Progress of Earth Observation and Earth Science in China

GUO Huadong[1,2], LIU Guang[1], LIANG Dong[1,2], ZHANG Lu[1], XIAO Han[1]

1 (Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100094)
2 (University of Chinese Academy of Sciences, Beijing 100049)

Abstract

Sustainability is the current theme of global development, and for China it is not only an opportunity but also a challenge. In 2016, the Paris Agreement on climate change was adopted, addressing the need to limit the rise of global temperatures. The United Nations (UN) has set Sustainable Development Goals (SDGs) to transform our world in terms of closely linking human well-being, economic prosperity and healthy environments. Sustainable development requires the support of spatial information and objective evaluation, and the capability of macroscopic, rapid, accurate Earth observation techniques plays an important role in sustainable development. Recently, Earth observation technologies have been developing rapidly in China, where scientists are building coordinated, comprehensive and sustainable Earth observation systems for global monitoring programs. Recent efforts include the Digital Belt and Road Program (DBAR) and comparative studies of the "three poles". This and other researches will provide powerful support for solving problems such as global change and environmental degradation.

Key words

Earth observation, Earth system science, Big Earth Data, Moon-based Earth observation, Global sustainable development, Digital Belt and Road Program, Three poles

Earth is our common homeland. However, global change, disasters, and environmental problems are affecting the safety and development of every country. China has actively responded to and participated in the UN SDGs, the Paris Climate Change Agreement and the Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters, and is cooperating with other countries to jointly achieve sustainable development of the planet. Earth observation technologies in China are developing rapidly. At present, Earth observation systems are being built to coordinate comprehensive research on sustainability. Major global monitoring programs include the DBAR and "three-pole" comparative studies of the North Pole, South Pole, and the "High-mountain Asia" region around the Himalayas and Qinghai-Tibetan Plateau. The data produced can provide powerful support for solving problems such as global change and environmental degradation.

1. Advances in Earth Observation

Sustainable Development Goals (SDGs) underscore the need for the scientific community and emphasize global issues such as climate change, renewable energy, food, health and water supply[1]. They also show the importance of coordinating research on every factor affecting those issues, such as society, the economy, and the environment, using global monitoring and simulation. In November 2017, the 23rd Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change was held in Bonn, Germany, to formulate guidelines for the implementation of the Paris Agreement. The main issues are controlling the global temperature within 2 degrees Celsius of that before the industrial revolution, and reducing greenhouse gas emissions in stages. In order to guide actions, it is necessary to determine the allocation and interdependence of the indicators at local, national, and global scales.

E-mail: hdguo@radi.ac.cn

Products and standards need to be established for monitoring, evaluating, and understanding the relationships among the indicators[2]. In order to achieve this goal, China has further strengthened the construction of observation facilities and improved international scientific programs to expand its capabilities for comprehensive observation to meet the goals of sustainable development. It has also strengthened the standards for Earth science data, the design of processing methods, and mechanisms to ensure global information sharing[3].

1.1 Moon-based Earth Observation

The Moon is the only natural satellite of Earth, and it can be utilized as a long-term, stable Earth observation platform. Compared to manmade satellite platforms, observing geoscience phenomena from the Moon has the advantages of longevity, consistency, and stability. Equipping various kinds of sensors on the lunar surface will provide an unprecedented guarantee of comprehensive multi-sphere studies at the global scale, and give solutions to a series of key scientific issues on the interaction between multiple spheres from the perspective of a geodynamic system. This can enhance the ability to observe geoscience phenomena and help deepen our understanding of the Earth system. In response to Earth system science and the development of and demand for global change research, Chinese scientists proposed a Moon-based Earth observation platform for long-term systematic observation. It will be the first systematic research about the principle and feasibility of a Moon-based platform[4].

Research on a Moon-based Earth observation platform has produced a simulation system for Moon-based Earth observation geometry and a model based on the geometrical relationship between the Sun, Moon, and Earth. After analyzing the spatial coverage, the temporal coverage, and the look vector pointing error, it has been found that equipping sensors in the full observation region of the lunar surface (80°S–80°N, 80°W–80°E) will have optimal performance for spatial, temporal, and angular coverage of a given Earth surface feature. Furthermore, based on the polar coordinate representation of nadir points, a new automatic geometric correction method has been proposed for cross-platform Moon- based Earth observation images. This achievement solves the distortion caused by the cyclic movements of the nadir point, Earth curvature, and elevation, and it also maintains the integrity and authenticity of the image[4, 5].

Regarding sensors and the observation strategy, the derivation of Doppler parameters with the removal of the stop-and-go assumption have been completed and a Moon-based SAR signal model based on curve trajectory has been established. Following this, a 2D spectrum of the Moon-based SAR was derived by utilizing the series reversion method. Based on the Earth-Moon geometric relationship and relative velocity of the radar, the observation geometry of a single base station's radar has been established. By means of calculating the solar zenith angle between a specific point's normal vector and the solar direction vector, an instantaneous observational scope variation and the theoretical value of the long wave and shortwave radiation can be derived. Chinese scientists also proposed to carry out research on observing Earth radiation's from the Moon. Using an active cavity radiometer with a total channel (0.2 to 100 μm), a solar channel (0.2 to 4 μm), and near-infrared channel (0.7 to 1.1 μm) was proposed for the total outgoing Earth radiation, the reflected solar radiation, and near-infrared thermal emission.

