/Multispectral Camera	450~520 520~590 630~690 770~890	4 m	69/5
GF-2/Multispectral Camera	450~520 520~590 630~690 770~890	4 m	69/5
GF-4	VNIR: 450~900 450~520 520~600 630~690 760~900	VNIR :50m	20

	MWIR: 3500~4100	MWIR:400m	
ZY-3/Multispectral Camera	450~520 520~590 630~690 770~890	6m	59/5
CBERS-01/02	CCDCamera: 450~520 520~590 630~690 770~890 Wide Field Imager (WFI): 630~690 770~890 IRMSS: 1550~1750 2080~2350 10.4~12.5μm	CCDCamera：20m （WFI）:258 m IRMSS: 78m/156m	CCD Camera：26/3 Wide Field Imager（WFI）：26/3 IRMSS: 26
CBERS-02B	CCD Camera： 450~520 520~590 630~690 770~890 High Resolution Camera（HR）： 500~800 Wide Field Imager（WFI） 630~690 770~890	CCD Camera：20m HR：2.36 m WFI：258 m	26/3
ZY-1 02C	520~590 630~690 770~890	10 m	55/3
CBERS-04	Panchromatic and Multi-spectral Camera: 510~850 520~590 630~690 770~890 Multi-spectral Camera: 450~520 520~590 630~690 770~890 Infrared Multi-spectral Camera： 500~900 1550~1750 2080~2350 10.4~12.5 μm Wide Field Imager（WFI）： 450~520 520~590 630~690 770~890	Panchromatic and Multi-spectral Camera:5m& 10m Multi-spectral Camera:20m Infrared Multi-spectral Camera：40m Infrared Multi-spectral Camera：80m Wide Field Imager（WFI）: 73m	Panchromatic and Multi-spectral Camera:26/3 Multi-spectral Camera:26 Infrared Multi-spectral Camera：26 Wide Field Imager（WFI）：26/3
SJ-9A/B	SJ-9AMulti-spectral Camera: 450~520	SJ-9AMulti-spectral Camera:10m	SJ-9A： 69/4

	520~590 630~690 770~890 SJ-9 BInfrared Camera: 800~1200	SJ-9 BInfrared Camera：73m	SJ-9 B：69/8
HJ-1 A和HJ-1 B/Broad-band MultispectralCCD & Infrared Camera	430~520 520~600 630~690 760~900 1550~1750（SWIR） 10.5~12.5μm（TIR）	VNIR:30m SWIR：150m TIR：300m	Wide Multi-spectral CCD：31/2 Infrared Camera：31/4

Table 2. Technical Parameters of Sensors of Global Land Satellites

Satellites/Sensors	Wave band（nm）	Spatial resolution	Orbital period / Revisit period (day)
IRS-P6/ LISS-III	520~590 600~680 770~860 1550~1750（SWIR）	23 m	24/5
IRS-P6/ AWIF	520~590 600~680 770~860 1550~1750（TIR）	56 m	24/5
LANDSAT 5 /TM	450~530 520~600 630~690 ） 760~910 1550~1750（SWIR） 10.5-12.5μm（TIR）	VNIR & SWIR：30 m TIR：120m	16
LANDSAT 8 /OIL	OIL Sensor 433~453 450~515 525~600 630~680 845~885 1560~1660 1360~1390 2100~2300 TIRS 10.6~11.2μm 11.5~12.5μm	OIL Sensor：30 m TIRS：100 m	16
EOS/ASTER	520~600 630~690 760~860 1600~1700（SWIR） 5TIR bands： 8.125~8.475μm 8.475~8.825μm 8.925~9.275μm 10.25~10.95μm 10.95~11.65μm	VNIR: 15m SWIR:30m TIR：90m	16

Table 3. Technical Parameters of Sensors of Marine Satellites

Satellites/Sensors	Wave band（nm）	Spatial resolution	Orbital period (day)	Signal to Noise Ratio
EOS/MODIS	405~420 438~448 483~493 526~536 546~556 662~672 673~683 743~753 862~877 2 TIR bands： 10.78~11.28µm 11.77~12.27µm	VNIR & SWIR：250&500m TIR:1000 m	16（Support swinging）	>800
ENVISAT/MERIS	407.5~417.5 437.5~447.5 485~495 505~515 555~565 615~625 660~670 677.5~685 700~710 750~757 758.75~761.25 767.5~782.5 855~875 885~895 895~905	300m	35（Support swinging）	1700

Comprehensive application of multi-source sensors has many advantages: on one hand, according to the ephemeris of high-spatial-resolution sensors, high-temporal-resolution virtual constellation for mariculture environmental parameters can be built to improve the temporal resolution of high dynamic monitoring of mariculture environmental parameters by remote sensing; on the other hand, the practical mariculture activities needs higher precision of remote sensing based inversion of mariculture environmental parameters, so fully utilizing the advantages of multi-source sensors can improve the relative accuracy of mariculture environmental parameters monitoring by remote sensing, which will make high-dynamic and high-accuracy monitoring of mariculture environment become reality and provide basic data for the scientific arrangements of mariculture in demonstration area.

