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Advances in China's Ocean Satellite Observation System Since 2024*

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Abstract Since 2024, China's ocean satellite program has made systematic progress in the construction of observation systems, expansion of mission portfolios, enhancement of ground-support capabilities, product development, and intelligent applications. An ocean satellite observation system composed of ocean color satellites, ocean dynamic satellites, and ocean surveillance and monitoring satellites has been initially established, providing multi-satellite coordinated observation capabilities over China's coastal seas, the global ocean, and polar regions. The successful launch of HY-4A has filled a gap in China's spaceborne ocean salinity observation capability and provided a foundational capacity for operational global ocean salinity monitoring and related scientific research. The stable operation of ground receiving systems, calibration and validation sites, and data-sharing infrastructure has provided reliable support for networked ocean satellite observations and operational applications. The upgrading of the ocean color satellite data processing system, the development of application-ready products for the Yellow Sea and East China Sea, and the generation of multi-parameter polar sea-ice products indicate that China's ocean satellite product system is evolving from basic data provision toward thematic, refined, and operational applications. The development of artificial intelligence foundation models represented by "SkyOcean" further suggests that ocean satellite applications are extending from two-dimensional sea-surface observations toward three-dimensional environmental reconstruction and prediction services.

Key words China's ocean satellites, Ocean salinity observation, Application products, Intelligent applications, Networked observation

Classified index P715.6

1 Introduction

Ocean satellites are an important technical means for achieving large-scale, continuous, and dynamic monitoring of the marine environment. They play an increasingly important role in marine ecological and environmental protection, marine disaster early warning, marine resource development, polar monitoring, and global ocean governance. After more than two decades of development, China has established an observation system covering ocean color satellites, ocean dynamic satellites, and ocean surveillance and monitoring satellites, and has developed systematic operational capabilities for monitoring sea surface wind fields, sea surface height, sea surface temperature, ocean color, sea ice, maritime targets, and coastal resources and environments.

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In recent years, China's ocean satellite program has exhibited several major characteristics. First, the range of observed variables has continued to expand. New missions such as ocean salinity observation have been advanced, and ocean remote sensing is extending from traditional monitoring of sea-surface parameters toward more comprehensive marine environmental sensing. Second, the product system has been continuously upgraded. Driven by demands related to marine ecological and environmental protection and restoration, as well as polar monitoring, a more refined, thematic, and operational product chain is gradually taking shape. Third, intelligent applications are developing rapidly. Artificial intelligence, foundation models, and multi-source data fusion methods are promoting a transformation of ocean remote sensing services from "data provision" to "intelligent services". Fourth, ground operations, calibration and validation, and data services have been continuously improved, indicating that China's ocean satellite development is moving from the stage of capability establishment toward capability enhancement and system maturity.

Against this background, this paper reviews and summarizes the major advances in China's ocean satellite program since 2024 from the perspectives of observation system evolution, ground support and data services, typical applications and product development, international cooperation, and future mission planning. The objective is to provide a reference for subsequent ocean satellite development planning, application deployment, remote sensing operational system construction, and related scientific research.

2 Evolution of China's Ocean Satellite Observation System

2.1 Current Operational Status of the In-orbit Ocean Satellite System

At present, China operates 11 ocean satellites in orbit, carrying 18 types of payloads in five major categories, including visible-light, hyperspectral, radar, microwave, and infrared sensors. These satellites have initially established high-precision, quantitative, and high-revisit spaceborne observation capabilities covering the global ocean, polar regions, and sea areas under China's jurisdiction. An independent ocean satellite observation system has essentially been formed (Table 1).

In terms of functional positioning, ocean color satellites mainly undertake long-term monitoring of sea surface temperature, ocean chlorophyll concentration, suspended sediment concentration, water transparency, and typical marine ecological and environmental variables. Ocean dynamic satellites primarily serve the retrieval of dynamic environmental parameters such as sea surface wind fields, sea surface height, ocean waves, sea surface salinity, and large-scale sea surface temperature. Ocean surveillance and monitoring satellites, supported by Synthetic Aperture Radar (SAR) and other payloads, provide high-resolution observational support for maritime target detection, ecological disaster monitoring, refined coastal dynamic environment retrieval, sea-ice identification, and monitoring of intertidal zones and coastal wetlands.

Currently, HY-1C and HY-1D have formed a dual-satellite network for operational ocean color observations. HY-1E, as a second-generation ocean color observation research and experimental satellite, marks the upgrading of China's ocean color satellite series and significantly enhances the capability for observing global ocean color environmental information. For ocean dynamics monitoring, China has established a five-satellite network composed of HY-2B, HY-2C, HY-2D, the China-France Oceanography Satellite (CFOSAT), and the Ocean Salinity Detection Satellite. This system provides all-weather, day-and-night capabilities for acquiring global ocean dynamic environmental information multiple times per day. For ocean surveillance and monitoring, GF-3 and two 1-m-resolution C-band SAR operational satellites together form an ocean surveillance and monitoring satellite constellation, providing operational and quantitative radar satellite data for multiple sectors, including ocean management, land resources, and emergency response.

Overall, ocean color satellites, ocean dynamic satellites, and ocean surveillance and monitoring satellites have gradually formed a coordinated and complementary configuration in terms of observed variables, spatial and temporal resolution, and spectral resolution. The multi-source satellite coordination model is shifting from "coexistence of platforms" toward "operational linkage".