In research on the lunar environment and observation site selection, simultaneous observations and a consistency test were completed for the same occultation event from deep-space bistatic stations. The preliminary test revealed strong correlation between the fluctuation of the lunar ionosphere and time variance of solar zenith angles. Taking into consideration the influence of the nodal precession of the ecliptic and the Moon's path, the illumination conditions of the two poles of the Moon at different periods were further studied. For the first time, the illumination results of half of the lunar precession period were given. A comprehensive analysis of the lunar South Pole was carried out along with an analysis of the special geological conditions of the South Pole-Aitken basin.

Based on national strategic needs, China's Chang'E IV mission of scientific exploration targets needs from three aspects: material composition, shallow structure, and the Moon's low-frequency radio environment. Moon-based Earth observation is a new research field, but is an inevitable trend after air-borne and space-borne platforms developed to a certain stage. This will give a new, unique solution to a series of key scientific issues about the Earth system.

1.2 Big Earth Data Science Engineering

The Chinese Academy of Sciences (CAS) has been fully aware of the importance of Big Earth Data and launched a project titled "Big Earth Data Science Engineering (CASEarth)" in the Strategic Priority Research Program (SPRP) of CAS, in order to carry out systimatic research on Big Earth Data. SPRP is a major scientific and technological task approved by the Chinese government to be deployed, organized, and implemented by CAS. It is oriented toward resolving major scientific and technological problems concerning overall and long-term development. It is a strategic action plan that integrates technical problem solving with team and platform building. The plan aims to make innovative breakthroughs and foster group power. If Big Earth Data is the engine that propels discovery and innovation in Earth science, then the purpose of CASEarth is to inject a new impetus for interdisciplinary, cross-scale, macro-scientific discoveries with Big Earth Data[6].

The overall objective of CASEarth is to establish an International Big Earth Data Scientific Center within five years, which mainly involves three parts. (1) Build the world's leading Big Earth Data infrastructure. To overcome the bottleneck of data access and sharing, CASEarth will develop the world's leading multi-disciplinary Big Earth Data and cloud service platform and make it a key national scientific and technological big data infrastructure that supports national macro-level decisions and major scientific discoveries. (2) Develop a world-class Big Earth Data platform to drive the discipline. CASEarth will explore the new big data-driven, multidisciplinary, globally collaborative paradigm of scientific discovery, and demonstrate and propel major breakthroughs in Earth system sciences, life sciences and the associated disciplines. (3) Construct a decision support system. The system should serve high-level government authorities using its capabilities for multiple issues using multi-angle, panoramic visual analysis, simulation, and deduction. The system should support a number of national projects, including "The Belt and Road", "Beautiful China", and the national globalization strategy, "Human Destiny Community" (see Figure 1)[6].

CASEarth will pursue its objectives through the following three aspects. (1) CASEarth will develop new approaches and paradigms for big data-driven scientific discoveries. The Big Earth Data System will reveal the complex interactions and correlations between different elements at different resolutions and scales by reproducing the spatial distribution and temporal dynamics of the land, oceans, atmosphere, and human elements. (2) CASEarth will innovate by constructing a high-precision Big Earth Data cloud service platform and the world's leading Digital Earth system to integrate and display the numerous data and information products generated by CASEarth. (3) CASEarth will create a big

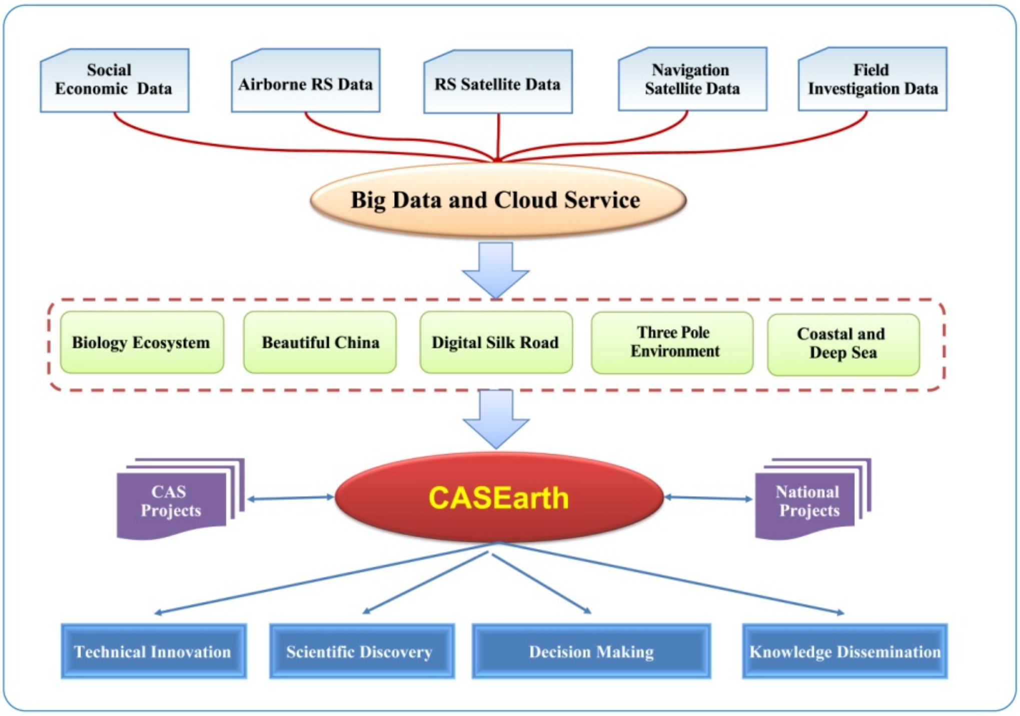

Fig. 1 Framework of CASEarth[6]

data-driven, visualized, interactive, dynamically evolving decision support environment for the government. It will provide macro-level, real-time Big Earth Data decision support, and prop up the China-led UN initiative, "The 2030 Agenda for Sustainable Development" [6].

