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Distribution of chlorophyll and harmful algal blooms (HABs): A review on space based studies in the coastal environments of Chinese marginal seas

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Abstract

Monitoring of spatial and temporal distribution of chlorophyll (Chl-a) concentrations in the aquatic milieu is always challenging and often interesting. However, the recent advancements in satellite digital data play a significant role in providing outstanding results for the marine environmental investigations. The present paper is aimed to review 'remote sensing research in Chinese seas' within the period of 24 years from 1978 to 2002. Owing to generalized distributional pattern, the Chl-a concentrations are recognized high towards northern Chinese seas than the southern. Moreover, the coastal waters, estuaries, and upwelling zones always exhibit relatively high Chl-a concentrations compared with offshore waters. On the basis of marine Chl-a estimates obtained from satellite and other field measured environmental parameters, we have further discussed on the applications of satellite remote sensing in the fields of harmful algal blooms (HABs), primary production and physical oceanographic currents of the regional seas. Concerned with studies of HABs, satellite remote sensing proved more advantageous than any other conventional methods for large-scale applications. Probably, it may be the only source of authentic information responsible for the evaluation of new research methodologies to detect HABs. At present, studies using remote sensing methods are mostly confined to observe algal bloom occurrences, hence, it is essential to coordinate the mechanism of marine ecological and oceanographic dynamic processes of HABs using satellite remote sensing data with *in situ* measurements of marine environmental parameters. The satellite remote sensing on marine environment and HABs is believed to have a great improvement with popular application of technology.

Keywords: Remote sensing; Chlorophyll; HABs; Chinese marginal seas; Marine environment

1. Introduction

China encompasses with four marginal seas namely the Bohai Sea, Yellow sea, East China Sea, and South China Sea situated on the northwestern region of Pacific Ocean. Three major waterways namely Yellow River, Yangtze River and the Pearl River flow generally eastwards into the Bohai Sea, East China Sea, and South China Sea, respectively (Fig. 1). China has encountered a fast economic growth since 1980s, especially in coastal areas through its production, import and exports. Anthropogenic activities confessed with rapid development of agriculture and industries along with population have put a great influence on these coastal waters and the marine environment. Marine chlorophyll concentrations have mounted high in many of the areas e.g., in Daya Bay of Guangdong Province, it was noticeably increased in the last two decades (Qiu, 2001). At the same time, the occurrence of harmful algal

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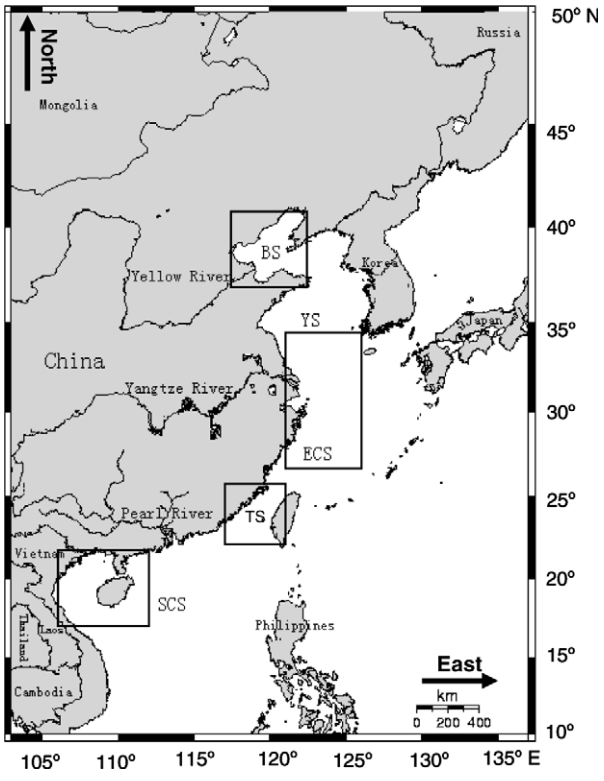

Fig. 1. The geographical location of Chinese marginal seas. BS: Bohai Sea; YS: Yellow Sea; ECS: East China Sea; SCS: South China Sea; TS: Taiwan Strait.

blooms (HABs) also had shown such characteristics of increasing frequency, expanding range, long-lasting period, and severe consequences.