Table 1 Overview of China's in-orbit ocean satellites

Category	Representative satellites	Main observation variables/applications
Ocean color satellites	HY-1C, HY-1D, HY-1E	Sea surface temperature, ocean color, water optical parameters, marine ecological environment, and disaster monitoring
Ocean dynamic satellites	HY-2B, HY-2C, HY-2D, CFOSAT, HY-4A	Sea surface wind field, sea surface height, ocean waves, sea surface salinity, sea surface temperature, *etc*.
Ocean surveillance and monitoring satellites	GF-3, 1 m C-SAR 01/02	Maritime target detection, refined coastal observations, sea-ice identification, wetland monitoring, *etc*.

Note Products related to the CFOSAT scatterometer and the HY-2D microwave scatterometer have been discontinued because of payload antenna anomalies.

Compared with the HY-2 series satellites, which have advantages in high revisit frequency and wide coverage, SAR offers stronger data acquisition and finer-scale observation capabilities in coastal waters, promoting the evolution of ocean dynamic environment observations from an "HY-2 wide-coverage-dominated" mode to a coordinated mode of "wide coverage plus refined supplementation". Meanwhile, in monitoring marine ecological disasters under cloudy and rainy conditions, SAR can work synergistically with optical remote sensing owing to its all-weather, day-and-night, and cloud-penetrating technical advantages, substantially improving the continuity and reliability of monitoring operations. In addition, the combined application of AIS and surveillance and monitoring satellites provides effective technical support for identifying and monitoring anomalous vessels.

2.2 Ocean Salinity Observation Mission

The construction of China's ocean satellite system has continued to improve, and the mission portfolio is expanding from the stable acquisition of traditional marine environmental parameters, such as ocean color, sea surface temperature, sea surface wind field, and sea surface height, toward integrated sensing of marine environmental variables. Ocean salinity is an important parameter for understanding ocean water-mass structure, the global water cycle, air-sea freshwater exchange, and climate-change processes. It is also a key observational variable linking ocean dynamic processes and air-sea interaction. Therefore, the Ocean Salinity Detection Satellite mission is of representative significance.

Successfully launched on 14 November 2024, the Ocean Salinity Detection Satellite (HY-4A) is China's first remote sensing satellite with ocean salinity information acquisition as its core objective. It fills the gap in China's spaceborne ocean salinity observation capability and further improves the national ocean satellite observation system[1]. The satellite primarily targets sea surface salinity observations while also supporting soil moisture detection. Sea surface salinity products can be applied to marine environmental monitoring and forecasting, polar monitoring, and research on air-sea interaction and climate change. Soil moisture products can support drought monitoring and agricultural environmental monitoring. In terms of accuracy indicators, the single-pass accuracy of HY-4A sea surface salinity products in low- and mid-latitude regions can reach 1 psu@50 km, while the 30-day averaged accuracy in open-ocean areas can reach 0.1 psu@200 km. The accuracy of soil moisture observations is better than 4%. These indicators show that the related observation products have the basic capability to support operational global-scale ocean salinity observations and related scientific research.

In terms of observational performance, HY-4A has global continuous observation capability, with a coverage rate of no less than 98% over global sea areas within three days. It can therefore effectively meet the needs for monitoring the global distribution of ocean salinity and its spatiotemporal variability. The satellite operates in a Sun-synchronous, repeating frozen dawn-dusk orbit at a mean altitude of approximately 654.7 km with an orbital inclination of 98.0004°. This orbit is conducive to improving global coverage efficiency, maintaining consistency in observation conditions, and satisfying requirements for long-term stable operation.

Regarding payload configuration, HY-4A carries two main payloads: an L-band Aperture Synthesis Microwave Radiometer (LASMR) and a Microwave Imager Combined Active and Passive (MICAP) (Figure 1). The LASMR focuses on L-band brightness temperature observations and provides high-sensitivity, multi-inci-

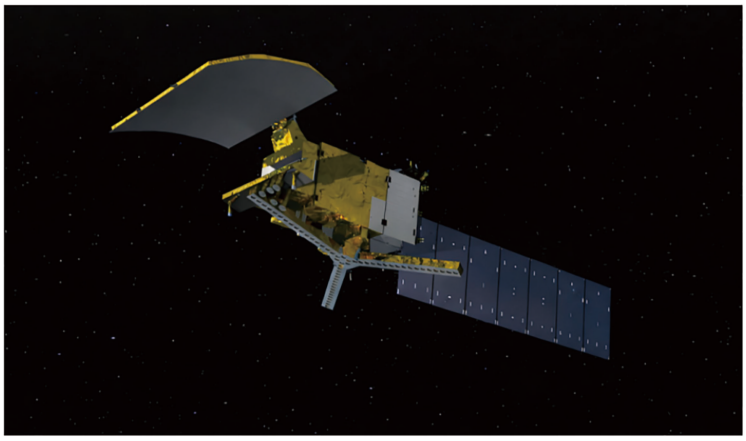


Fig. 1 Schematic diagram of the Ocean Salinity Detection Satellite

dence-angle observation data for sea surface salinity retrieval. The MICAP obtains environmental correction information, such as sea surface roughness and sea surface temperature, through synergistic observations by a microwave radiometer and a microwave scatterometer. It also provides a long-term stability reference for L-band radiometric brightness temperature detection and enables RFI detection and mitigation (Table 2). In-orbit test results show that the multi-parameter joint retrieval method constructed using dual-payload observations and a radiative transfer model performs well in sea surface salinity retrieval and environmental parameter correction, and that the functions and performance of the relevant payloads meet the design specifications.