CASEarth consists of eight research components to help it achieve technological breakthroughs and obtain innovative results: CASEarth Small Satellites; Big Data and Cloud Service Platform; Digital Belt and Road; Beautiful China; Biodiversity and Ecological Security; Three-Dimensional Information Ocean; Spatiotemporal Three-Pole Environment; and the Digital Earth Science Platform. The initiative can become an international, exoteric big data center, comprehensively enhancing national technological innovation, scientific discovery, macro-decision making, public knowledge dissemination, and other significant outputs[6].

1.3 Frontiers of Earth Observation Research

1.3.1 Research on Atmospheric Parameters

In the last two years, China has carried out researches on aerosol optical thickness, atmospheric water vapor content, tropospheric ozone, and atmospheric wind fields, published more than 200 research articles in major international magazines, and great achievements have been made in atmospheric remote sensing.

Research on haze has gradually become more in-depth, focusing on the establishment and optimization of inversion algorithms, models, and data revision, along with further development of databases and hardware upgrades. At the same time, due to the impact of air pollution on human health, especially cardiovascular and pulmonary diseases, some scholars have broadened the scope of their studies. The correlation between aerosol optical depth and atmospheric pollution related problems caused by air pollution have been researched. For example, some scientists used MODIS data and a Geo-Weighted Regression model (GWR) to study the correlation between cardiovascular and cerebrovascular diseases and aerosol concentrations in East China, and established the corresponding databases and recommendations for the prevention of cardiovascular and cerebrovascular diseases[7]. Another study used LANDSAT-5 and HJ-1A satellite data combined with GIS technology and a gray correlation method to explore the relationship between respiratory diseases and respirable particulate matter concentration. The particle size and incidence are negatively correlated[8].

1.3.2 Research on Ocean Parameters

In the last two years, the research on ocean remote sensing in China has focused on inversion algorithms and datasets that are mainly about sea surface height, seawater depth, sea surface velocity and seawater quality. Generally speaking, multi-satellite, multi-channel research has become a trend. Multi-model inversion methods can significantly improve the ability to monitor the temporal and spatial variations of ocean hydrological parameters and are likely to be a major research direction for global hydrological remote sensing of the ocean in the future[9].

In marine monitoring, the China Ocean Satellite has shifted from a single model to multiple types, from a pilot application to a business service, moving rapidly toward serialization and business operations. In 2017, for the first time, China monitored Sargassum, a large brown alga, as an operational service. After nearly six months of follow-ups, the State Marine Environmental Monitoring Center completed satellite monitoring of the Yellow Sea and the East China Sea, and released 58 golden cyclone monitoring reports[10].

Remote sensing technology is playing an increasingly important role in China for protecting its interests and maritime rights, marine development and management, marine environmental protection, marine disaster prevention and mitigation, and marine scientific researches[11].

2. Progress of Earth Observation Applications

2.1 Earth Observation for the Belt and Road

The Digital Belt and Road Program (DBAR) is an international collaborative research program committed to developing into a platform for sharing advanced Earth observation technologies across countries involved in China's Silk Road Economic Belt and the 21st-century Maritime Silk Road (Belt and Road). In support of the Belt and Road initiative, DBAR will help to effectively apply Earth observation technology to sustainable economic and societal development. DBAR identified a set of scientific questions related to the research and development challenges along the Belt and Road. These challenges include adaptation to climate and environmental change, mitigation of disaster risk, water availability and safety, agriculture and food safety, protection of natural and cultural heritage, urban and infrastructure development, management of coastal and marine environments, and sustainability in High-mountain Asia and Arctic areas. DBAR has recognized these challenges as its main foci, which are clusters of outstanding research and development questions relevant to attaining SDGs in the Belt and Road region[3, 6].

The DBAR Foci are categorized into one Big Earth Data category and eight interconnected theatrical areas. The foci cover areas where the effects of climate change are more pronounced, including two key comprehensive regions, coastal and marine environments and high-mountain and Arctic environments. The areas of interest also encompass disasters, water resources, urban activity, infrastructure, heritage, and agriculture. However, Big Earth Data is the main focus of DBAR's data-centric solution to the research and development challenges it faces[12].

The Earth system processes relevant to understanding and modeling the response of terrestrial and marine ecosystems to climate and development in the Silk Road Economic Belt and the 21st-century Maritime Silk Road (Belt and Road) region is extremely wide and complex, from fragile coral reefs to high-elevation glaciers. Advancing scientific knowledge will require a well-balanced combination of detailed in-situ experiments and accurate retrieval of surface observations from the radiometric data acquired by satellites. The latter is a major challenge, even using the well-documented biogeophysical data products generated by the space agencies in USA, Europe, China, and Japan[13].

Some Belt and Road countries are operating a growing fleet of Earth observation satellites and there is an overall solid knowledgebase, but so far the investments in the development and generation of accurate data products have been limited. Also, merging raw data acquired by multiple satellites into a stream of multi–source data products is, in many ways, an uncharted territory, both from the policy and the technological point of view. At the same time, the opportunity offered by the Belt and Road Initiative to bring Belt and Road data assets to full fruition for the common benefit should not be missed[14].

