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# Progress of FengYun Meteorological Satellite Integrated Observation System (2024–2026)*

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**Abstract** This paper systematically presents the comprehensive progress of the FengYun (FY) meteorological satellite integrated observation system during 2024–2026. With the successful launched of FY-3H polar-orbiting satellite and FY-4C geostationary satellite, the FY constellation has improved the polar four-orbit networking and geostationary two-satellite coordinated configuration, realizing optimized GEO-LEO satellites collaborative observation. Major breakthroughs have been made in hyperspectral detection, active microwave remote sensing, high-precision geolocation and radiometric calibration, as well as intelligent ground operation. The product system has been expanded to 85 geophysical parameters in six categories, with significant innovations in multi-source data fusion, physical-constrained retrieval and AI-driven algorithms. FY satellite data have been widely applied in weather forecasting, severe disaster monitoring, climate change assessment, ecological environment protection, space weather services and key industrial fields. Up to now, FY satellites have provided data and application services to 139 countries and regions, conducted international emergency support for disaster prevention and mitigation, and deeply participated in global meteorological governance. This paper summarizes the technological advances, application benefits and global contributions of the FY system, and prospects its future development in higher precision, intelligence and global services.

**Key words** FengYun meteorological satellite, Observation system, Ground segment, Remote sensing application, Global meteorological service

**Classified index** P715.6

## 1 Introduction

The FengYun (FY) meteorological satellite integrated observation system constitutes a critical national space infrastructure of China, serving as the core space-based observation platform for meteorological disaster prevention and mitigation, climate change adaptation, ecological civilization construction, and space environment se-

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curity. It also acts as a major vehicle for China's engagement in global meteorological governance and provision of global public meteorological services. Over more than 50 years of development, the FY satellite program has established a complete operational architecture featuring coordinated polar-orbiting and geostationary satellite series, which have been formally integrated into the core constellation of the World Meteorological Organization (WMO) Global Operational Meteorological Satellites, emerging as a major player in the international meteorological satellite community[1–5].

The period of 2024–2026 marked comprehensive breakthroughs for the FY Satellite System toward the core goals of constellation improvement, technological innovation, application deepening, and global service. The layout of the FY constellation has been optimized and upgraded: the polar-orbiting series added the FY-3H satellite, updating a four-satellite, four-orbit coordinated observation pattern; the geostationary series successfully launched the FY-4C satellite, establishing an observation mode of dual-satellite networking, east-west deployment, and mutual backup. Core technologies are independently controllable. Key technologies such as hyperspectral detection and active microwave remote sensing have achieved breakthroughs, and observation accuracy and data quality have been further improved.

The ground segment has completed intelligent upgrading. The FengYun Smart Brain integrated operation and control system has entered operational service, significantly enhancing end-to-end, full-factor monitoring and command decision-making capabilities. High-precision geolocation and calibration technologies have been increasingly sophisticated. The product portfolio has expanded to cover 85 geophysical parameters across six categories: clouds and radiation, atmosphere, land, ocean, cryosphere, and space weather, fully satisfying the fundamental Earth observation requirements of the WMO Integrated Global Observing System (WIGOS). Multiple product algorithms and key technologies have seen innovative breakthroughs. Data services have expanded to 139 countries and regions worldwide.

Satellite data have achieved remarkable results in numerical weather prediction data assimilation, disaster monitoring and early warning, climate assessment, space weather forecasting, and key industry services. International services and cooperation have been deepened steadily. The capability of FY satellites to serve the Belt and Road Initiative has improved, and China's participation in the governance of FY satellite affairs has enhanced its international service and influence.

## 2 FY Constellation

From 2024 to 2026, the FY constellation added FY-3H and FY-4C, realizing an optimized high-low orbit constellation layout, upgrades to satellite platforms and core payloads, and innovation in coordinated observation architecture[6].

### 2.1 Newly Launched Satellites

#### 2.1.1 FY-3H

FY-3H is the eighth satellite in the FY-3 series. Launched successfully on 27 September 2025, it is currently under commissioning and will take over from FY-3D to become China's new-generation afternoon-orbit operational meteorological satellite upon completion. FY-3H carries nine sets of advanced remote sensing instruments (Table 1).

Building on the core operational capabilities of global imaging and atmospheric vertical sounding inherited from the FY-3 series, FY-3H has expanded two major capabilities.

(1) The new-generation GAS-II has been carried. Adopting advanced spectral splitting and area-array detection technologies, it achieves, for the first time, high-precision global detection of column concentrations of $CO_2$ and $CH_4$ with a 100 km swath, 3 km spatial resolution, and up to 0.04 nm spectral resolution. This provides independent space-based data support for global climate monitoring, greenhouse gas accounting, and China's dual carbon strategy. The key technologies including refined spectral calibration, high-precision radiometric calibration, and precise geolocation of the instrument have successfully broken through. The obtained spectral lines clearly reveal rich atmospheric absorption spectral information reflected by bright targets in cloudy areas, dark ocean targets, and medium-brightness land targets, as shown in Figure 1.

(2) The space weather monitoring instruments have been upgraded**.** The improved WAI-II achieves 130° field-of-view lamp calibration and 10 km high-resolution aurora imaging for the first time, accurately captur-

**Table 1 FY-3H remote sensing instruments**

| | Instruments full name | Acronym | Status |
|---|---|---|---|
| 1 | Medium Resolution Spectral Imager-III | MERSI-III | Inherited |
| 2 | Hyperspectral Infrared Atmospheric Sounder-II | HIRAS-II | |
| 3 | Micro-Wave Temperature Sounder-III | MWTS-III | |
| 4 | Micro-Wave Humidity Sounder-II | MWHS-II | |
| 5 | Micro-Wave Radiation Imager-II | MWRI-II | |
| 6 | GNSS Radio Occultation Sounder-II | GNOS-II | |
| 7 | Ionospheric PhotoMeter-II | IPM-II | |
| 8 | Greenhouse-gases Absorption Spectrometer-II | GAS-II | New |
| 9 | Wide-field Auroral Imager-II | WAI-II | Improved |

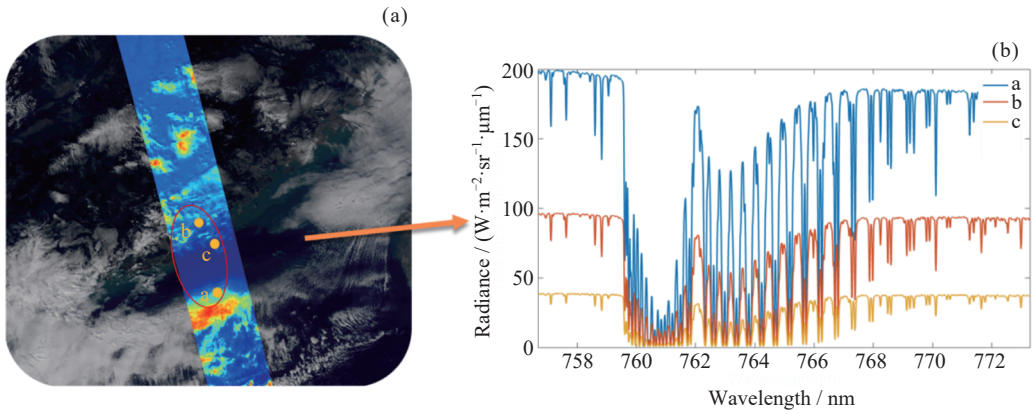



Fig. 1 Refined spectra of different detection targets for GAS-II (a-Cloud area, b-Land, c-Ocean). (a) Regional monitoring data acquired by GAS-II on global orbits. (b) High-resolution spectra (758–772 nm) for cloud, land, and ocean targets

ing auroral boundaries and particle precipitation information, and greatly improving support for space weather early warning and research.