2.3 Coordinated Development of Public-service and Commercial Satellites

As marine environmental monitoring requirements increasingly shift toward greater refinement, timeliness, and scenario-specific applications, a single class of public-service operational satellites can no longer fully meet multi-level observation needs. In recent years, commercial remote sensing satellites have developed rapidly in high-resolution imaging, rapid revisit, flexible constellation deployment, and thematic applications. They have demonstrated certain advantages in refined coastal observations, maritime target identification, polar supplementary monitoring, and disaster emergency response, and are becoming an important complementary force in the national ocean observation system. Commercial satellites are entering the field of marine environmental observation at an accelerated pace, initially forming a development trend characterized by coordination with public-service operational satellites. New observation capabilities represented by "Blue Carbon-1", "Tianmu-1", and multiple types of small SAR satellites effectively supplement public-service operational satellites in high-resolution, high-frequency, and region-specific observations. The ocean satellite observation system is thus showing a development trend in which national operational backbone satellites play the leading role while commercial supplementary satellites provide coordinated support.

Among these new capabilities, the "Blue Carbon-1" ocean remote sensing satellite, successfully launched in January 2025, carries a high-resolution imaging spectrometer with eight visible spectral channels and two shortwave-infrared spectral channels, enabling remote sensing observations at 10 m resolution. The "Tianmu-1" constellation currently has 23 satellites operating stably in orbit. Based on BDS/GNSS remote sensing technology, it is compatible with signals from the four major navigation systems, namely BeiDou, GPS, Galileo, and GLONASS. It provides high-frequency global three-dimensional detection capability and can acquire environmental variables such as global sea surface wind fields and sea ice on an all-weather and day-and-night basis[2]. In addition, small SAR satellites such as Haisi-1, Chaohu-1, Hongtu-1, and Luojia-2 have been launched and put into operation in succession, and their data products have become important supplementary sources for ocean satellite observations.

From the perspective of system functions, public-service operational satellites have advantages in long-term continuous operation, observational stability, and

Table 2 Payloads and technical specifications of the Ocean Salinity Detection Satellite

Payload component	Main function	Technical specifications
LASMR	Acquires L-band sea-surface radiometric brightness temperature	1.400–1.427 GHz; 20 MHz; V/H/T3; sensitivity better than 1.5 K; stability better than 0.12 K; calibration accuracy 1.0 K; resolution better than 38 km; swath width better than 950 km
MICAP: microwave radiometer, L band	Provides brightness temperature detection and a stability reference	1.400–1.427 GHz; 25 MHz; V/H/T3; sensitivity better than 0.15 K; stability better than 0.12 K; resolution better than 75 km× 50 km; swath width better than 950 km
MICAP: microwave radiometer, C band	Provides environmental correction information	6.9 GHz; 200 MHz; V/H; sensitivity better than 0.5 K; stability better than 0.3 K; resolution better than 15 km× 25 km; swath width better than 950 km
MICAP: microwave radiometer, K band	Provides environmental correction information	18.7 GHz; 200 MHz; V/H; sensitivity better than 0.5 K; stability better than 0.3 K; resolution better than 15 km× 25 km; swath width better than 950 km
MICAP: microwave scatterometer	Acquires sea surface roughness and supports RFI detection and mitigation	1.25 GHz; HH/VV/HV/VH; bandwidth $\leqslant$5 MHz; peak power $\geqslant$200 W; calibration stability better than 0.1 dB; resolution 50–100 km; swath width better than 950 km

strong operational assurance capabilities, and therefore constitute the main body of national-level marine environmental monitoring and operational services. Commercial satellites have greater advantages in flexible deployment, rapid response, application innovation, and differentiated supply, making them suitable for high-frequency supplementary observations, refined monitoring of specific regions, and emergency response tasks. The coordinated development of these two types of satellites can improve the spatio-temporal coverage, observation accuracy, and service efficiency of the ocean observation system.

3 Development of Ground Support and Data Service Capabilities

3.1 Data Reception and Ground Operation System

China's ocean satellite ground operation system has established a complete operational chain covering data reception, mission scheduling, calibration and validation, and transmission and distribution. The ground receiving system, composed of three fixed stations in Beijing, Mudanjiang, and Hainan, together with the mobile station on the research vessel Xuelong, is equipped with 24 antennas of multiple types. It has integrated reception capability for polar-orbiting and geostationary satellites and can simultaneously support the real-time acquisition and transmission of data from 15 satellites.

According to the 2025 operational statistics of the National Satellite Ocean Application Service, approximately 25900 orbits of satellite data were received in 2025, with a total data volume exceeding 385 TByte. This indicates that China's ocean satellite data reception capability has entered a stage of stable and efficient operation. The continuous enhancement of ground-system operational capabilities provides fundamental support for networked ocean satellite observations and operational applications.