2.2 Constitution of Virtual Satellite Constellation

Current satellite remote sensing system constituted by multiple sensors can be categorized into three general types according to design techniques (Huang, 2014) : (1) One single sensor system with function of multiple sensors integrated, such as the multi-mode microwave sensors on Shenzhou 4 and Shenzhou 5, which integrates the function of radiometer, altimeter and scatter meter; (2) One single satellite carrying several different types of sensors, such as ENVISAT-1, a European Space Agency (ESA) multifunctional remote sensing satellite, which was launched into orbit on March 2002, with 10 instruments carrying atmospheric, oceanic, terrestrial observation sensors aboard; (3)Various sensors on many different satellites, which have the same or different specifications are constituted as constellations, formations or networks. Multiple satellites work together to accomplish tasks in this type. Based on differences of collaborative approaches it can be subdivided into three types (Wei, 2016): (a) Networking flight. Constellation, which is constituted of several satellites and is designed based on the satellites' coverage, has a certain shape in this type, such as the space surveillance network of 5 geostationary meteorological satellites above the equator; (b) Formation flight. The system of this type consists of a few or dozens of satellites, which keep a certain distance and flight attitude from each other. The satellites flying as a formation can replace a large satellite on the function. This type of systems are mainly used in military fields. In addition, the COSMO (Constellation of Small

Satellites for Mediterranean Basin Observation), a radar satellite system, takes this approach of collaboration to improve the temporal resolution. One satellite of COSMO will fly over the sample area every 6 hours. (c) Combined application of satellites at different orbital altitude. Such as the EOS (Earth Observation System), belonging to a large US-led international cooperation project, which is participated in by many other countries. More than 20 sensors of this system on satellites at different orbital altitude can observe the Earth collaboratively.

Discussed on application level, current combined applications of multi-source sensors mainly focus on information fusion and parameters collaborative inversion, including information fusion and parameters collaborative inversion using the data of visible light sensors and the data of both visible light sensors and microwave sensors, etc.(Zhou, 1998; Chen, 2014; Ray ,2004; Ma , 2001; Xing, 2016). There have been a lot of researches on related technology at home and abroad, so the technology is relatively mature. Spectral information enhancement and geometrical information enhancement are common approaches of information fusion. And the former can be proceeded at 3 different levels, including Pixel Level, Feature Level and Decision Level (Yang, 2014). Among them, the fusion at Decision Level is a kind of high-level information fusion, the result of which can provide scientific basis for various management activities or decision-makings (Yun, 2015; Niu, 2003).

WGCV (Working Group on Calibration and Validation) of CEOS (Committee of Earth Observation Satellite) have been doing the research on finding out the methods of inter calibration and inter comparison of different data sources for years. According to their research, the group points out that inter calibrating and inter comparing different data to meet the users' actual demand are more promising than developing new sensors. The concept of Virtual Constellation was first mentioned on the 19th Plenary Session of CEOS, which was held in London in 2005.

Based on the concept of Virtual Constellation above, selecting high-spatial-resolution sensors, the ephemerides of which are comprehensively taken into account, to form a Virtual Constellation, which has high temporal resolution, to meet the demand for high-spatial-and-temporal-resolution mariculture environmental parameters information, is becoming a prevalent service mode for specific industries. With the in-depth research of some key technologies, constitution of the virtual constellations is set to become a new solution to the contradiction between spatial resolution and temporal resolution in remote sensing field.

3. Analysis of Key Technologies of Virtual Constellation for Mariculture Environmental Parameters

Some problems arise with the constitution of virtual constellation, such as (1) the discrepancy of the inner detectors of sensors, (2) low signal-to-noise ratio of high spatial-resolution sensors, (3) the diversity of band width and radiation characteristic among the sensors and(4) the different variations of properties of atmospheric aerosols and waters at different transit time. These problems are able to be solved through quantitative relative calibration of application of high-spatial-resolution sensors in regional waters and atmospheric correction.

3.1 Relative Calibration Technology

3.1.1 Striping removal : Using multiple detectors at the same time to acquire images is a common method used by most sensors on current satellites. Due to different detectors have different responses to received signals of objects, there are stripes over the acquired images along the same direction as the detector array. This phenomenon is called striping. Striping is very obvious on the images of relatively homogeneous terrain objects, especially the low-reflectivity waters. As striping phenomenon seriously influences the quality and visibility of images, making a huge obstacle for the out-of-orbit calibration of sensors and the quantification of information, and further causing large error of atmospheric correction and inversion of optical characteristics of waters, it is necessary to eliminate the negative effects of striping before quantifying the information. Striping removal is often proceeded by correcting every output value of detectors depending on the information reflected in the satellite images to reduce or isolate discrepancies between detectors. Unlike other image processing, to ensure the follow-up research on quantification of satellite data, the original physical meanings of data must be maintained after striping removal, and in order not to affect the accuracy of the inversion of information of waters, using quantitative method in the process of striping removal is essential.