In addition, FY-3H has simultaneously optimized functions such as atmospheric temperature and humidity profile detection, and land-surface and ocean observation, serving the three core fields of numerical weather prediction, climate assessment, and space environment monitoring in an all-round way.

### 2.1.2 FY-4C

FY-4C is the second operational satellite in China's new generation geostationary meteorological satellite series. It was successfully launched on 27 December 2025, and is under commissioning. After that, it will replace FY-4A and become an important part of the geostationary orbit layout of FY satellites. Together with FY-4B, it establishes an operational pattern of dual-satellite operation and in-orbit backup for geostationary meteorological satellites.

The satellite platform inherits the three-axis stabilized attitude control technology of the FY-4 series and adds electric propulsion, sun tracking, and dual-channel Ka-band data transmission, achieving high-precision control and positioning as well as long-life stable operational service capability. FY-4C is equipped with six remote sensing instruments (Table 2).

Compared with previous satellites, its capabilities of remote sensing instruments have been comprehensively improved.

(1) Enhanced imaging and sounding capabilities. For the first time internationally, AGRI has realized full-disk imaging capability of 500 m true color and 250 m panchromatic, with imaging time reduced from 15 min to 10 min, and 1 min high-frequency continuous observation over key areas. The spatial resolution of GIIRS is improved from 12 km to 8 km, temporal resolution from

2 h to 1 h, spectral accuracy from 7 ppm to 5 ppm (1 ppm=$10^{-6}$), and radiometric accuracy from 0.7 K to 0.5 K. LMI has a high-speed imaging capability of 500 frames per second and can intelligently identify lightning events from 30 Gbit·$s^{-1}$ massive data streams.

(2) Expanded space weather observation capabilities. Three newly developed space weather instruments are deployed: MUSI realizes hyperspectral ionospheric detection in the extreme ultraviolet band from geostationary orbit for the first time; SUVI and SXUS fill the gaps in China's geostationary orbit solar activity monitoring and forecasting technologies. Figure 2 shows the four-channel images of solar flare observed by SUVI on FY-4C.

It can be seen that FY-4C has achieved comprehensive upgrades in imaging accuracy, detection dimensions, and instrument functions, making it the geostationary meteorological satellite with the strongest comprehensive detection capability in the world.

### 2.2 Coordinated Observation of the FY Constellation

#### 2.2.1 Joint Observation System of GEO-LEO Satellite

As of May 2026, 10 FY satellites are in-orbit operation illustrated in Figure 3[6], building a globally unique integrated observation network based on GEO and LEO satellites. For LEO satellites, FY-3E/F/G/H form a full network in four near-Earth orbits: Sun-synchronous early-morning, morning, afternoon orbit, and drift orbit. China has become the only country in the world to operate four civil LEO meteorological satellites simultaneously. For GEO satellites, FY-4B and FY-4C work together to achieve full regional coverage. FY-4C is equipped with an inter-satellite communication subsystem, and will carry out intelligent inter-satellite linkage with FY-3 in the future, further improving observation efficiency by leveraging the respective advantages of satellites in different orbits.

#### 2.2.2 Overall Performance Improvement of FY Constellation

The overall observation performance of FY constellation has been improved. The global observation timeliness of FY-3 satellites has been shortened from 12 h to 4 h, and the observation timeliness of FY-4 reaches up to 1 min. FY-3 satellites realize full-spectrum three-dimensional quantitative observation, and FY-4 satellites focus on regional high-timeliness dynamic monitoring.

**Table 2 Remote sensing instruments on FY-4C**

| | Instrument | Acronym | Status |
|---|---|---|---|
| 1 | Advanced Geostationary Radiation Imager | AGRI | Improved |
| 2 | Geostationary Interferometric Infrared Sounder | GIIRS | |
| 3 | Lightning Mapping Imager | LMI | |
| 4 | Solar extreme-UltraViolet Imager | SUVI | New |
| 5 | Multi-band ionosphere Ultraviolet Spectral Imager | MUSI | |
| 6 | Solar X-ray and extreme-Ultraviolet Spectral fluxmeter | SXUS | |

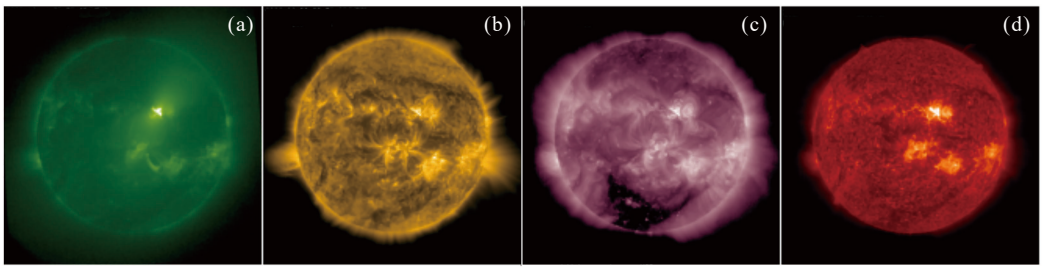



Fig. 2 X1.1 class solar flare observed by FY4 C/SUVI at wavelengths of 94 Å (a), 171 Å (b), 211 Å (c) and 304 Å (d) at 20:50 UTC on 30 June 2026

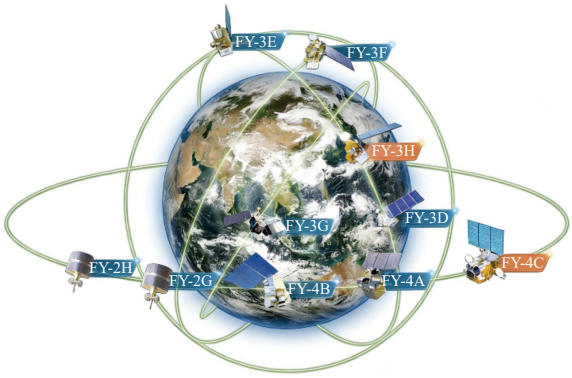



Fig. 3 FY Constellation[6]