For data calibration and validation, China has established a network of calibration and validation sites covering key sea areas nationwide. This network includes nine calibration sites and 23 observation stations, such as the Yellow Sea and East China Sea optical validation site, the Xi'an scatterometer calibration station, the Zhuhai Wanshan altimeter calibration site, and the Xisha offshore calibration site. It has formed coordinated support capabilities for multiple payload types and established integrated capabilities for radiometric calibration, product validation, and in-orbit performance evaluation. These capabilities provide a reliable data-reference basis for quantitative retrieval and long-term time-series applications of ocean satellites.

3.2 Data Processing, Sharing, Distribution, and Operational Services

In terms of data processing and sharing services, China has established data processing and distribution systems covering multiple satellite series, including ocean color and dynamic environment satellites. The system has approximately 2 Pflop of computing capability and 50 PByte storage capacity, supports the processing of data from

various ocean payloads, and can meet the needs of large-scale operational production and long-term historical archiving. Through the ocean satellite internet service system of the National Satellite Ocean Application Service (Figure 2), users worldwide can perform data retrieval, ordering, and customized distribution. The service user base covers government departments, research institutions, universities, and international users, with more than 6800 registered users.

Meanwhile, in response to operational application needs, throughout 2025, the National Satellite Ocean Application Service distributed approximately 6516 TByte of data to more than 600 users through its operational sharing platform. HY-1 ocean color satellites and HY-2 series dynamic environment satellites were the main data sources, while multi-source data such as CFOSAT and SAR were also included.

Overall, China's ocean satellite data services are transforming from "data provision" toward "high-quality services and application support", thereby providing a solid foundation for marine scientific research and operational applications.

4 Progress in Typical Applications and Product Development

With the continuous improvement of China's networked ocean satellite observation capability, ground processing capability, and operational service capability, ocean satellite applications have expanded from single-image interpretation and basic parameter retrieval to an integrated operational support system for national marine ecological early-warning monitoring, marine disaster prevention and mitigation, global marine environmental monitoring, polar observations, maritime safety supervision, and marine resource development (Table 3).

Ocean color satellites, ocean dynamic satellites, and ocean surveillance and monitoring satellites are complementary in terms of observed variables, spatial and temporal resolution, and application scenarios, providing stable data sources and product support for different application requirements. On this basis, product forms and application modes are also evolving from the provision of basic imagery toward application-ready products, operational thematic products, and intelligent products.

4.1 Development of Application-ready Products for the Yellow Sea and East China Sea

To meet the needs of marine ecological monitoring and marine disaster emergency response in the Yellow Sea and East China Sea, the "China Ocean Color Satellite Yellow Sea and East China Sea Imagery and Remote Sensing Index Dataset" has been developed based on HY-1C, HY-1D, and HY-1E satellite data. Designed for satellite remote sensing monitoring of the Yellow Sea and East China Sea, this dataset provides application-ready remote sensing imagery, remote sensing indices, cloud-cover information, and other thematic products. With medium spatial resolutions of 50 m/100 m and dai-

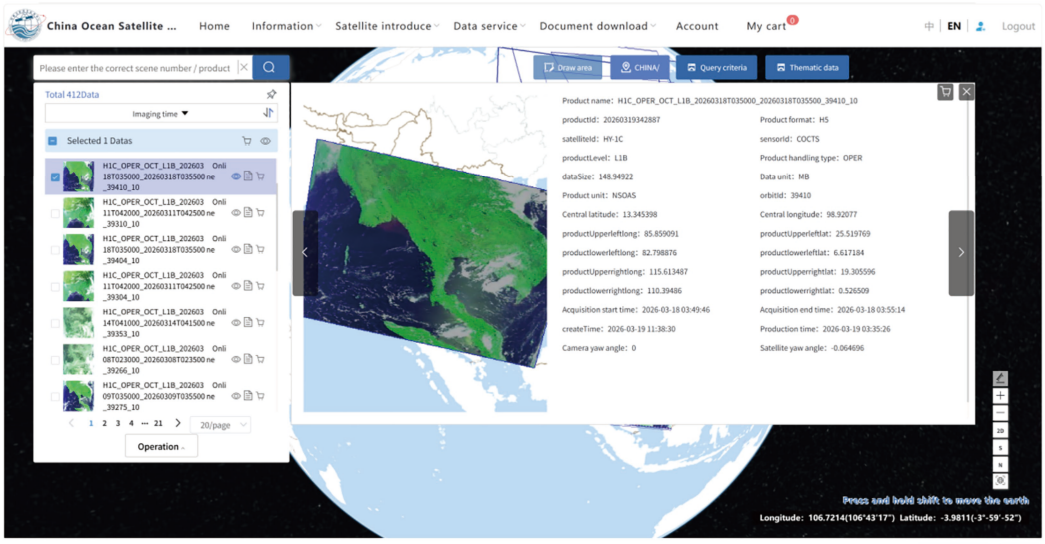


Fig. 2 Schematic diagram of the ocean satellite internet service system

ly product updates, it provides stable data support for monitoring marine ecological disasters, including green tides caused by *Ulva prolifera*, *Sargassum*, red tides, and offshore oil spills.