The radiances received by satellite sensors above the ocean generally comes from the scattering of atmospheric moister and aerosols, reflectance of sea surface and ocean color factors (including pigment, suspended material and yellow material etc.), and the reflectance of seabed in case of shallow waters. Those reflecting radiances from pigment, suspended material, and yellow materials are the so called water leaving radiances, of which 5% being the target for ocean color satellite sensors out of total radiance received. In ocean body (case I water), the water leaving radiance is mainly due to chlorophyll reflectance while in coastal water body (case II water), lots of sand and other suspended materials besides ample of phytoplankton are responsible. Especially in estuarine areas, the water leaving radiance mostly comes from the combined distribution of chlorophyll, suspended sand, yellow material, and the like.

Chlorophyll has its specific absorption and reflecting spectrum. The information of chlorophyll concentration in seawaters could be retrieved with the help of ocean color satellite images based on their spectral characteristics. Retrieval of chlorophyll concentration in the oceans with remote sensing is much easier than in coastal waters because of its mature arithmetic of chlorophyll concentrations from remote sensing. Significant studies have been carried out on spectral characteristics of water bodies in Chinese marginal seas, forming a scientific basis for the application of remote sensing technology in coastal waters (Li et al., 2002; Yue et al., 1999; Wu et al., 1998; Ren and Zhao, 2002; Zhang et al., 1992; Fu et al., 1997). Earlier, Chinese researchers have used foreign satellite data to study Chinese marine environments since the first Chinese ocean color satellite (HY-1) was launched only during May 2002. Satellites that provide data on chlorophyll concentration and other marine environmental parameters are listed in Table 1.

2. Chlorophyll and marine primary production in Chinese marginal seas

2.1. Marine chlorophyll

Dynamic changes in spatial and temporal distribution of chlorophyll concentrations in wide range sea areas could be monitored with ocean color satellite remote sensing. Tang

Table 1
Satellites being used to study the ocean color and coastal environments in China

Satellite	Launched by	Sensor	Function period	Factor monitored	Application
Nimbus-7	USA	CZCS	1978 Jun–1986 Dec	Ocean color	Chlorophyll concentrations in Chinese marginal seas (Tang et al., 1998), the upwelling in Taiwan Strait (Tang et al., 2004d)
ADEOS-1	Japan	OCTS	1996 Aug–1997 July	Ocean color and SST	High chlorophyll concentration zones on the north of South China Sea (Tang and Kawamura, 2002a; Tang et al., 2004c)
SeaStar	USA	SeaWiFS	1997 Aug–current	Ocean color	Chlorophyll concentrations on the surface layer of South China Sea (Tang et al., 2003a, 2004c), Upwelling in Taiwan Strait (Tang et al., 2002b, 2004d)
ROCSAT	Taiwan–China	OCI	1999 Jan–current	Ocean color	Upwelling in Taiwan Strait (Tang et al., 2004d), chlorophyll concentrations in South China Sea (Tang et al., 2004c)
FY-1B	China	VHRSR	1990 Sep–current	Ocean color	HABs in Bohai Sea, Yangtze River and Pearl River estuaries during 1999 and 2000 (Cong et al., 2001)
NOAA series	USA	AVHRR	Since 1970	SST	HABs in Pearl River estuary and Hong Kong waters (Tang and Ni, 1996; Tang et al., 2003b)
Landsat series	USA	TM	Since 1972	Marine monitoring	HABs in Bohai Sea (Hu et al., 1991)
HY-1	China	COCTS	2002 May–current	Ocean color	Distribution of chlorophyll concentration, SST, suspended material, and the occurrence for HAB (NSOAS)