A breakthrough has been made in multi-band cooperative detection technology for instruments, achieving full-spectrum coverage from soft X-ray, ultraviolet, visible, infrared to microwave. Among them, the visible channel of FY-4 satellites reaches 250 m spatial resolution, and the infrared hyperspectral detection spectral resolution reaches 0.625 $cm^{-1}$. The number of channels of HIRAS-II on FY-3 has increased from 1370 to 3053, and the spectral coverage has been expanded to three bands (650–1136 $cm^{-1}$, 1210–1750 $cm^{-1}$, 2155–2555 $cm^{-1}$). MWTS and MWHS realize synchronous high-precision detection of atmospheric temperature and humidity. Precipitation Measurement Radar can detect weak precipitation changes of 0.2 $mm \cdot h^{-1}$. The space weather monitoring system has formed a multi-instrument coordinated architecture of GNOS-II, IPM-II, and WAI-II, realizing all-round space weather monitoring and early warning from the atmosphere to the ionosphere and from electron density to particle precipitation, while greatly enhancing solar activity monitoring capability.

# 3 Ground Segment

## 3.1 Operation and Control

An intelligent integrated operation and control system centered on the FengYun Smart Brain has been constructed for the ground segment, realizing centralized monitoring and intelligent scheduling of the entire operational process and all factors of FY satellites (see Figure 4). It covers the full chain of "satellites – ground stations – control – research – production – service – application". It is an innovation in AI-integrated systems for FY satellite operation and control.

The FengYun Smart Brain integrates core information such as in-orbit satellite status, ground station network operation, data processing progress, product distribution, and application service effectiveness, enabling one-screen control of macro situations and layer-by-layer penetration of micro details. Through hierarchically progressive thematic interfaces, it completes refined monitoring in multiple scenarios including instrument operation, IT resource scheduling, data preprocessing, product quality inspection, disaster monitoring, and international services.

## 3.2 Data Processing

### 3.2.1 Geolocation

During 2024–2026, key breakthroughs were made in technologies including Orbit Motion Compensation (OMC), attitude-orbit error correction, resident and navigation accuracy analysis, and limb sounding tangent height correction. A high-precision geolocation technology system adapted to GEO-LEO satellites and imaging/sounding instruments has been further improved.

An OMC algorithm model adapted to FY-4 instruments has been developed, and a multi-attitude refer-




Fig. 4 FengYun smart brain: an intelligent command and decision platform for multi-satellite integrated operation control, satellite-ground monitoring, data quality evaluation, and application services

ence conversion system has been established, effectively compensating for scanning registration errors of large-field-of-view long-linear-array instrument and significantly improving the navigation accuracy and geolocation calculation efficiency[7]. On-orbit measured data from FY-4 GIIRS are used to verify and analyze the resident and navigation accuracy. The results show that the detector achieves a resident accuracy of 1/10 pixel and a navigation accuracy of 1 pixel[8]. The attitude-orbit error source tracing and correction model of FY-3D have been completed, and the on-orbit attitude solution algorithm has been optimized, effectively suppressing orbit and attitude system errors. The along-track and cross-track positioning accuracy of 1-km resolution images of the MERSI-II has been improved by 20%[9]. For the Ozone Monitoring Suite-Limb (OMS-L) on FY-3F, an ellipsoidal virtual tangent height solution model has been constructed to quantify the impacts of the Earth ellipsoid, attitude-orbit parameters, and installation deviations on limb tangent point positioning. High-precision tangent height correction is realized through pitch installation parameter correction, with tangent height correction accuracy better than 0.4 km, cross-track pointing deviation better than 0.1°, and annual vertical pointing seasonal variation less than 0.01°, meeting the geometric correction accuracy requirements for atmospheric trace gas profile retrieval[10].

### 3.2.2 Calibration

A full-link high-precision radiometric calibration system integrating laboratory calibration, on-board calibration, active external calibration, and inter-calibration for FY satellites has been fully established, realizing full-spectrum and full-factor calibration for visible, infrared, microwave, and active radar, with data consistency and long-term stability reaching international advanced levels.

Meanwhile, new calibration methods have been developed for different instruments, and pre-launch calibration verification and in-orbit calibration evaluation have been carried out[11,12]. For active radars, a satellite-ground integrated external calibration technology using ground Active Radar Calibrators (ARC) has been developed, realizing in-orbit measurement of radar antenna patterns and absolute calibration of the entire system, ensuring the accuracy of quantitative products such as three-dimensional precipitation and sea surface wind fields[13]. The in-orbit radiometric performance of MERS-III has been systematically evaluated using the global Pseudo Invariant Pixel (PIP) cross-platform comparison method. Results show that the radiometric bias standard deviation of most channels is less than 2%, temporal radiometric stability is better than 3.5%, and overall evaluation uncertainty is lower than 3.38%[14].

Artificial intelligence technology has been introduced, and an AI Infrared Radiometric Calibration (AIRC) method for FY-4 satellites has been proposed. A Radiometric Calibration Neural Network (RCNN) has been constructed to learn the mapping relationship based on historical high-precision calibration data, realizing the transformation from Reference Traceability (RT) to State Traceability (ST). The calibration accuracy is comparable to that of the blackbody calibration system, promoting the construction of a unified observation system for infrared hyperspectral instruments[15].

### 3.2.3 Product System and Algorithm Innovation

From 2024 to 2026, FY satellite product system has been continuously enriched and improved, forming six categories and 85 geophysical parameter products covering cloud and radiation, atmosphere, land, ocean, cryosphere, and space weather, fully meeting the core observation requirements of the WIGOS for the six Earth spheres. Products are divided into a five-level system according to standardized processing flows, covering raw observation data, Level-0 unpacked and spliced data, Level-1 radiometric corrected data, Level-2 geophysical quantitative parameters, and Level-3 spatiotemporally fused gridded products. Each level is supported by self-developed algorithms and quality control models.

FY satellites products have broken through the limitations of traditional single physical algorithms, forming product algorithm innovations including multi-source data fusion, physical model optimization, spatio-temporal refined reconstruction, and machine learning technologies, covering atmosphere, land, ocean, space weather, and other fields.