In terms of product design, this dataset does not simply provide single-scene raw imagery. Instead, based on reflectance calculations from L1B data acquired by optical payloads such as CZI, cloud identification processing is performed by considering the characteristics of different satellite sensors. Remote sensing index products, including NDVI, RVI, and BRVI, are further generated (Figure 3). Taking floating algae monitoring as an example, this product chain extracts floating algal pixels over the sea by applying multi-index threshold constraints and filtering out cloud and land pixels. It then generates thematic products for operational floating algae monitoring through multi-orbit data mosaicking, observation-domain masking, human-computer interactive correction, and statistical analysis of coverage area and distribution range.

Overall, although medium-resolution products are weaker than high-resolution imagery in representing fine spatial details, they can still effectively reflect overall distribution patterns and area scales, making them suit-

Table 3 Operational support system of ocean satellites

Application field	Main observation requirements	Main satellites/payloads	Typical products	Operational applications
Marine ecological early-warning monitoring	Ocean color, chlorophyll, floating algae, red tides, oil spills	HY-1C/D/E, GF-3, 1 m C-SAR	Chlorophyll, suspended sediment, floating algae index, oil spill identification products	Monitoring of green tides caused by *Ulva prolifera*, red tides, *Sargassum*, and oil spills
Marine disaster prevention and mitigation	Sea surface wind field, ocean waves, sea ice, sea surface height	HY-2B/C/D, CFOSAT, GF-3, 1 m C-SAR	Wind field, ocean waves, sea level anomaly, sea-ice products	Monitoring of typhoons, storm surges, and sea-ice disasters
Global marine environmental monitoring	Sea surface temperature, ocean color, sea surface height, sea surface salinity	HY-1C/D/E, HY-2B/C/D, GF-3, 1 m C-SAR, CFOSAT, HY-4A	Global marine environmental parameter products	Research on climate change and air–sea interaction
Polar monitoring	Sea-ice extent, concentration, edge, and polar environment	HY-1C/D/E, HY-2B, GF-3, 1 m C-SAR	Multi-parameter polar sea-ice products	Polar navigation and climate-change assessment
Maritime safety and resource management	Vessels, maritime targets, wetlands, shorelines	GF-3, 1 m C-SAR, AIS	Vessel identification, wetland classification, refined coastal observation products	Marine regulation, emergency response, and resource management

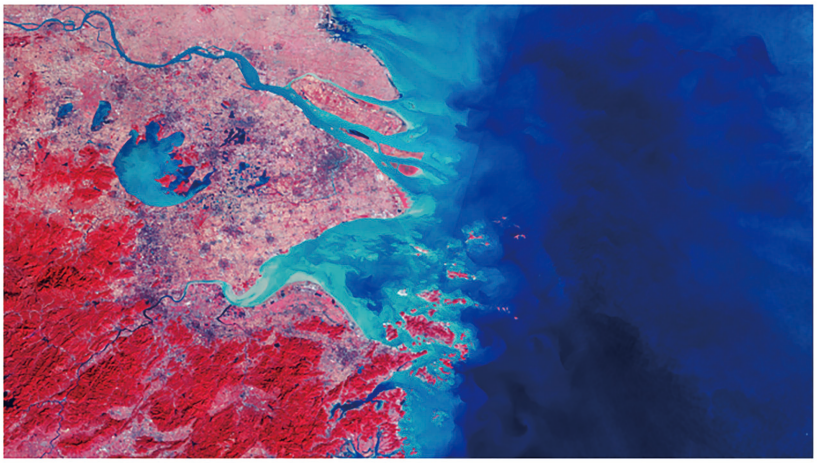


Fig. 3 Local image example from the "China Ocean Color Satellite Yellow Sea and East China Sea Imagery and Remote Sensing Index Dataset"

able for large-scale and continuous operational monitoring. This dataset represents the development of China's ocean color remote sensing products from basic imagery provision toward thematic and application-ready products for regional operational applications.

4.2 Upgrade of the Ocean Color Satellite Data Processing System

As the operational applications of China's ocean color satellites continue to deepen, the related data processing system has gradually moved beyond the initial stage of satisfying basic product production and entered an upgrade stage oriented toward multi-scenario applications, improved product quality, and thematic expansion. Although HY-1C and HY-1D have both exceeded their five-year design lifetimes, they remain in stable operation in orbit. Through upgrades to the operational processing programs for COCTS L2 and L3 data, a Version 2.0 product system has been established and has replaced the previous version for archiving and distribution.

This upgrade is reflected in three aspects: product form, product type, and product quality. First, the quick-look display has been improved from a single display mode to the overlay of RGB imagery and chlorophyll-a information, enhancing product retrieval and rapid interpretation capabilities. Second, new NDVI L2/L3 products and L3 products of remote sensing reflectance, Rrs, in visible bands have been added, expanding thematic application capabilities for coastal ecological environment and marine disaster monitoring. Third, based on cross-comparison with similar MODIS products, the upgraded chlorophyll-a concentration and sea surface temperature products show clear improvements in both spatial structure representation and quantitative accuracy (Figure 4).

From the perspective of system evolution, the upgrade of the COCTS data processing system has not only enhanced the application value of in-orbit operational satellites but also indicates that China's ocean color satellite ground processing system is continuously evolving from a "product-production-oriented" system toward a "quality-driven and application-oriented" system. This provides a foundation for improving data processing, product calibration, and operational service capabilities for subsequent ocean color satellites.