Therefore, the DBAR vision is the promotion of international cooperation that integrates Earth observation science, data, technology, and applications to address environmental change and attain SDGs in the Belt and Road region[1]. The uniqueness of DBAR is the goal of building upon the diverse Earth observation capacities in the Belt and Road countries in Asia, Africa, and Europe through comprehensive and well-funded actions.

The mission of DBAR is to mobilize Earth observation-related scientific knowledge, technology, and data to enable the Belt and Road countries to sustainably develop their infrastructure, economy, natural resources and culture, and to support decision makers towards meeting the SDG targets relevant to Belt and Road countries[12].

The above-mentioned vision and mission statements call for the DBAR Science Plan to meet the following three objectives in its implementation. (1) To address knowledge gaps in Earth system processes that constrain the attainment of the SDGs in Belt and Road countries. (2) To promote advanced science and decision support services to extract effective information from massive, diverse and ever-growing volumes of Big Earth Data. (3) To enhance capacity building and technology transfer within a system of partnerships and research networks[12].

DBAR's work flow foresees the synergistic exploitation of multiple data streams by developing an integrated data processing and analysis system to extract effective information from the data streams. DBAR has established seven Working Groups, named Big Earth Data (DBAR-DATA), Agriculture and Food Security (DBAR-AGRI), Coastal Zone (DBAR-COAST), Environmental Change (DBAR-ENVI), Natural and Cultural Heritage (DBAR-HERITAGE), Disaster Risk Reduction (DBAR-DISASTER), and Water (DBAR-WATER), and two Task Forces (TFs) named Urban Environment (DBAR-URBAN) and High Mountain and Cold Regions (DBAR-HiMAC)[13].

2.2 Environmental Protection

On June 5, 2017–the 46th World Environment Day–the theme was "A Green Mountain is a Golden Hill". This profoundly reveals the essential relationship between development and protection. Ecological protection is the process of preserving natural value and increasing natural capital. Protecting the environment means protecting the potential and staying power of economic and social development. As China has attached more and more importance to the coordinated development of the environment and productivity, Earth observation has played an increasingly important role in environmental protection.

2.2.1 Pollution Monitoring with Earth Observation

In terms of pollution, what has concerned Chinese scholars most in the last two years is air pollution, mainly measuring the characteristics of PM2.5 concentration distribution and its changing trend as well as the space-time distribution of aerosol optical thickness. Research areas have been distributed in various regions of China, and studies have used remote sensing data from HJ-1 and MODIS/Terra to determine the spatial distribution of PM2.5 mass concentration with high resolution and precision. The results show that reducing population density is an effective method for reducing PM2.5 concentration[15], and meteorological factors have more influence on PM2.5 than geography[16]. With the deepening of governance measures, monitoring data show that the average distribution of PM2.5 has been gradually reduced. Compared with 2013, the average concentration of PM2.5 in Beijing, Tianjin, Hebei, the Yangtze River Delta and Pearl River Delta decreased by 39.6%, 34.3% and 27.7%, respectively in 2017. PM2.5 pollution is getting better, as shown in Figure 2[17]. To further its research, China has established the world's first large-scale integrated ground sounding system. The multi-component, multi-element system can cover the entire atmosphere and obtain more comprehensive, long-term, continuous observations with high vertical resolution and high temporal resolution. In other words, it can provide a new means for monitoring air pollution. Recently, the Gaofen-4 satellite and the FY-3 meteorological satellite launched in 2017 can both monitor haze. The mid-resolution spectral images taken by the satellite can achieve high-precision, quantitative inversion of cloud and aerosol parameters, and provide a scientific basis for environmental monitoring.

2.2.2 Environmental Change Monitoring

For the environment, remote sensing mainly plays a role in dynamic monitoring and evaluation. In recent years, remote sensing technology has provided technical support for regional environmental monitoring. By temporal and spatial fusion of satellite data and surface-measured spectral data, China conducted time series monitoring of the vegetation coverage of wetland and grassland ecosystems in northwestern China. This laid the foundation for subsequent studies on the change in the carbon budget and the spatiotemporal scale of the conversion of wetland ecosystems on the plateau[18]. China carried out ecological research on the cowfish in the middle and lower reaches of the Yangtze River in 2017. It was the first attempt to monitor the environmental quality of the habitat by using an unmanned aerial vehicle[19]. As an ecological reserve that plays an important role in local and downstream ecological protection, remote sensing technology helps to protect the environment in Sanjiangyuan Nature Reserve. The Aviation Geophysical and Remote Sensing Center completed the “Remote Sensing Emergency Monitoring of Sanjiangyuan Nature Reserve” project and quickly identified the status quo and change information of mineral resources and the geological environment of mines from 2015 to 2017 in order to protect the environment in the area. The protection provided basic data, and a total of 20 remote sensing monitoring maps of mineral resource development at 1:500 000 and 1:25 000 scales of Sanjiangyuan Nature Reserve were made. This shows that Earth observation has opened up a new approach to regional monitoring of the environment[20]. In October 2017, China released the “2017 Annual Report on Remote Sensing Monitoring of Global Ecosystems” to the world, the results of which aroused widespread concern in the field of international Earth observation. In particular, the environments along the "Belt and Road" have received extensive attention. The research integrates the