(1) Atmospheric product algorithm optimization. In cloud remote sensing, for FY-4 satellites, a Cloud Amount Neural Network (CLANN) for AGRI 3 D cloud amount has been developed, with high consistency CALIPSO data (correlation coefficient up to 0.92)[16]. A

deep learning-based cloud mask model, Convolutional Attention Cloud Mask Network Plus Plus (CACM-Net++) has been developed, producing more consistent cloud distributions, particularly over nighttime land regions[17]. An algorithm for Cloud-Cleared Radiances (CCR), from collocated observations of hyperspectral IR sounders and advanced imagers onboard the same geostationary platform has been developed, effectively solving the problem of high uncertainty in GIIRS CCRs, increasing GIIRS effective observation data volume by three times, and recovering 37% of partially cloudy fields of view. The CCRs can be assimilated as CLRs in Numerical Weather Prediction (NWP) models without worrying about the cloud impact[18]. For FY-3 MERSI nighttime cloud detection, a Transformer-based Nighttime Cloud Detection (TNCD) framework, which integrates spatial features and utilizes an advanced Transformer architecture with relative position encoding, layer scaling, and channel attention mechanisms, has been proposed, with overall accuracy exceeding 90% when applied to MERSI cloud detection[19]. In aerosol remote sensing, an improved aerosol retrieval algorithm based on a nonlinear surface model from FY-3D/MERSI-II data[20], FY-4B land aerosol retrieval algorithms coupling hourly land surface models with spatio-temporal variability characteristics[21], and an adaptive dark-target algorithm for retrieving land aerosol optical depth have been established[22]. Figure 5 shows the Amazon rainforest wildfires in South America in August 2024 captured by the FY-3D/MERSI-II AOD product. Compared with the same period in 2023, the affected area and impact magnitude are clearly illustrated.

(2) Land and ocean product algorithm iteration. For land surface elements, the FY-3E WindRAD water cloud model has been optimized, and pixel-by-pixel parameter fitting combined with SMAP data has realized high-precision surface soil moisture in low-to-moderate vegetation conditions, with ubRMSD controlled at 0.02–0.06 $cm^3 \cdot cm^{-3}$[23]. A regional-scale all-sky gridded diurnal near-surface air temperature ($T_{air}$) estimation method based on FY-4B measurements has been constructed, realizing all-sky hourly gridded retrieval of $T_{air}$ with a correlation coefficient greater than 0.95[24]. For ocean surface elements, aiming at complex sea conditions such as rainy days and typhoons, a Lightweight Deep Neural Network (LWDNN) for FY-3D MWRI sea surface wind speed has been developed, with RMSE less than 2.0 $m \cdot s^{-1}$ under all weather conditions and less than 1.5 $m \cdot s^{-1}$ in the clear-sky region, in the wind speed range of 20–70 $m \cdot s^{-1}$, the results are shown in Figure 6[25]. The backscatter characteristics of Open Water (OW), First-Year Ice (FYI), and Multi-Year Ice (MYI) under different seasonal, wavelength, and polarization conditions based on the unique capabilities of FY-3E WindRAD scatterometer has been investigated. It provides vital support for the development and refinement

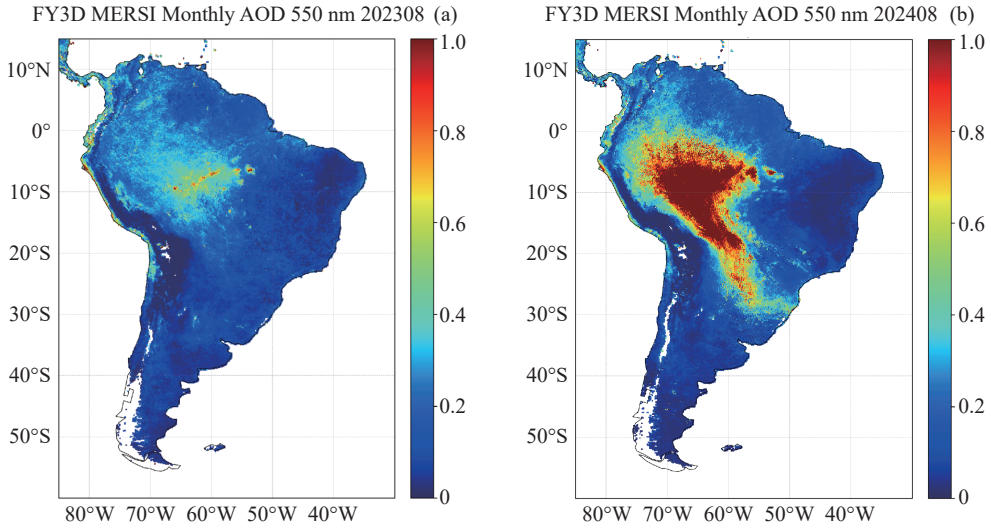



Fig. 5 Spatial distribution of monthly average AOD retrievals obtained from FY-3D/MERSI-II during Aug. 2023(a) and Aug. 2024(b)

of algorithms for FY-3E WindRAD operational sea ice products [26].

(3) Space weather product algorithm innovation. A TIEGCM-based inversion model for Ionosphere-Thermosphere (I-T) parameters is constructed by integrating sparse observational data with physics-based numerical simulations. Driven by three-dimensional electron density fields, the model combines high-resolution data-constrained electron density reconstructions with the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) to achieve end-to-end inversion of implicit I-T physical parameters. The Architecture of the TIEGCM-based inversion model is shown in Figure 7. Supervised neural networks pre-trained on massive TIEGCM simulation datasets are embedded into the framework to automatically capture the intrinsic coupling relationships among diverse I-T state variables, supporting rapid, stable, and physically consistent parameter retrieval[27]. A deep learning-based vertical decomposition model for ionospheric Total Electron Content (TEC) has been developed, which maps global ionospheric TEC data to vertically layered electron density profiles (60–800 km) using a Multilayer Perceptron (MLP) model, achieving significantly higher accuracy than the IRI-2020 model and enabling cost-effective, high-resolution global ionosphere reconstruction for space weather applications[28].

(4) Artificial intelligence technology application. in addition to the various machine learning methods mentioned above, a Deep Diffusion Model for Satellites

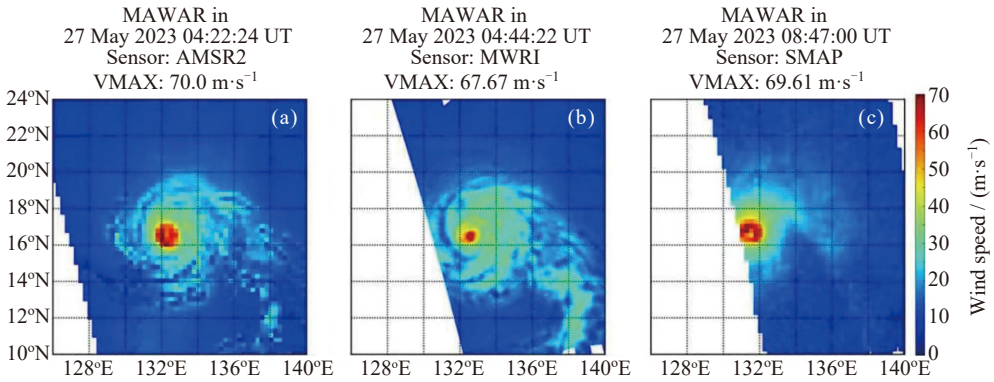



Fig. 6 Spatial distributions of the AMSR2 all-weather SSWS (a), MWRI SSWS retrieved by the LWDNN (b), and SMAP SSWS (c) for typhoon MAWAR