3.1.2 Relative radiation calibration: Radiation calibration, as a basis of quantitative application of remote sensing data, includes many methods such as In-lab Calibration, On-board Calibration, On-site Calibration and Cross Calibration. Domestic and foreign high-spatial-resolution sensors, which constitute virtual satellite constellations, are mainly carried on land satellites, which have lower signal to noise ratio than marine satellites. As there are differences in radiation characteristics among sensors, to make the data among multi-source sensors comparable and to improve the radiometric accuracy, it is necessary to carry out relative radiation calibration. The Cross Calibration is a very promising calibration method, fundamental to maintain the accuracy and quantitative application of satellite data(Evans,1998; Hu, 2001). As is shown in the Table 1, Table 2 and Table 3, though the majority of satellites are set up to transit over a certain location at 10:30 a.m. local time, they actually transit at different time points, which will result in the different variations of properties of atmospheric aerosols, sea surface roughness and characteristics of waters, etc. at different transit time. For these objective problems have significant influence on the accuracy of relative radiation calibration, the influences on relative radiation calibration, resulting from different band width of satellite sensors and transit time difference, need to be reduced or eliminated.

3.2 Atmospheric Correction Techniques of Broad-Band non-Ocean Color multi-Source Sensor over Coastal Case II Turbid Waters

Mariculture areas in China are mainly located in turbid waters of Case II, the atmospheric correction in which is one of technical difficulties in current international ocean color remote sensing field. The Gordon standard atmospheric correction algorithm, which is developed for ocean color satellite sensors, has been sustainably running in Case I waters and has been accepted throughout the world. For the basic assumption of this algorithm that “water-leaving radiance in near infrared waveband is zero” fails because of the difficulties caused by both turbid waters and absorptive aerosol in Case II waters at the same time, if Gordon algorithm is applied in Case II waters, it will result in “Over-correction” in blue waveband and the appearance of negative water-leaving radiance values, leading to the failure of this algorithm (LI, 2016; Hu, 2006; He, 2014). In order to obtain high-reliability mariculture environmental parameters, developing atmospheric correction algorithm applicable to Case II waters is essential. As current researches on the atmospheric correction algorithm applicable to Case II waters are mainly based on ocean color sensors, the bandwidth setup of which is very different from those of high-spatial-resolution land satellite sensors, which are used to constituted virtual satellite constellations, and the signal-to-noise ratio of the latter is often low while the received signal intensity of waters only takes up a tiny proportion of the total signal received by remote sensors, to highlight the information of radiation leaving waters, researching on developing an effective atmospheric correction algorithm appears particularly important.

As is shown in Table 1 and Table 2, the selected high-spatial-resolution satellite data sources, have the similar bandwidth distribution, which can be divided into categories: (a) sensors of VNIR bands with center wavelength of 4XX, 5XX, 6XX, 7XX or 8XX nm; (b) sensors of SWIR bands in addition to 4 VNIR bands above, namely 15XX-17XX nm, such as LANDSAT/TM, IRS-P6/LISS-III, IRS-P6/AWIF, EOS/ASTER and HJ-1/Broad-band Multispectral CCD.

Compared with ocean color sensors, such as EOS/MODIS and ENVISAT/MERIS, the data of the satellites above have following features: (1) having broader bandwidth, usually about 80nm, compared with the 10nm bandwidth of ocean color satellite data; (2) having fewer bands, one infrared band only. It does matter to finding out atmospheric correction algorithm applicable to turbid waters when the data sources have broad bands but one infrared band only.

4. CONCLUSION

Using Semi-analytical algorithms to build a bio-optical model in demonstration area to obtain environmental parameters of ocean, for now, has following difficulties: (1) radiation data of four or more bands are required to determine the parameters in the algorithm, so during algorithm developing, enough consistent and high-spectral-fidelity data sets are required to make it perform better than the empirical algorithms, which need data of two bands only.(2) Some bold assumptions are made to reduce the amount of unknown variables in algorithm, but the assumptions are often inaccurate, for instance, some parameters areas signed as a constant, whereas these parameters are actually variables. (3) Some difficulties caused by the equation $Rrs = f (b_b / (a + b_b)$. (in this equation, the “Rrs” stands for remote sensing reflectance, the “a” stands for absorption coefficient and the “b_b” stands for backscattering coefficient of water, most of parameters in this equation will change when band changes.)

Current researches on atmospheric correction algorithm applicable to Case II waters are mainly based on ocean color sensors, while what virtual satellite constellation concerns is atmospheric correction algorithms in turbid waters with the data of broad-band from high-spatial-resolution land satellite sensors, the bandwidth setups of which are very different from those of ocean color sensors. If the algorithm is successfully developed, it can not only improve the accuracy of obtaining water-leaving radiance from the data of high-spatial-resolution land satellites, but also can contribute to promoting applications of land satellite remote sensing data in marine monitoring.

Mariculture areas are often located in the turbid Case II waters, for the properties of which are different from those in other regions, developing specific algorithms to obtain mariculture environmental parameters is necessary. In addition, as seen in Table 1 and Table 2, though the wavelength range of multi-source sensors are different, they have similarities in general, for example, they all consist of wavebands of 520-590nm,600-690nm and 770-860nm. In order to avoid influences on inversion results by different spectral responses of different remote sensors, the inversion mode needs to be adjusted slightly.

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