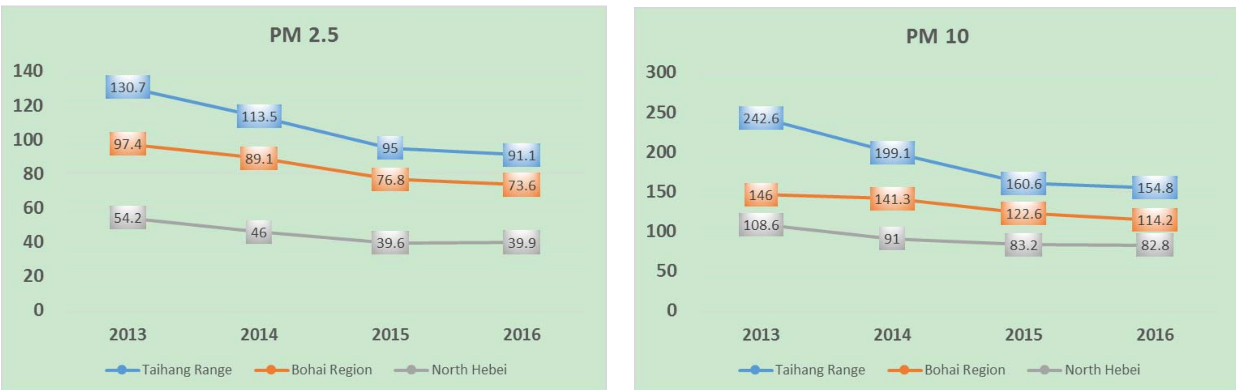

Fig.2 Beijing-Tianjin-Hebei region PM2.5 and PM10 average concentration time series (μg/m^3)[17]

entire region of Asia, Europe, Africa, Oceania, and the surrounding oceans into thematic monitoring areas with coverage of more than 170 countries and regions and 9 major maritime areas. FY satellite data will fully support the preparation of the report. In June 2017, China started the second comprehensive expedition of the Qinghai-Tibetan Plateau[21].

2.2.3 Xiong'an New Area Heritage Study with Earth Observation Techniques

On April 1, 2017, China set up a state-level "New Area" in Xiong'an, Hebei Province. It is another new area with national significance following the special economic areas of Shenzhen and Pudong New Area. In the process of building the New Area, experts proposed the slogan of "New construction, heritage first". Earth observation now plays an important role in protecting historical relics in the area. As early as the Han Dynasty, Xiong, Rongcheng and Anxin existed as counties, and they now compose the Xiong'an New Area. The three counties have a long history and profound cultural heritage, with many protected cultural relics and intangible cultural heritage. For example, there remain the Song Liao Ancient War Road built by General Yang Yanzhao in Xiong County, Liangmatai site in Rongcheng from the Shang and Zhou Dynasties, and two Neolithic sites, Liangzhuang and Liucun, in Anxin County. These are approved as immovable "cultural relic protection sites", and there are more immovable cultural relics that have not been approved as cultural relic protection sites[22].

Researchers carried out airborne laser surveying and mapping on the archaeological sites of the New Area in order to obtain comprehensive and accurate topographic data and further information of the relics. They intended to find the burial conditions of the underground cultural relics in the New Area using advanced airborne lidar, high-resolution aerial surveying and other technologies. Specifically, the research employs 3D laser scanning of the area, regional airborne laser point cloud data, filtering and other related software and methods of data processing and analysis, digital orthophotos, terrestrial digital elevation models of filtered vegetation and houses, historical aerial images, historical archeological data and this year's survey results. The overlay analysis shows suspected ancient relics and ancient rivers and other detailed information for the next step of field surveys and data integration into an archaeological geographic information system and digital integrated information management platform[23]. Lidar provides real-time, active, direct and fast access to the measured object with high-density, high-precision 3D spatial information. This can contribute to restoration, protection, and research efforts. Remote sensing images can reflect the features of the terrain, landscape, water system and vegetation, and play an important role in exploring the distribution of sites covering a large area. All in all, advanced remote sensing technology can scientifically interpret the sequence of historical development and the cultural aspect of Xiong'an New Area, display its cultural heritage, and contribute to the protection of historical heritage.

2.3 Disaster Reduction

At present, China has basically completed the satellite series, "Small Satellite Constellation for Environment and Disaster Monitoring and Forecasting", "Fengyun", "Haiyang", and "Ziyuan". A new generation of remote sensing satellites, represented by the "Gaofen" series, is accelerating development and promoting the transformation of China's disaster remote sensing from research and application to business services. Researches on disaster remote sensing methods for earthquakes, floods, droughts and other single disasters are progressing in the direction of whole processes, that is, total-factor, multi-disaster quantitative monitoring and evaluation that is minute and comprehensive.

2.3.1 Earth Observation for Earthquakes

Earthquakes are a sudden, major disaster with great destructive power that can easily cause loss of life and property once they occur. In recent years, China has stepped up its efforts in seismic monitoring and forecasting, as well as in earthquake disaster prevention and post-disaster emergency relief. Progress has been made in the study of disaster loss assessment based on high-resolution infrared images and research on early warning methods for earthquake-based disasters.

The FY-2E/G infrared remote sensing data of China's stationary weather satellite in 2017 show that thermal anomalies before the Taiwan M5.9 earthquake occurred on October 6, 2016, showing obvious spatiotemporal features that are relatively easy to identify and can be used as precursors to earthquakes. Earthquake prediction is a scientific issue that is constantly reviewed and discussed, but the current understanding of the genetic mechanism of the thermal anomalies is not yet mature, given the complexity of earthquake anomalies, regional and meteorological anomalies, and other precursor anomalies. This situation is evidenced by the fact that whether this anomaly can be used as a criterion in future earthquake prediction still needs test in a large number of earthquake cases[24].