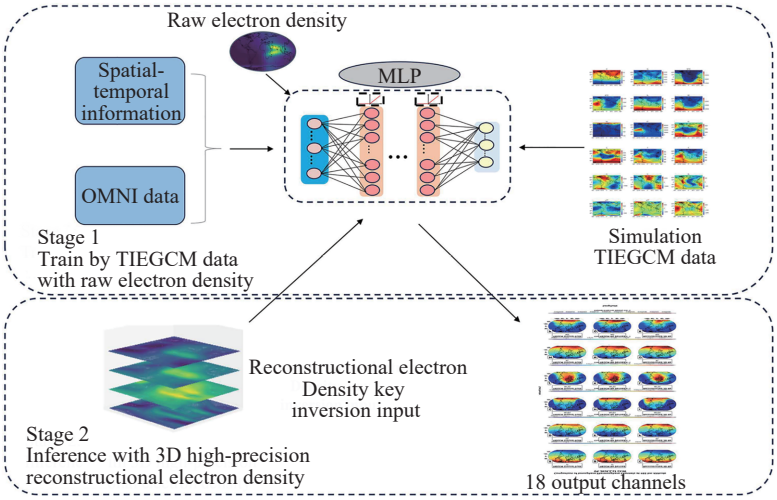



Fig. 7 Architecture of the TIEGCM-based inversion model for end-to-end mapping from observable data to latent ionosphere-thermosphere state variables

(DDMS) has been pioneered, constructing an AI convective nowcasting system that realizes large-scale thunderstorm nowcasting with 15-min resolution and up to 4 h in advance. As shown in Figure 8, for the 29 July 2023 extreme torrential rainfall over Beijing–Tianjin–Hebei induced by Typhoon Doksuri, NowcastNet and PredRNN-v2 fail in 4 h forecasts, and PySTEPS cannot capture convective cell evolution; DDMS outperforms all contrasting methods obviously[29]. Based on the Light Gradient Boosting Machine (LGBM) machine learning framework, an FY-4B AI precipitation estimation model has been constructed, with multi-dimensional accuracy indicators superior to international precipitation products such as GPM/IMERG[30]. The U-Net deep learning model is used to intelligently identify Trapped Lee Waves (TLWs) propagating in the lower troposphere, explaining the causes of environmental disasters related to strong turbulence in mountainous areas in the afternoon[31].

These new AI technologies make up for the lack of observation data, effectively characterize the multi-scale spatio-temporal evolution of the atmosphere and ionosphere, significantly improve the refinement and intelligence level of geophysical and space physical parameter retrieval, and provide new technical support for meteorological satellite products and applications.

### 3.3 Data Services

#### 3.3.1 Data Archiving

A large-capacity, high-reliability, intelligent data archiving and management system has been built. As of April 2026, the archived satellite data volume has exceeded 59 PByte, covering 57 satellites in 12 series at home and abroad, with more than 1500 data products. Figure 9 shows the statistics of satellite data archiving from 1988 to 2025. Data management adopts standardized classification, intelligent retrieval, and efficient access technologies to realize rapid archiving, precise retrieval, and secure backup of data, ensuring long-term preservation and efficient access.

#### 3.3.2 Data Services

In terms of data sharing services, a space-ground integrated comprehensive meteorological satellite data service system has been constructed, providing data sharing services through satellite direct reception stations, the China Meteorological Administration Data Broadcasting System (CMACast), the WMO Information System (WIS), the FY Satellite Data Service Network, and satellite data resource pools, enabling the acquisition, exchange, management, and service of domestic and foreign satellite data. As of the end of April 2026, the number of registered users on the FengYun Satellite Data Service website has exceeded 207000, with 1.859 million orders completed and data ordered exceeding 8 PByte.

## 4 Remote Sensing Application

### 4.1 FengYun Earth Platform

After three years of construction, the FengYun Earth Platform has for the first time realized synchronous direct access to FY satellite products at the national, provincial, municipal, and county levels. It has built a nationally

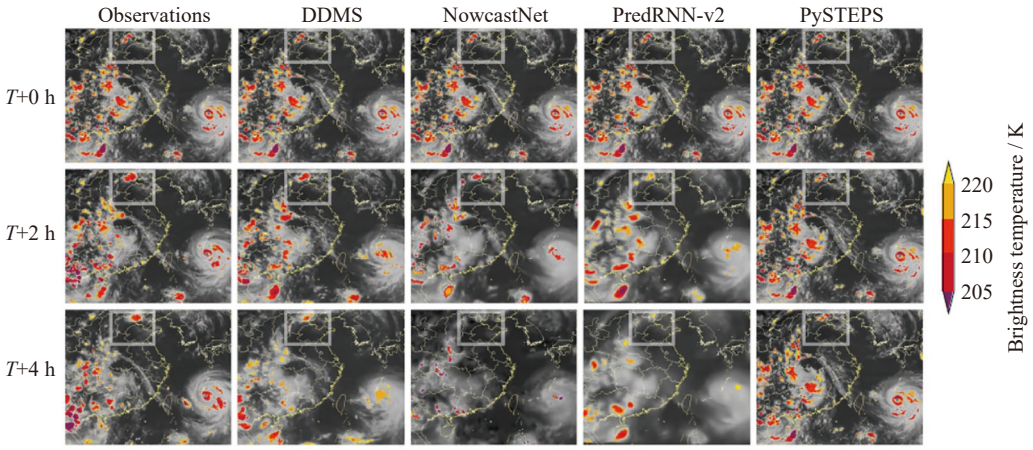



Fig. 8 4 h lead time nowcasting comparison of multiple models for the severe convective extreme rainstorm event in the Beijing-Tianjin-Hebei region on 29 July 2023 associated with Typhoon Doksuri

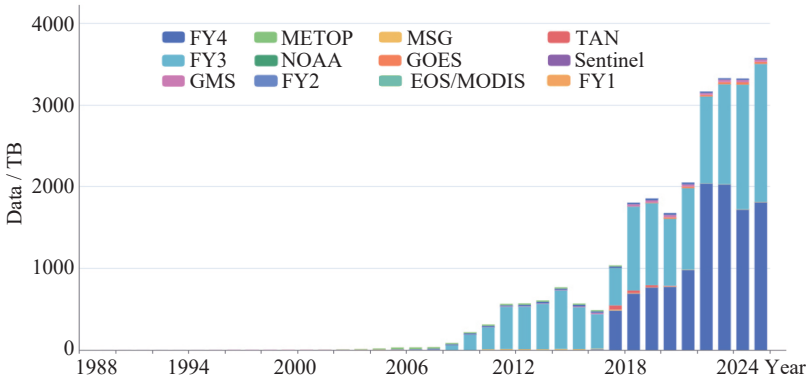



Fig. 9 Statistics of satellite data archiving from 1988 to 2025

unified and full-domain covered satellite remote sensing application service foundation.