4.3 Progress in Multi-parameter Polar Sea-ice Products

Polar regions are among the most sensitive key regions to global climate change and are also important frontiers for research on air-sea interaction, cryosphere evolution, and the global water cycle. In recent years, relying on China's ocean satellites, operational monitoring capabilities for polar marine environments have continued to improve. An operational multi-parameter polar sea-ice product system has been developed, focusing on sea-ice concentration, sea-ice extent, sea-ice type, and sea-ice drift velocity. This development promotes the extension of polar remote sensing monitoring from single-parameter retrieval to multi-parameter coordinated observation and integrated application (Figure 5). The retrieval and development of operational products for multiple sea-ice parameters based on the active and passive microwave payloads of HY-2B constitute important progress at this stage[3,4].

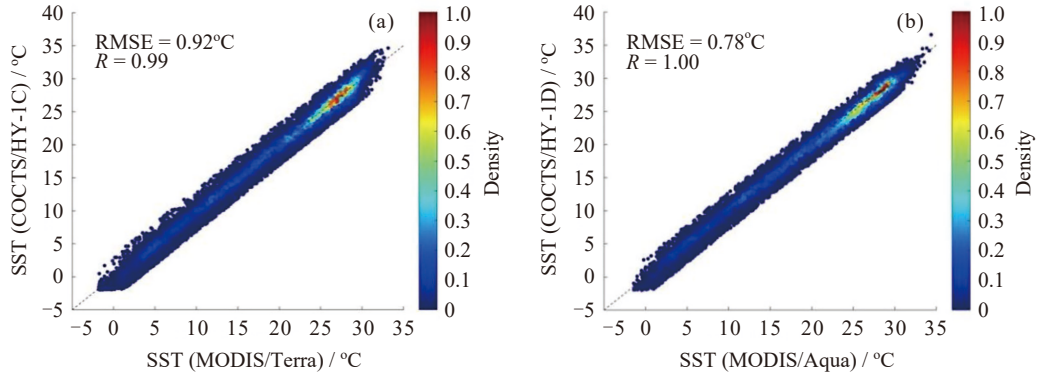


Fig. 4 Consistency comparison between upgraded sea surface temperature daytime products from COCTS on HY-1C/D and corresponding MODIS products, using data from 20 June 2025 as an example. (a) HY-1C *vs.* Terra, (b) HY-1D *vs.* Aqua

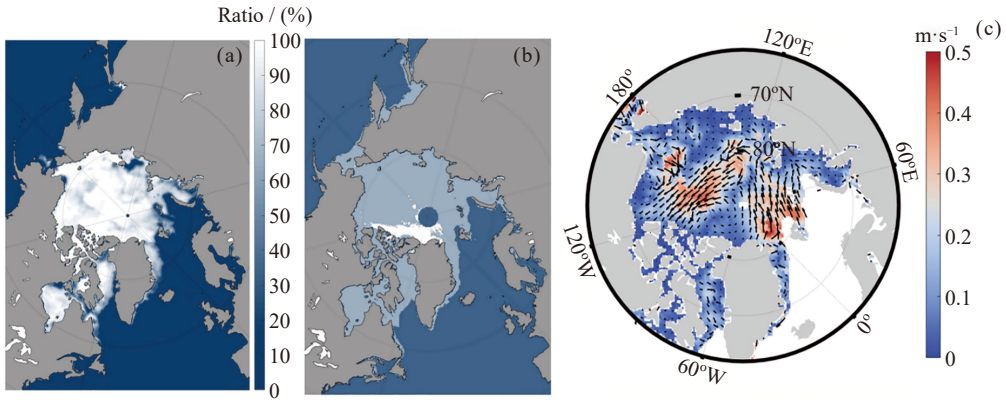


Fig. 5 Schematic diagram of operational multi-parameter polar sea-ice products based on the active and passive microwave payloads of HY-2B (Sea-ice concentration and sea-ice drift velocity)

For sea-ice concentration, in response to sensor differences among brightness temperature data from different microwave radiometers, related studies have developed a Bootstrap retrieval method based on dynamic brightness temperature tie points. Through steps such as dynamic feature selection, weather filtering, climatological constraints, and land-contamination correction, the consistency and stability of sea-ice concentration retrieval have been improved. *In-situ* observation-based evaluation results indicate that sea-ice concentration products retrieved from Chinese satellite data achieve accuracy comparable to that of international counterpart products, as measured by correlation coefficient, bias, and root-mean-square error.

For sea-ice extent and sea-ice type, the synergistic observation advantages of the HY-2B microwave scatterometer and scanning microwave radiometer have been used to develop dynamic support vector machine models for ice-water discrimination and sea-ice type classification. These models enable effective identification of first-year ice and multi-year ice during the Arctic freezing season. Comparisons with mainstream international products, such as NSIDC and OSISAF, as well as independent observations from MODIS and SAR, indicate that the results for sea-ice extent and type have high consistency and can meet operational application requirements.

For sea-ice drift, to address the insufficient texture information in low-resolution passive microwave data, an Arctic freezing-season sea-ice drift retrieval method has been developed based on HY-2B/SMR 37 GHz brightness temperature data. Retrieval accuracy is improved through techniques including brightness temperature resampling, texture enhancement, sub-pixel displacement estimation, and multi-polarization result fusion. Validation using Arctic buoy data shows that the retrieved sea-ice drift velocities are in good agreement with observations.