In 2016, based on medium-wavelength infrared (3–5 μm) data of a stationary meteorological satellite, the relative power spectral characteristics of medium-wavelength infrared emission with respect to strong earthquakes were studied. Combining 28 strong earthquakes that occurred in mainland China from 2006 to 2016, the study summarized the characteristics of relative power spectrum anomalies before and after strong earthquakes, and found that in most earthquakes there are different degrees of mid-wavelength infrared thermal anomaly information. Comparative analysis of medium-wavelength infrared and thermal infrared, long-wavelength radiation data showed that the dominant frequencies corresponding to various data in the same earthquake case are nearly identical, and the mid-wavelength infrared data have the advantage of anomalous amplitude[25].

2.3.2 Research on Ice and Snow Disasters

With global climate change becoming more and more prominent, China has been greatly affected by snow disasters. Research on snow disaster monitoring based on remote sensing data has been carried out in China.

In northwestern China, in Qinghai province, Chinese scientists selected disaster-prone socioeconomic factors, meteorological factors, and factors related to livestock husbandry, caused by snow disasters in Qinghai Province. The study was based on the theory and method of meteorological disaster risk assessment. Through spatial analysis methods, a systematic analysis of the spatial distribution of snow risk factors in Qinghai Province and the characteristics of the comprehensive risk level of snowstorms show that the spatial distribution pattern of grassland areas and pasture yield was basically consistent with the overall risk of snowstorms[26]. The research quickly and accurately assessed the level of snow risk in Qinghai Province.

In Xinjiang in 2016, using remote sensing methods combined with many kinds of remote sensing data, current ground observation data, and historical ground observation, a comprehensive analysis of snow information was carried out to establish the Belt and Road snow cover database and data products along the transportation routes in Xinjiang and Central Asia[27].

3. Progress of Earth Observation Infrastructure

3.1 Civil Aerospace Development

From 2016 to 2018, China conducted a total of 45 launch missions and 42 missions were completely successful. The specific launch information is shown in the Tables below. The launches include one high-resolution satellite mission, four scientific satellite missions, and five commercial satellite missions. These satellites have been widely used in various fields such as economics, science, and technology and achieved remarkable social and economic benefits (see Table 1–3).

3.1.1 High-resolution Earth Observation System

The GF-3 satellite was launched on August 10, 2016, and is the first C-band multi-polarization Synthetic Aperture Radar (SAR) imaging satellite in China with a resolution of one meter. The GF-3 satellite has twelve imaging modes, including the traditional stripe imaging mode, scanning imaging mode, as well as wave imaging

Table 1 2016 China Launch Mission

No.	Satellite	Launch time	Rocket model	Status
1	ChinaSat-15	2016-01-16	CZ-3B	Success
2	Beidou M3-S	2016-02-01	CZ-3C/YZ-1	Success
3	Beidou IGSO-6	2016-03-30	CZ-3A	Success
4	Shijian-10	2016-04-06	CZ-2D	Success
5	Yaogan 30	2016-05-15	CZ-2D	Success
6	Ziyuan III-02	2016-05-30	CZ-4B	Success
7	Beidou G7	2016-06-12	CZ-3C	Success
8	Tiange-1	2016-06-25	CZ-7	Success
9	Shijian 16-02	2016-06-29	CZ-4B	Success
10	Tiantong-1 01	2016-08-06	CZ-3B	Success
11	GF-3	2016-08-10	CZ-4C	Success
12	QUESS	2016-08-16	CZ-2D	Success
13	GF-10	2016-09-01	CZ-4C	Failure
14	Tiangong-2	2016-09-15	CZ-2F T	Success
15	Shenzhou 11	2016-10-17	CZ-2F T	Success
16	Shijian-17	2016-11-03	CZ-5	Success
17	XPNAV 1	2016-11-10	CZ-11	Success
18	Yunhai-1	2016-11-12	CZ-2D	Success
19	Tianlian I-04	2016-11-22	CZ-3C	Success
20	FY-4	2016-12-11	CZ-3B	Success
21	TanSat	2016-12-22	CZ-2D	Success
22	SuperView	2016-12-26	CZ-2D	Success

Table 2 2017 China Launch Mission

No.	Satellite	Launch time	Rocket model	Status
1	TJS 2	2017-01-05	CZ-3B	Success
2	Jilin-1 03	2017-01-09	KZ-1A	Success
3	Tiankun-1	2017-03-03	KT-2	Success
4	Shijian 13	2017-04-12	CZ-3B	Success
5	Tianzhou 1	2017-04-20	CZ-7	Success
6	Zhuhai-1 01/02	2017-06-15	CZ-4B	Success
7	ChinaSat 9A	2017-06-19	CZ-3B	Failure
8	Shijian 18	2017-07-02	CZ-5	Success
9	Yaogan-30 A/B/C	2017-9-29	CZ-2C	Success
10	VRSS-2	2017-10-09	CZ-2D	Success
11	Beidou-3 M1/M2	2017-11-05	CZ-3B/YZ-1	Success
12	Fengyun 3D	2017-11-15	CZ-4C	Success
13	Jilin-1 04/05/06	2017-11-21	CZ-6 Y2	Success
14	Yaogan-30 D/E/F	2017-11-25	CZ-2C	Success
15	LKW-1	2017-12-03	CZ-2D	Success
16	Alcomsat-1	2017-12-11	CZ-3B/E Y40	Success
17	LKW-2	2017-12-23	CZ-2D	Success
18	Yaogan-30 G/H/I	2017-12-26	CZ-2C	Success