Guided by the core philosophy of IT-based, Interactive, and Instant ($I^3$), FengYun Earth Platform has achieved a series of key technological innovations. It pioneered the deep integration of traditional database and big data management technologies, enabling full-process quality monitoring and online real-time computing of 148 categories and 934 types of massive multi-source heterogeneous satellite data. A light-weight, highly available cloud-client service architecture has been constructed, breaking through technologies including 10000-level concurrent user access, minute-level cloud image push, and high-rate data compression. It overcame the core technologies of space-ground integrated intelligent observation and cooperative control, reducing the FY-4B rapid scan observation region switching time from 2 h to 15 min and delivering satellite product services to users within 5 min. The platform systematically addresses three major bottlenecks in satellite application: service timeliness, algorithm scientificity, and product fusion. It has innovatively developed a multi-source satellite fusion algorithm and quantitative remote sensing product system, comprehensively enhancing the intelligent, intensive, and real-time application level of FY satellites, and providing original technical support for the operational application of China's meteorological satellites.

### 4.2 Meteorological Forecasting and Disaster Monitoring Applications

#### 4.2.1 Support for NWP and Data Assimilation

FY satellite observation data have been fully integrated into China's global NWP model (CMA-GFS) and regional NWP systems. Satellite data assimilation accounts for 88%, and FY satellite data assimilation accounts for more than 25%. Focusing on FY-3 series MWTS, MWHS, HIRAS, and FY-4 series GIIRS, key technologies such as fast radiative transfer, near-surface microwave assimilation, adaptive water vapor assimilation, and thinned quality control have been broken through, significantly improving data assimilability and assimilation efficiency. The daily assimilable data volume, such as FY-3F MWTS and FY-3E HIRAS has exceeded 450000 profiles, with an assimilability rate of over 50%[32]. After assimilation of 15 min intensive observation data from FY-4B GIIRS, the analysis of typhoon thermal structure and environmental fields has been significantly improved, and the track forecast errors for super typhoons such as Gaemi and Yagi in 2024 have been significantly reduced by up to 22.5%, providing core support for the precision development of meteorological forecasting[33].

#### 4.2.2 Severe Weather Monitoring and Early Warning

An all-weather, full-coverage, high-timeliness severe weather monitoring and early warning system based on FY satellites has been constructed, realizing accurate monitoring and early warning of multiple types of disasters such as typhoons, rainstorms and severe convection, cold waves, dust storms, and heavy fog.

(1) Typhoon monitoring: geostationary satellites capture the whole process of genesis, movement, and intensity change with high-frequency imaging. Combined with infrared and microwave detection of FY-3 satellites, the bottom circulation structure and eyewall position of typhoons is observed, and the temperature

anomaly structure is identified (Figure 10). Precipitation measurement radar obtains the three-dimensional structure of precipitation cloud systems and cloud physical characteristics, supporting typhoon positioning, intensity determination, and wind-rain impact forecasting[34].

(2) Rainstorms and severe convection: FY-4B High-speed imager realizes minute-scale, 250 m resolution regional intensive observation, capable of capturing convective initiation signals 30–40 min in advance and accurately tracking the development and evolution of convective systems.

(3) Cold waves: polar-orbiting and geostationary satellites collaboratively monitor cold air advancement, rain-snow phase transition, snow cover, and strong winds at sea[35,36].

(4) Sandstorms: multi-channel spectral data enable rapid identification, quantitative intensity analysis, and path tracking; products such as dust aerosol optical depth, dust index, dust visibility, and PM10 concentration are retrieved to quantitatively assess dust storm intensity.

(5) Heavy fog: multi-channel brightness temperature threshold technology distinguishes fog from low clouds and surface targets, and quantitatively retrieves micro-physical parameters such as fog optical depth, liquid water particle size, and liquid water content[37].

From 2024 to 2026, FY satellites have supported the response to many major severe weather events, providing key data support for disaster prevention and mitigation decision-making.

### 4.3 Climate Monitoring and Assessment Applications

Based on long-sequence observation data of FY satellites, a global climate comprehensive monitoring system covering key elements such as outgoing longwave radiation, sea surface temperature, snow cover, sea ice, land surface temperature, and vegetation has been built, integrated into the FY Satellite Remote Sensing Climate Operational Platform, realizing real-time dynamic monitoring of key climate parameters globally. In particular, land surface temperature reconstruction technologies have been developed: the RMSE after reconstruction using a two-point machine learning method is about 2.6 K[38]; the temporal dimension reconstruction technology based on diurnal variation models reduces the RMSE of summer land surface temperature in the Heihe River Basin to less than 4 K[39].

Based on multi-source fused long-sequence datasets, large-scale climate system monitoring such as global convective activity, polar vortices, monsoons, and ENSO has been carried out. For the western Pacific subtropical high, the index system has been optimized, spatial morphology determination methods improved, and ridge line descriptions perfected, significantly improving the indicative ability for abnormal summer precipitation and high temperatures in China[40]. Coupling FY satellite cloud and water vapor products has formed a complete technical chain of satellite observation – circulation diagnosis – anomaly attribution.

Integrating FY satellite data with ground observations and reanalysis data, an extreme climate event in-

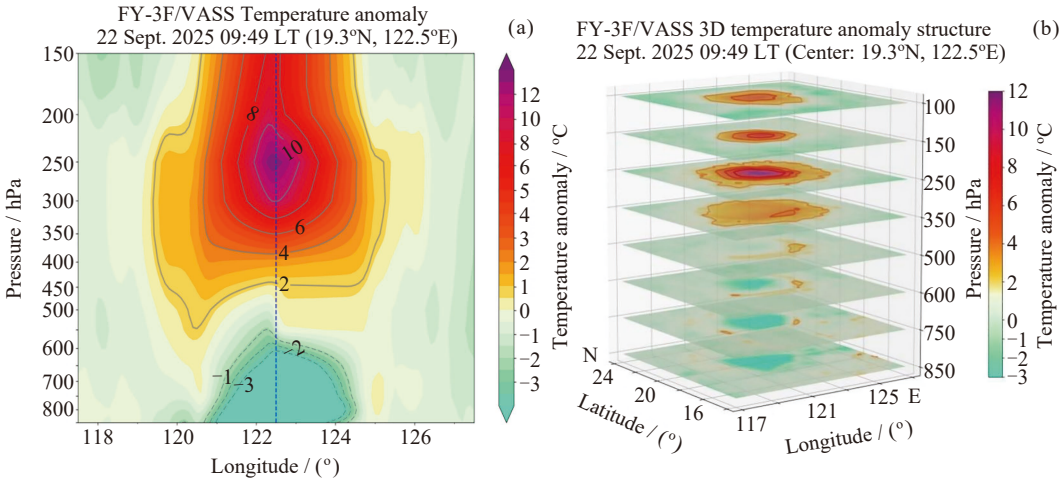



Fig. 10 3D temperature structure of typhoon Bolaven

dex system for China and Eurasia has been established, realizing refined monitoring and comprehensive assessment of the intensity, duration, and impact range of extreme climate events in key global regions. With the application of new products from FY-3H and FY-4C, the quantification and refinement of climate monitoring and climate change response will be further improved.

