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2012–2014 China's Earth Observation and Earth Science Development

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ABSTRACT

Human beings are now facing global and regional sustainable development challenges. In China, Earth observation data play a fundamental role in Earth system science research. The support given by Earth observation data is required by many studies, including those on Earth's limited natural resources, the rapid development of economic and social needs, global change, extreme events, food security, water resources, sustainable economic and urban development, and emergency response. Application operation systems in many ministries and departments in China have entered a stage of sustainable development, and "The State Key Project of High-Resolution Earth Observation Systems" has been progressing since 2006. Earth observation technology in China has entered a period of rapid development.

KEY WORDS

Earth observation, Earth system science, Big data, High-resolution Earth observation systems, Global and regional sustainable development

1 Earth Observation Science Research Development

1.1 Providing Basic Data for Earth System Research

The 12th Five-year Plan and the 13th Five-year Plan, regarding global change research programs, both recognize Earth observation technology as an important data acquisition tool and a basic research data source. Now there are products from 30 satellites accumulated over the last 50 years available for the study of global changes, according to EOS and GEMS[1–4].

In China, the state key project for high-resolution Earth observation systems (Gaofen, referred to as GF) will play a leading role in constructing a space-air-ground integrated observation system. Seven GF satellites will be launched by the end of 2018. Airborne remote sensing and drones have the ability to provide fast, real-time and accurate remote sensing data. Land and sea observation research infrastructure provide real-time in-situ observations. Altogether, with the Digital Earth platform, they are a comprehensive, multitemporal, long-term, continuous monitoring and data accumulation system, providing the capability for three-dimensional, dynamic monitoring and analysis of the Earth system. Using this ability will support Earth system science and sustainable development in terms of energy and resources, environmental monitoring, disaster warning, and national maritime security. What follows is an overview of such plans, concerning Earth system science.

Construction of the Earth System Simulator Based on Earth Observation Data

Construction of an Earth system simulator is a long-term plan (2012–2030) for China's major national science and technology infrastructure. The Earth system simulator is an important symbolic entry into a comprehensive level of Earth science in the study of climate change, disaster prevention and mitigation, environmental management, and other fields. After the facility is completed, it will greatly enhance the overall capability to simulate the Earth system in China and to predict major natural disasters and climate changes[5]. Science in many areas study must make use of super computing environments and storage systems, with massive, intelligent data analysis and visualization in order to simulate various spheres of the Earth: complex environmental systems, simulating the Earth system's cyclical changes and long-term climate change, describing and predicting in detail the Earth's physical, chemical and biological processes, and constructing a simulator of the Earth system.

The Earth system simulator and Earth observation data can promote the study of global changes and sustainable development, including the following items.

(1) Studies on global change characteristics, mechanisms, local trends and extreme climate adaptation. This includes studying extreme weather and climate change processes and the characteristics of wet and dry weather transitions, evaluating the contribution of local land-atmosphere interaction in dry and wet conditions, revealing the driving mechanism of wet-dry transition with climate change, predicting future climate change trends and effects, studying the regional change process of extreme climate events, regional difference formation and its mechanisms, evaluating the influence of extreme climate events on the development of agriculture and human society, and exploring the thresholds and modes of human adaptations.

(2) Studies on the influence of marine environment changes. This includes studying marine environment and global warming interaction processes and mechanisms; predicting future changes in the marine environment; revealing the variation characteristics and mechanisms of sea-level rise, storm tides, and sea ice; studying the effects of ocean acidification on marine biological changes; and determining the impact of urbanization on coastal ecosystem change.

(3) Studies on safety thresholds of ecological systems and the fragile carbon and nitrogen cycle. This includes studying the carbon and nitrogen cycle in physical and biogeochemical processes, revealing the interaction rules and mechanisms of global change and the carbon nitrogen cycle, assessing the impact of the carbon and nitrogen cycle on global warming, studying the response of fragile ecological systems to global change, building a risk assessment model of the impact of global warming on fragile ecological systems, and providing these systems' safety thresholds along with suggestions for their protection to decision-makers.