Table 3 2018 China Launch Missions

No.	Satellite	Launch time	Rocket model	Status
1	SuperView 03/04	2018-01-09	CZ-2D	Success
2	BeiDou-3 M7/M8	2018-01-12	CZ-3B/YZ1	Success
3	LKW-3	2018-01-13	CZ-2D	Success
4	Jilin-1 07/08	2018-01-19	CZ-11	Success
5	Yaogan-30 J/K/L	2018-01-25	CZ-2C	Success
6	Zhangheng-1	2018-02-02	CZ-2D	Success

mode and global observation imaging mode for marine applications. Furthermore, it has the most imaging modes of any synthetic aperture radar satellite. It has a wide swath and high spatial resolution enabling both a large-scale census and a detailed examination of specific areas to meet the needs of different users for different targets. Figure 3 below shows the first batch of images obtained by the National Defense Science and Technology Industrial Bureau from the GF-3 satellite[28].

3.1.2 Scientific Satellite

The Chinese Carbon Satellite was successfully launched on December 22, 2016. This is the third global carbon satellite after Japan's GOSAT satellite and the U.S. OCO-2 satellite, with a monitoring accuracy of 1–4 ppm. Its main payload is a hyperspectral, high spatial resolution CO_2 detector capable of detecting three atmospheric absorption spectra at 2.06 μm, 1.6 μm, and 0.76 μm with

Fig.3 Satellite imagery of Beijing Capital Airport from GF-3

a maximum resolution of 0.04 nm. The other payload is a multispectral cloud and aerosol detector. It also assists in the accurate measurement of CO_2 through two main observation modes, the sky-bottom and flare of the main plane. A team from the Chinese Academy of Sciences used the TanSat satellite data from July to December 2017 to carry out a global vegetation chlorophyll fluorescence inversion study and successfully obtained global chlorophyll fluorescence products.

Yunhai-1 successfully entered space on November 12, 2016, equipped with China's first fully polarized microwave radiometer to further probe the polarization of observed targets, achieving the extraction of electromagnetic wave frequency, phase, amplitude and polarization information. Moreover, it can achieve long-term numerical weather forecasting, improving the accuracy of those forecasts.

The successful launch of Zhangheng-1 marked China's emergence as one of the few countries with high-precision geophysical field satellites in orbit. Using a common small satellite platform, it is equipped with eight kinds of payloads including a search coil magnetometer, high-precision magnetometer, electric field detector, GNSS occultation receiver, plasma analyzer, high-energy particle detector, Langmuir probe and tri-band beacon transmitter. This is the first satellite of the Chinese Earthquake Observation System based

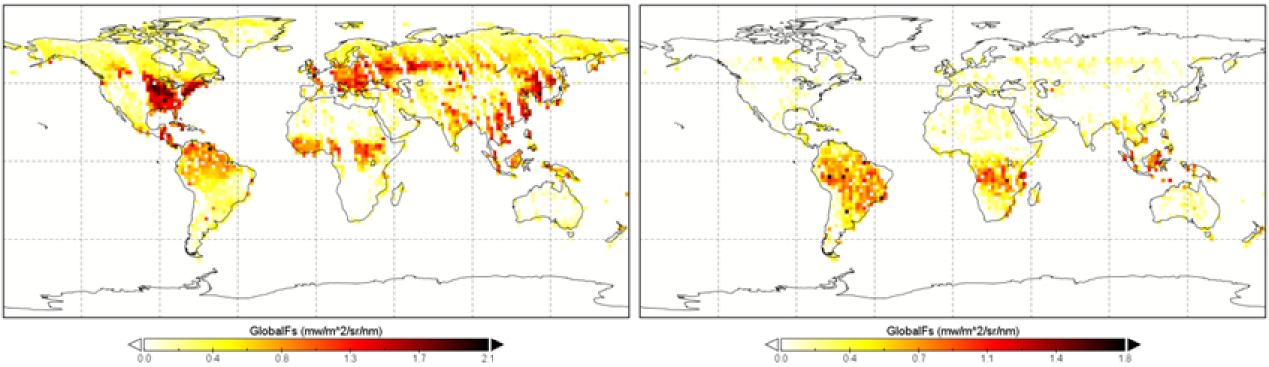

Fig.4 The first global chlorophyll fluorescence product of China's TanSat (July 2017, left; December 2017, right)

on space born observation platforms. It is capable of dynamic, wide viewing angle and all-weather space-to-Earth observation by acquiring global electromagnetic field, ionosphere plasma, and high-energy particle observation data.

The Water Cycle Observation Mission is one of the five new scientific satellites China is planning to develop and launch in the next five years. The satellite will help to understand the mechanisms of water distribution, transmission and phase change in the Earth system. The breakthrough in understanding the spatial and temporal distribution characteristics of the water circulation system reveals the characteristics of water cycle changes in the context of global change and deepens the scientific understanding of the response and feedback of the water cycle to global change. In 2016, the Water Cycle Observation Mission completed the key technologies of active and passive collaborative inversion and experimental verification, and the background model passed its acceptance test.