### 4.4 Ecological and Environmental Remote Sensing Applications

In the terrestrial ecology field, dynamic monitoring of vegetation growth, droughts, flood and key ecological regions has been realized. Relying on satellite vegetation index products, continuous monitoring of ecological quality and vegetation coverage in key regions such as the Yangtze River Basin, the Yellow River Basin, the Qinling Mountains, the Qinghai-Xizang Plateau, and Northeast Ecological Function Zone has been carried out. In aquatic ecology and flood monitoring, FY satellites efficiently identify water bodies using multi-spectral features, realizing continuous tracking of dynamic changes in water area of key lakes and reservoirs, forming a more than 30-year long-sequence dataset (Figure 11) [41].

In the atmospheric environment remote sensing monitoring, FY-3 series has enabled China to carry out global atmospheric environment remote sensing monitoring with independent satellites for the first time, realizing all-weather, quantitative monitoring of aerosols, ozone, polluting gases, greenhouse gases *etc*.[42]. The FY-3F Ultraviolet Hyperspectral Ozone Sounder, through nadir + limb combined detection mode, improves the monitoring accuracy of stratospheric and tropospheric ozone, polluting gases, and aerosols, supporting regional atmospheric environmental quality evaluation and pollution source tracing [43]. The GAS-II on FY-3H realizes global greenhouse gas column concentration detection with 100 km swath and high spectral resolution for the first time. A Global Emission Inventory of Biomass Burning (GEIOBB) has been developed, providing important data support for improving air quality simulation[44].

### 4.5 Space Weather Applications

#### 4.5.1 Space Weather Forecasting Models

China's first-generation full-chain operational numerical forecasting system for space weather has been established. Key technologies including cross-scale, cross-material-state, cross-model and cascaded coupling have been broken through in the system development. Numerical space weather forecasting with full-chain coverage and partial regional coupling is realized, and full-process management of numerical models is supported to enable routine operational execution at minute-level intervals. Panoramic characterization of the Sun-Earth space environment under data-sparse conditions has also been achieved, and comprehensive promotion of forecasting service capacity has been accomplished accordingly.

The world's first chained intelligent forecasting mo-

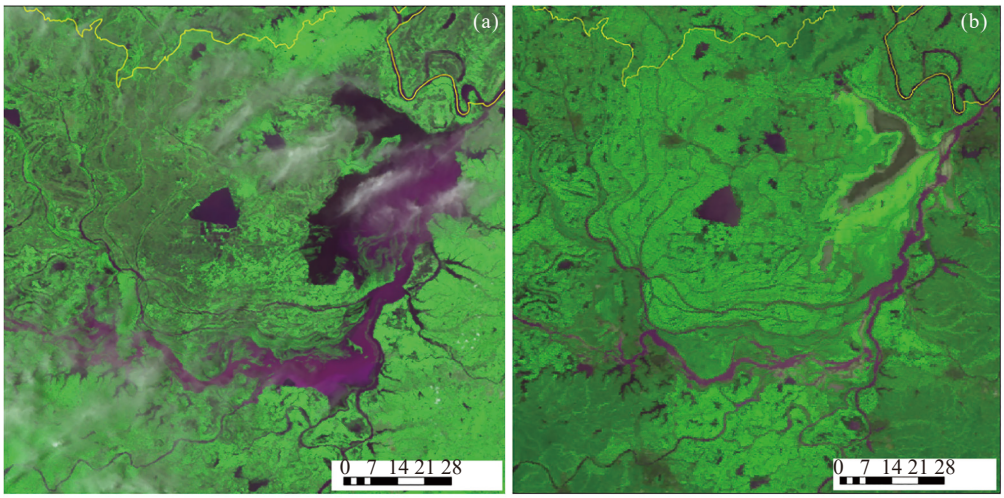



Fig. 11 Water reduction of the Dongting Lake induced by high temperature and drought monitored by FY-3D on 14 June (a) and 5 September (b) in 2022

del for space weather — Fengyu AI Large Model — has been independently developed, and its schematic diagram is shown in Figure 12. Cross-domain operator optimization technologies based on domestically controllable AI frameworks are adopted, and an original chained training architecture together with an intelligent coupling optimization mechanism has been pioneered. By means of full-chain coupled training, the complete physical processes of solar wind disturbing the Earth's space environment are faithfully reproduced, and full-chain AI modeling covering the solar wind, magnetosphere and ionosphere is implemented for the first time globally. Prediction errors of global Total Electron Content (TEC) for multiple extreme intense geomagnetic storm events in the past two years have been controlled within 10%, and world-leading technical performance has been attained.

#### 4.5.2 Space Weather Monitoring Operations

Routine monitoring of the solar-terrestrial space environment with FY-3 and FY-4 satellites has been carried out, monitoring solar EUV radiation, solar flares, geomagnetic indices, auroral morphology and particle precipitation, ionospheric total electron content, airglow changes, space particles and magnetic field disturbances, *etc*., realizing real-time data acquisition, operational processing, and product generation. Monitoring data have been fully integrated into the national space weather monitoring and early warning operational system.

On this basis, the FengYun Space integrated space weather operational platform has been built independently, forming a closed-loop technical architecture of observation – retrieval – forecasting – service. The platform integrates multi-source observation and physical forecasting models, with capabilities including space weather diagnosis, short-term forecasting, medium-to-long-term trend early warning, extreme event analysis, and emergency response. It provides customized services for highly sensitive industries such as aerospace, aviation, communications, and electric power, and fully supports the operation of the ICAO Global Space Weather Center, carrying out regular international joint monitoring, rotating early warnings, and global space weather briefings, providing important scientific and technological support for global aviation safety and space facility protection.