(4) Simulating and predicting global and regional land cover, water, and energy exchange. This is realized by monitoring global land cover dynamics, revealing global change and land cover change interaction mechanisms, globally assessing the impact of land cover change and warming on ecosystem services, studying Earth surface energy and water exchange processes, improving the energy and water exchange process model, and simulating and predicting the Earth's surface energy exchange process and its effects on global and regional change.

(5) The basic theory, effect and risk assessment of geo-engineering. This includes exploring new methods, geo-engineering schemes, and theories; evaluating various geo-engineering scenarios and their technical feasibility, economic benefits, ecological impacts, and socioeconomic influences; and simulating the effects of geo-engineering.

(6) Studies on the impact of global and regional change on economics and society, and its countermeasures. This includes building an ecological civilization, studying climate change and human activity interaction processes, evaluating the effects of global warming on vegetation patterns, studying response mechanisms and adaptation models of the rapid urbanization of social systems in response to global and regional change, evaluating the impacts of global warming on urban development patterns, and proposing sustainable development strategies of urbanization adapted to global and regional change.

1.2 Continuing to Carry Out Remote Sensing Science Experiments and Innovation

In April 2014, the State Key Laboratory of Remote Sensing Science organized field experiments with full-band multiscale remote sensing for complex surface radiation transmission mechanisms, modeling, inversion, and validation. Many experts from related research institutes and different remote sensing operations took part in the experiments. The experiments were carried out at the same time at three experimental remote sensing stations in Huailai, Chengde, and Baoding in Hebei Province.

1.2.1 Scientific Objectives

This experiment was focused on three aspects. The first was developing a full-band multiscale remote sensing platform for studying and modeling complex surface radiative transfer mechanisms, including research on all-band multiscale remote sensing model integration and comprehensive testing, as well as setting up a multiscale remote sensing radiative transfer simulation platform. The second was developing multiscale quantitative remote sensing production systems for studying multisource remote sensing synergy inversion theory and methods, and the scale effects and transition methods of quantitative remote sensing products. The third was developing a multiscale quantitative remote sensing production system, according to the demand of research on surface radiation balance, the water cycle, and the carbon cycle.

1.2.2 Experimental Contents and Products[6]

The verification of an all-band multiscale remote sensing model. Taking the Huailai remote sensing test field as a base, the surrounding vegetation, soil, snow, and atmosphere were remotely sensed using a full range of active and passive sensors for radiative transfer model verification, improvement and integration research; verification of a visible/near infrared two-layer model, heat infrared radiation model, microwave radiation and scattering model, laser radar model, and atmospheric radiation transmission model.

Six types of experiments and some models. Models include the two coniferous reflectance models for visible and near infrared in terms of the broad-leaved spectrum model; spectral model of continuous vegetation canopy radiative transfer; discrete vegetation canopy model; bare soil bidirectional reflectance model; thermal infrared radiation models in terms of the thermal infrared emissivity spectral model; broadleaf thermal infrared emissivity spectral model; crop full growth period directional thermal radiance model; discrete vegetation canopy thermal infrared radiation model; bare soil thermal infrared emissivity and infrared radiation model; models of microwave radiation in terms of the bare soil radiation model; wheat, grass, and tree microwave radiation model; microwave scattering models in terms of bare soil scattering; multi-scattering model; wheat and grassland coherent microwave scattering model; forest radar backscatter model; laser radar models in terms of complex scene laser echo and photon-counting lidar; atmospheric radiative transfer models in terms of the visible near infrared atmospheric radiation transmission model, thermal infrared atmospheric radiative transfer model, and microwave radiative transfer model.

Validation and collaborative observation test of multiscale quantitative remote sensing products. Product validation was carried out on a multiscale remote sensing network through quantitative, collaborative observation around the area of Beijing, Tianjin, and Hebei. Researchers collected multiscale data of typical surface cover from kilometer to 100-meter to 10-meter scales, providing support to quantitative product improvement, remote sensing algorithm validation, and scale effect research.

Airborne remote sensing data and products. The experiment coverage was the 30 km × 50 km area around the Huailai test station, and there were two to three phase flights in the period from May to August 2014. The airborne sensors included a high-resolution multi-spectral CCD, hyperspectral camera, thermal infrared camera, laser radar, high-resolution Synthetic Aperture

Radar (SAR), and microwave radiometer.