4.4 Regional Ocean Artificial Intelligence Foundation Model

Artificial intelligence is becoming an important direction in the development of ocean satellite remote sensing operations. Compared with traditional ocean remote sensing, which mainly provides sea-surface state information, operational marine environmental services increasingly require reconstruction of subsurface three-dimensional thermohaline and dynamic structures and prediction of future states. In this context, regional ocean artificial intelligence foundation models represented by "SkyOcean" have begun to enter operational application scenarios.

"SkyOcean" is designed for the northwestern Pacific region. Based on multi-source satellite fusion products, it establishes a regional ocean AI application framework covering the chain of " remote sensing–reconstruction–prediction". The model extends observational applications from two-dimensional sea surface information to the prediction of three-dimensional spatial structures and their temporal evolution. It is capable of generating prediction products for the next 10 days, spanning from the sea surface to a depth of 650 m, with a spatial resolution of 1°/8 (Figure 6).

Validation based on Argo observations shows that the prediction errors of temperature, salinity, and cur-

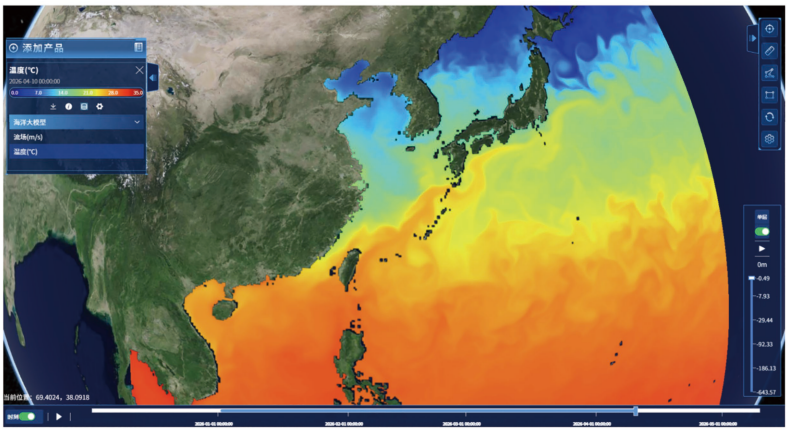


Fig. 6 Schematic diagram of the "SkyOcean" foundation model

rent fields are smaller than those of operational numerical forecasts. It can also support the three-dimensional characterization, identification, and tracking of typical ocean dynamic processes such as mesoscale eddies, and has already been put into operational use.

Overall, the exploration of foundation models represented by "SkyOcean" indicates that China's intelligent applications of ocean satellites have begun to move beyond local tasks such as image recognition and single-parameter estimation toward higher-level applications, including multi-source fusion sensing, three-dimensional environmental reconstruction, and prediction services.

5 Progress in International Cooperation

In recent years, China's international cooperation in ocean satellites has formed a multi-level cooperation pattern centered on data exchange, joint development, application demonstrations, and capacity building. Cooperation has extended to Europ, Africa, ASEAN countries, and Latin America.

In cooperation with Europe, the National Satellite Ocean Application Service has established an operational data exchange mechanism with the European Organisation for the Exploitation of Meteorological Satellites, promoting the integration of Chinese ocean satellite data into operational systems such as the European Centre for Medium-Range Weather Forecasts. It has also continued to advance cooperation with the Centre National d'Études Spatiales of France on CFOSAT, achieving significant results in sensor performance validation, algorithm development, calibration and validation, scientific product generation, and global data sharing. This cooperation has further promoted the extension of next-generation China-France ocean satellite collaboration toward subsequent coordinated missions. Meanwhile, China has also carried out altimeter calibration cooperation with relevant institutions in Greece, continuously improving the quantitative application level of ocean satellites.

In cooperation with developing countries, relying on the China-Africa Satellite Remote Sensing Application Cooperation Center and the China-ASEAN Satellite Remote Sensing Application Center, China has actively provided products and technical services to African and ASEAN countries, including sea surface wind fields, sea surface temperature, ocean color anomalies, mangrove monitoring, and fishery environmental support. As an example, Figure 7 shows a chlorophyll-a concentration monitoring product derived from HY-1C/COCTS for China-ASEAN sea areas. China has also promoted bilateral cooperation and demonstration applications with multiple countries. Overall, China's international cooperation in ocean satellites is gradually expanding from "data sharing" toward "joint research and development, joint application, and joint services", providing strong support for global marine environmental monitoring, disaster prevention and mitigation, and sustainable ocean development.