### 4.6 Key Industry Applications

FY satellite agricultural remote sensing services cover planting area extraction, growth monitoring, yield estimation, and agro-meteorological disaster assessment. High spatio-temporal resolution vegetation indices are reconstructed using satellite data fusion technology, and a winter wheat yield estimation model is constructed by coupling BP neural networks, realizing refined crop yield retrieval and spatial distribution mapping at farmland and county scales, forming a large-scale, dynamic food production assessment capability to serve precision agricultural production and national food security[45]. For road and air transportation, monitoring and early warning services for road icing and extreme weather from FY satellites are provided to ensure traffic safety and transportation efficiency. Monitoring and early warning of power grid mountain fires, and assessment of wind and

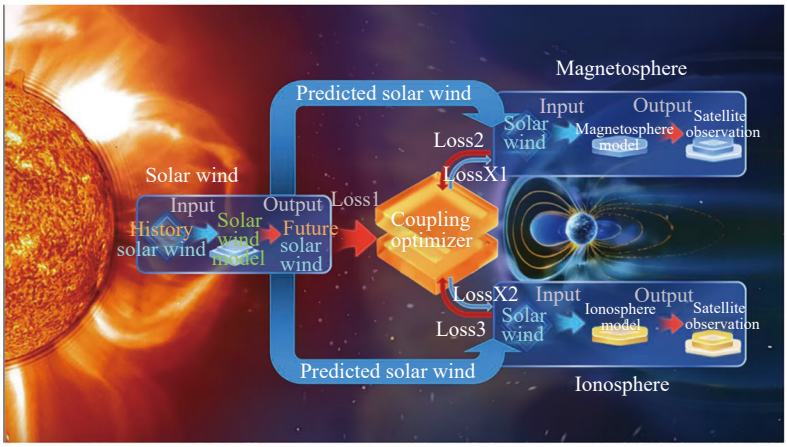



Fig. 12 Schematic diagram of Fengyu AI large model

solar energy resources are carried out to improve the safe operation of energy facilities and resource development efficiency[46].

# 5 Global Services and International Cooperation

## 5.1 Global Data Sharing and Distribution

Adhering to the concept of global openness and sharing, a comprehensive, multi-level, and efficient FY global data sharing and distribution system has been built. As of May 2026, FY satellite data services cover 139 countries and regions worldwide, with a cumulative data distribution volume of more than 8 PByte to international users and over 1.85 million international data service orders completed. Data distribution is fully connected to the WIS, compatible with international common data formats and standards. Overseas service nodes such as South Africa, Ethiopia, and the United Arab Emirates have been opened to optimize global data access speed, reducing cloud platform product loading time from seconds to milliseconds, greatly lowering the threshold for international users to use data. Meanwhile, a regular international data training mechanism has been established to provide FY satellite data application training for developing countries, enhance local users' data application capabilities, and promote the wide application of FY satellite data in global meteorology, disaster prevention, and ecology.

## 5.2 Global Services

Relying on the FY satellite system, precise and practical remote sensing application services are provided for countries along the Belt and Road Initiative and other developing countries, helping local disaster prevention and mitigation and sustainable development. The FY Satellite Emergency Support Mechanism (FY-ESM) has registered 38 international emergency users. From 2024 to 2026, it has provided more than 190 international disaster emergency remote sensing services for many countries around the world. The Mazu Early Warning Program has been implemented and applied in many developing countries, improving their extreme weather early warning capabilities. Meanwhile, exclusive meteorological support services are provided for the Pacific Games and other events, helping regional connectivity and people's livelihood improvement, demonstrating China's commitment to global public services.

As a core part of ICAO-designated China-Russia Consortium (CRC), the center upgrades the integrated ICAO space weather service platform, unifies advisory formats and product grids, and opens mobile-based global service access. It collaborates with other three global space weather centers to align warning thresholds and optimize aviation service. Supported by FY satellite observations and self-developed AI model as well as numerical prediction system, it improves ionosphere and geomagnetic disturbance prediction, provides forecast products and regular aviation meteorology training for airlines and air traffic control system. As China's first civil aviation-based global space weather center, it completed seven international duty rotations from 2024 to 2026 to serve 193 ICAO member states.

## 5.3 Cooperation with International Organizations

The FY satellite system is deeply integrated into the global meteorological governance system, comprehensively strengthening cooperation with international organizations such as the WMO and the Coordination Group for Meteorological Satellites (CGMS), realizing standard alignment, data interoperability, and capacity building. It fully participates in the construction of WIGOS, and FY satellite data have been officially included in the WMO Global Shared Core Dataset. As a core member of the CGMS space-based observation benchmark, it participates in the formulation of international meteorological satellite observation standards, calibration standards, and product standards, promoting the internationalization of China's meteorological satellite technical standards.

In-depth cooperation has been carried out with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Russia, and many meteorological satellite agencies in the Asia-Pacific region, conducting cross-data verification, joint retrieval, technical exchanges, and personnel training. The 15 th Asian-Pacific Meteorological Satellite User Conference has been successfully held, building a platform for regional meteorological satellite cooperation and exchanges. Through all-round international cooperation, the international influence of FY satellites has been continuously enhanced, making it an important core force for the co-

ordinated development of global meteorological satellites.

## 6 Future Development

In the future, the FY satellite system will continue to optimize the constellation layout, promote two-way upgrading of satellite observation and application capabilities, and drive the FY satellite system toward higher precision, greater intelligence, and a more complete pedigree.

In terms of observation capabilities, key technologies such as hyper-spectral full-spectrum detection, real-time on-board calibration, intelligent on-orbit processing, and high-speed large-capacity data transmission will be broken through to further improve spatial, temporal, and spectral resolution and observation reliability. In terms of application capabilities, artificial intelligence, big data, and cloud computing technologies will be deeply integrated to optimize quantitative remote sensing retrieval algorithms, enhance capabilities in numerical prediction assimilation, intelligent disaster early warning, accurate climate assessment, and chained space weather forecasting. The global service system will be improved, the scope of data services expanded, and the international service model optimized to build a more inclusive and efficient global satellite meteorological service platform.

Meanwhile, the collaborative development of operational FY satellites and commercial meteorological small satellites will be promoted to build a new meteorological satellite observation system with complementary advantages, resource sharing, and coordinated observation. The integration and joint retrieval of FY satellite data and commercial satellite data will be promoted to enrich the product system and improve application service accuracy. A cooperation model of technological collaborative innovation, unified standard specification, and win-win result sharing will be explored to promote the industrialization development of China's meteorological satellites.

## 7 Conclusion

From 2024 to 2026, FY meteorological satellite integrated observation system has achieved all-round breakthroughs in constellation construction, observation capability, ground operation, data processing, application services, and international cooperation. The polar four-orbit networking and geostationary two-satellite coordinated constellation have been fully established, with FY-3H and FY-4C successfully launched. The intelligent operation and control system, high-precision calibration, and innovative product algorithms have been achieved, supporting remarkable applications in weather forecasting, disaster monitoring, climate assessment, ecological environment, space weather, and key industries. Adhering to openness and sharing, FY satellites have provided services to 139 countries and regions, deeply participating in global meteorological governance. In the future, the FY system will further enhance observation and application capabilities, deepen global services and international cooperation, and make greater contributions to global meteorological development and space technology progress.

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

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