Application of remote sensing in the land surface process model. Selecting underlying representative surface or ecological zones, the tests were organized into different temporal and spatial scales. The main goals were to comprehensively understand the interaction characteristics of the main surface types and the atmosphere, to reveal the influence on weather and climate at different scales, and to develop and improve land surface process parameters in representative geographical, biological and climatic regions. This experiment used a regional climate model to provide atmospheric environment simulation data for the remote sensing test area and to provide the driving data for a land surface hydrological model and environmental air quality model at four spatial resolutions (27, 9, 3, and 1 km). Based on multiscale satellite remote sensing data, energy and water balance parameters were obtained through remote sensing including the surface albedo, photosynthetic active radiation and precipitation, soil parameters (surface temperature, humidity, surface roughness and topography), and vegetation parameters (LAI, NDVI, biomass and NPP) in the land surface process model. According to different types of satellite remote sensing data, different methods were used to strengthen the combination between surface observation and satellite remote sensing data, including the drivers, assimilation and verification. Another aspect was performing scale transformation of the local parametric observation results on land surface processes, estimating land surface process parameters at numerical model grid scales, testing the scale effect of land surface process parameterization, and improving regional and global land surface parameterization.

1.2.3 Experimental Data Management and Sharing

In order to produce credible, high-level scientific results, the sharing of data was an important part of this all-band multiscale remote sensing mechanism test. All test data were acquired through the "remote sensing scientific data sharing platform", which integrates remote sensing data, remote sensing models and key parameters of product authenticity testing for the integration of remote sensing, positioning in the test of scientific data sharing service, and quantitative remote sensing product validation.

1.3 Achievements in Research on High-resolution Radar Information Modeling and Algorithms

The German radar satellite TerraSAR-X, with a resolution of 1 m, was successfully launched on June 15, 2006. The TerraSAR-X satellite is equipped with X-band high-precision synthetic aperture radar with a wavelength of 3 cm. The accuracy of the radar is higher than C-band radar with a wavelength of 5.7 cm and L-band radar with a wavelength of 24 cm. For a 5 km × 10 km observation scene, the resolution can reach 1 m. On December 14, 2007, Canada's Radarsat-2 was launched. Radarsat-2 is a commercial satellite carrying a high-resolution C-band sensor with the capability for one-meter resolution imaging. The successful launch of SAR satellites and the commercialization of their data have opened an era of high-resolution SAR applications. How to make the best use of high-resolution remote sensing SAR has become a concern in the field. The National University of Defense Technology reached new milestones in the target scattering model and the core algorithm of radar polarimetric and interferometric information, yielding positive effects on the use of high-resolution SAR data.

Synthetic aperture radar refers to a type of imaging radar carried on satellite or aircraft platforms. SAR includes a variety of patterns, such as polarization and interference. Since SAR shows great potential in many military and civilian areas, such as Earth observation, reconnaissance and surveillance, remote sensing, and marine disaster assessment, many countries have launched a variety of polarimetric SAR satellites and focused on their use in recent years. Constructing a theoretical physical model that can finely describe the artificial target, polarization scattering mechanism has become a popular topic. The National University of Defense Technology conducted the meticulous and accurate inversion of different terrain scattering characteristics and made breakthrough progress on inversion accuracy by introducing an optimization algorithm. Two of their papers were accepted by *IEEE Geoscience and Remote Sensing*. With the rapid development of SAR technology, the amount of SAR data has increased rapidly. How to interpret polarimetric SAR data and extract information from data accurately and efficiently has become a focus of research, and also a bottleneck in quantitative microwave remote sensing research. The second paper put forward a new idea of building a polarization and target scattering model using the interference information, and also proposed a core algorithm, which has attracted the attention of scholars in China and abroad.

2 Progress of Earth Observation Applications and Basic Research

2.1 Haze Monitoring and Mitigation Management[4, 7]

Haze is the atmospheric pollution caused by increasing

PM2.5 particulate matter emissions from the process of industrialization. China has the world's largest and fastest growing industrialized emerging economy. In recent years, continuous prolonged haze has occurred in eastern China, leading to increasing respiratory diseases, other health problems, and even traffic accidents and flight delays. While learning from Britain, Germany, and Japan's experiences with air quality during industrialization, which took 50, 30, and 20 years to improve respectively, China is experiencing a period of change from simple pollution to compound pollution with causes more complex than the aforementioned cases. Thus it is more difficult to monitor, mitigate, and manage. A 2003 haze event survey report suggested the importance of using space science and technology to support the management and research of haze, giving impetus for the expansion of remote sensing applications to this field.