3.1.3 Commercial Satellites

The SuperView-1 01/02 satellite was successfully launched on December 28, 2016. Its panchromatic resolution is 0.5 m, multi-spectral resolution is 2 m, orbit height is 530 km and width is 12km. It is the first commercial Chinese satellite constellation with high-agility, multi-mode imaging capabilities. It can not only obtain image data with multi-point, multi-band splicing, but also for 3D acquisition. A single shot produces an image up to 60 km×70 km. On January 9, 2018, China launched a Long March 2D carrier rocket with the SuperView-1 03/04 satellite at Taiyuan Satellite Launch Center. It has a 0.5 m high-resolution sensor for continuous strip imaging, multi-strip stitching, stereo imaging, and fast, multi-target, multi-mode, wide-coverage imaging. The first series of four 0.5m high-resolution optical remote sensing satellites in the Super View Commercial Remote Sensing Satellite System have completed networking, marking the formal completion of China's first 0.5 m high-resolution commercial remote sensing satellite constellation.

On January 9, 2017, China’s first forestry satellite, “Jilin forestry-1”, was successfully launched. This satellite has professional image quality, high-agility and mobility,

Fig.5 SuperView-1 02 image of Potala Palace Scenic Area SuperView-1 03, 04 image of Dubai Airport

and highly integrated electronic systems. It has a variety of imaging modes such as TDI push-scan imaging, staring/semi-staring video imaging, space-based astronomical target shooting, and night shooting. It can capture sub-meter resolution color dynamic video, and its width is greater than 11 km×4.5 km. The satellite is in a leading position in the world.

The Jilin-1 04/05/06 video satellite was successfully launched on November 21, 2017. It uses an integrated design, with wide imaging, high-resolution imaging, multi-spectral imaging, video imaging and other observation capabilities. It will gradually improve the constellation's observation capabilities to better promote remote sensing industrial applications and commercial marketing. On January 19, 2018, the Jilin-1 07/08 video satellite was launched. This is a commercial high-resolution optical remote sensing satellite with a resolution of 1 m and a width of 19 km. It has various imaging modes such as conventional push-scan imaging, gaze video imaging, and low-light imaging.

On June 15, 2017, two video nanosatellites (OVS-1A and OVS-1B) were successfully launched. The satellites carry a hyperspectral camera and a visible light camera. Each satellite has a mass of 55 kg and an optical resolution of 1.98 m. They have two working modes: staring video and band imaging.

3.2 National Key Research and Development Plans

3.2.1 Remote Sensing and Navigation

The Ministry of Science and Technology issued the national key research and development plan for specific projects in Earth observation and navigation. The goal of "Earth observation and navigation" focuses on a few topics. The plan faces the major needs of the country's economic restructuring and construction of an ecological civilization. It addresses the implementation of the Belt and Road initiative and the new urbanization and development planning, Earth science research, and other major needs. It is also a reaction to the harsh challenges of global change and regional response, focusing on the forefront of the international development of Earth observation and navigation technologies. The plan significantly enhances the technical support capabilities of comprehensive information on Earth observation and navigation. The key breakthroughs are precision acquisition of information, quantitative remote sensing applications and other common key technologies for complex system integration. An objective is to carry out research on forward-looking Earth observation and navigation technologies and theories, application demonstrations, and other technical topics. This will lay the foundation for the construction of an integrated, accurate, autonomous, and controllable Earth observation and navigation information system. In 2017, sixteen projects with sixteen research missions were started in seven technical directions. In 2018, thirteen research missions will be launched in eight technical directions. The total funding is one billion CNY[29, 30].

3.2.2 Global Change and Response

Global change has affected and will continue to affect the survival and development of mankind. Today, it has become a major issue of political, economic and diplomatic concern to all countries in the world and to all sectors of society. To properly cope, global changes cannot be separated from the support of scientific research. In March 2016, the Ministry of Science and Technology issued projects specific to global change and response: Global Change and Response focuses specifically on the key processes, mechanisms and trends of global change; Global Change Impact, Risk, Mitigation and Adaptation; Data Products and Big Data Integration Analysis; and Earth system model development. Countries and regions should continue to deploy projects in response to global changes and ways of sustainable development. In 2017, priority was given to twenty-four research directions. In 2018, priority will be given to twelve research directions, with a total funding of 700 million CNY[31, 32].

4. Perspectives on Trends in Earth Observation

The United States released "Emerging Science and Technology Trends: 2016–2045—A Synthesis of Leading Forecasts Report" (April 2016) as an analysis of source documents identifying 690 individual trends related to science and technology, as well as trends related to broader contextual factors that will shape the evolution of S&T over the coming decades. From this dataset, 24 emerging science and technology trends were identified. Among them, the Internet of things, smart cities, blended reality, mobile and cloud computing, space technology, and technology for climate change were closely related to the future development of the Earth observation field[33].

With the progress of Earth observation research and the continuous improvement of CASEarth, our ability to deal with huge dynamic data will be gradually improved in China's future. People will be able to use big data in their lives, and in the meantime to force the government and various institutions to be responsible for their policies. Big data in the field of Earth observation is becoming a new key to our cognition of Earth. Chinese scientists are actively promoting research in this cross-disciplinary field. To this end, the journal *Big Earth Data* was formally inaugurated in February 2018, as a sister publication of the *International Journal of Digital Earth*, aiming to provide an efficient and high-quality platform for promoting big data sharing, processing, and analysis, thereby revolutionizing our understanding of Earth's systems. Another publication based in China, the *International Journal of Digital Earth*, focuses on knowledge-based solutions to build and advance applications to improve human conditions, protect ecological services and support future sustainable development for environmental, social, and economic conditions. They will become an important guide in the field of Earth observation, and will continue to make important contributions to driving innovation in the discipline, ultimately to influence sustainable development.

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