6 Conclusions and Outlook

Since 2024, China's ocean satellite observation system

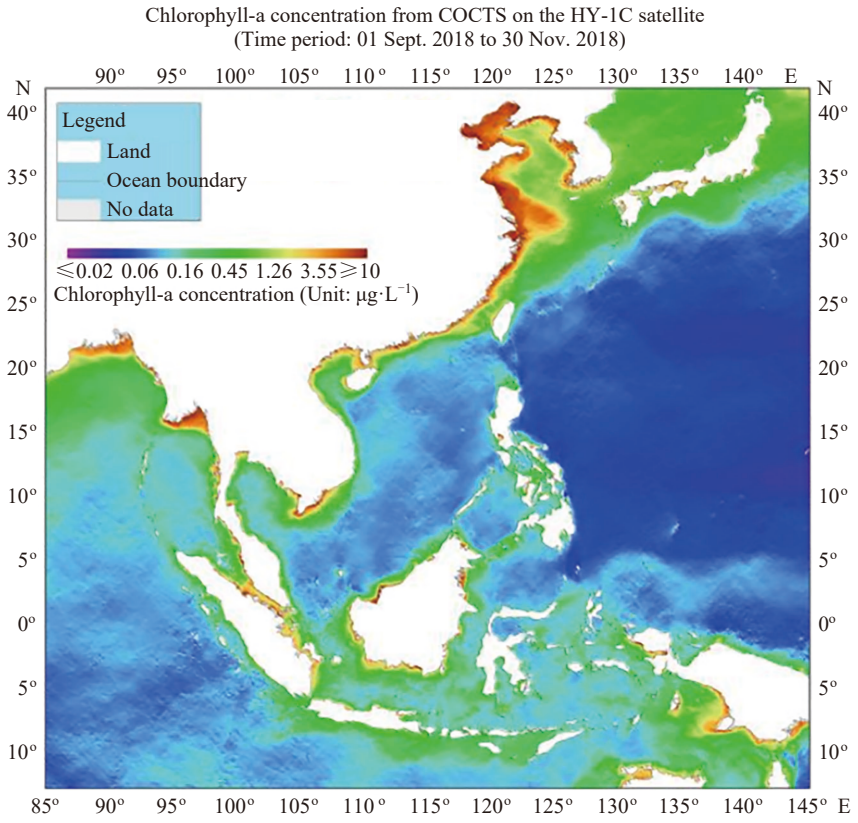


Fig. 7 Example of chlorophyll-a concentration monitoring product for China-ASEAN sea areas

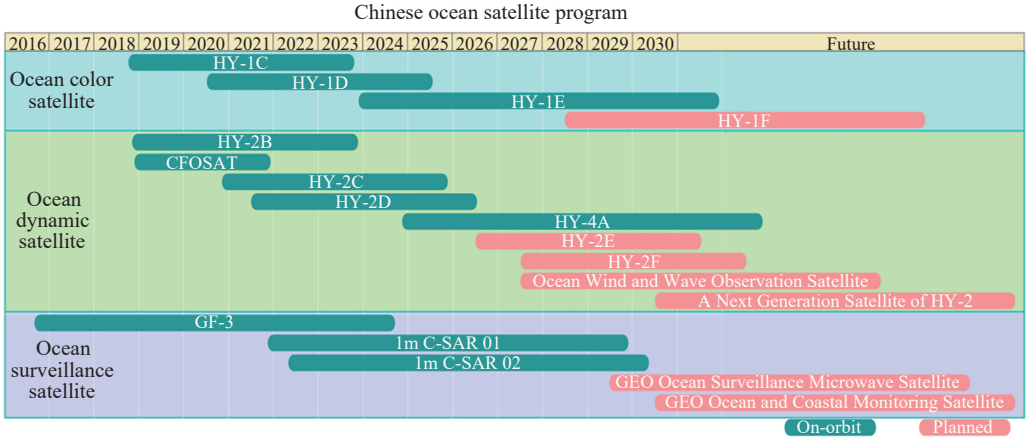


Fig. 8 Development plan of China's ocean satellites

has made systematic progress in networked operation, expansion of observed variables, application product upgrading, ground-support capability development, and intelligent applications. The observation system has continued to improve, and the successful launch of HY-4A has filled the gap in China's spaceborne ocean salinity observation capability. The development of ocean color application-ready products, the upgrade of the COCTS processing system, and the generation of multi-parameter polar sea-ice products indicate that the product system is extending from basic product provision toward quality optimization, thematic deepening, and operational services. Intelligent applications represented by "SkyOcean" show that ocean satellite applications are

expanding from sea-surface observations toward three-dimensional environmental representation and prediction services. At the same time, capabilities in ground operations, calibration and validation, and data distribution services have continued to improve, providing solid support for the operational use of ocean satellites.

According to existing plans, China will focus on advancing missions such as next-generation operational ocean color satellites, HY-2E/F, next-generation polar-orbiting ocean dynamic satellites, sea wind and wave detection satellites, and geostationary ocean observation satellites, as summarized in Figure 8. These missions will gradually build an integrated observation system characterized by coordinated development of "polar-orbiting + geostationary" and "operational satellites + research satellites".

Looking ahead, while maintaining existing observation capabilities, it is necessary to continuously improve spatial and temporal resolution and observation accuracy, further address shortcomings in polar observations, and develop capabilities for sea surface current fields and subsurface profile detection. At the same time, China's ocean satellite development should continue to focus on multi-satellite and multi-payload consistency and long-term stable calibration, construction of high-timeliness and high-quality product chains, improvement of coastal complex-environment observation capability, physical consistency and reliability of multi-source fusion products, and the interpretability of artificial intelligence. Only by continuously promoting the coordinated evolution of the observation system, ground-support system, and intelligent application system can ocean satellites better support marine ecological early warning, disaster prevention and control, resource development, and global ocean governance.

Conflict of Interests The authors declare that there is no conflict of interests

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