2.1.1 Complexity of Haze Forming Mechanisms and Accumulation Conditions

The compositional character of the formation of haze hazards in China is mainly a representation of the multisource, secondary conversion to air suspensions. The soot pollution caused by the rapid development of low-end industries is being transformed into compound pollution. The air pollution problem suffered by developed countries over a hundred years of industrialization has also hit China, but in addition to the same sources of pollution found in those countries, such as automobile exhaust and industrial and power plant emissions, China's pollution is also fed by (i) fine particles produced by sandstorms, construction sites, road traffic, and burning emissions caused by residents; and (ii) secondary fine particles generated through complex chemical reactions and conversions. Experimental data have shown that in the formation process of secondary contamination of fine particles, oxidized organic particles accounted for 44%, while 21% was soot-type organic matter, 17% was nitrogen enrichment of organic matter, and 18% was hydrocarbon organic particulate matter.

Meteorological and Geographical Conditions for Haze Formation

Haze occurs when atmospheric dispersion conditions are very poor, which leads to pollutant emissions continually accumulating at low altitudes. Due to the high humidity of fog and haze, both droplets and fine particulate matter interact with each other, and this rapidly increases the formation of pollution. Furthermore, particular geographic conditions can aid the accumulation of haze. Beijing and Shijiazhuang, for example, are surrounded on three sides by mountains, and are topographically high in the west and low in the east. The western mountains have an average elevation of 500 to 700 meters, while Beijing and Shijiazhuang are located in a plain with an average elevation of 30 to 70 meters. The conditions of atmospheric dispersion are poor, thus exacerbating urban air pollution when there are weak northwesterly winds.

2.1.2 Government Role in Haze Mitigation Management and Technology Development

Haze in China has evolved over a long time period in high concentration because of the transmission and mixing of suspended particles caused by geographical conditions and atmospheric circulation. All of these characteristics can be monitored by space observation technologies. Using GIS and spatial databases can help to describe the condition, distribution, and migration of atmospheric pollution.

(1) Regulatory role in the state plan. Space-based observation can supervise the sources of atmospheric pollution from industrial emissions in terms of coal-fired heating, vehicle exhaust, and construction dust, which are the major components of haze, and so space observation can provide information to decision-makers. The Ministry of Science and Technology and the Ministry of Environmental Protection delivered "Blue Sky" planning in 2012. In the plan, an objective is to build space-Earth integrated networks to monitor the sources of atmospheric pollution and haze. The State Council issued "Ten Implementations for Air Pollution Remediation" in 2013. The requirements of governance and control of atmospheric pollution are focused on monitoring and collecting data on air pollution sources in industrial emissions, coal-fired heating, vehicle exhaust, and construction dust to form a haze data chain and keep up sustainable collaboration technology. This can provide information support for government decision-making and improve air quality.

(2) Studies on suspended particulate matter and haze forming mechanisms. Suspended particulate matter (haze) gets transported between cities and surrounding regions, and the study of transmission mechanisms is key to support haze monitoring using space-based observation techniques. According to the latest statistical results, from south to north, the concentration of total suspended particles demonstrates a threshold phenomenon by Huaihe River resulting from the heating policy in winter, mainly consuming coal. The transmission phenomenon for all suspended particles is significant in the adjacent cities such as Beijing, Shijiazhuang and Baoding. According to the latest statistics in 2014 by the Beijing Environmental Protection Agency, PM 2.5 observations show that 28% to 36% of the particulates come from surrounding regions, 31.1% from local cars and trucks, 22.4% from coal-burning, 18.2% from industry, 14.3% from local construction dust, and 14% from other sources. The haze's components include 26% organic pollution, 17% nitrate, 16% sulfate, 11% amine salt, and others.

2.2 Urbanization and Groundwater Source Detection Using Remote Sensing Techniques[8-9]

Joseph Stiglitz, Nobel Laureate in economics, predicted that Chinese urbanization and American high-tech development will be the two events most affecting the development of human society in the twenty-first century.

2.2.1 China's New Kind of Urban Development

According to the *Guangming Daily*, at present China has 658 cities and 19,722 towns, and the urbanization of the population reached 710 million by the end of 2012. At a rate of 51.27%, the urban population has exceeded the rural population for the first time in history. The middle-income population will reach 600 million and the urbanization rate will exceed 60% in the year 2020. The Development and Reform Commission website introduced that China has formed a group of 10 cities. The *Chinese Science Daily* pointed out that in the development process of new towns in China, the ecological environment and the carrying capacity of resources is limited, accompanied by many other problems, such as air pollution and disaster risk. In the management and security of water resources, the problems will be more serious in arid and semi-arid areas in northern China where water balance is mainly maintained by precipitation. The "Chinese Water Resources Sustainable Development Strategy Research Report" pointed out that the scarce situation of water resources in China will last for a long time. The current average occupation is 2,200 cubic meters per person, accounting for 1/4 of the world average level, and China has been listed as a water resource shortage country by the United Nations. Of the total 669 cities, there are 400 cities in a water supply shortage, and among them 110 cities are in a serious water shortage. Of the 32 big cities with a population over 1 million, 30 are in a long-term water shortage[10].

2.2.2 Role of High Resolution Remote Sensing in China's New Urbanization

High-resolution satellite imagery is an important tool in the construction of new environmentally friendly towns. In the past, the acquisition of construction data in the course of urbanization mainly depended on ground measurement and the city's water environment. Thermal environment data acquisition mainly relies on ground collection, which is limited by ground measurement stations. High-resolution remote sensing can be implemented for urban monitoring at a large scale, and the data can be updated. For example, city growth boundary control is important in urban construction. We can clearly see the speed and direction of the city's expansion through high-resolution satellite images acquired at different time. In addition, high-resolution remote sensing can lend various techniques to applications in other fields, like supporting energy-saving building assessments, monitoring environmental quality, and evaluating flood drainage in urban construction[11].

2.2.3 Technical Progress in Surface and Groundwater Resource Monitoring from Space

One of the challenges in the field of science and technology development in space-based Earth observation is soil moisture and groundwater resources, specifically in the context of ecological processes and human urbanization on the Earth's surface. From the 1960s, the indirect estimation of surface soil moisture by remote sensing information from vegetation and soil used visible shortwave infrared and thermal infrared technology. In the 1990s, estimating soil moisture and groundwater reserves was done with microwave technology. Since 2000, methods for estimating soil moisture and groundwater reserves have been developed to use surface hydrology models and remote sensing data assimilation. In recent years, the detection of groundwater storage change has begun to use satellite gravity theories and techniques.

(1) Visible and near-infrared soil moisture detection. Visible and near-infrared wavelengths (0.45–1.1 μm) reflect the nature of the electromagnetic response of 3–5 cm of surface soil. Since the 1960s, remote sensing scientists have combined the principle of electromagnetic waves with soil, vegetation science, synchronizing measurement and statistical reflection of the electromagnetic energy of soil, vegetation, and different water content.

Observations of the impact on spectral reflectance indicate that dry soil has high reflectivity, the reflectivity is almost constant before the moisture content of the absorbent reaches its maximum, and increasing water leads to reduced reflectivity. A correlation model could be established based on statistical regularities between the remote sensing band and the ground measurement results, and inversion and estimation of soil moisture could be conducted using the model.

(2) Thermal infrared soil moisture detection. Under conditions of surface temperature, infrared energy emitted by surface objects is mainly in the far infrared region longer than 3 μm, belonging to the thermal radiation region. Surface thermal radiation is not only a matter of the surface state, but also a function of the internal material composition and temperature. Under the assumption that topsoil moisture determines deep soil moisture, deep soil moisture content can be inverted to 100 cm. Thermal infrared detection technology in remote sensing utilizes the two mid-infrared wavelength windows at 1.58–1.64 μm (3a band working during the day) and 3.55–3.93 μm (3b band working at night), as well as two windows of thermal infrared wavelengths 10.30–11.30 μm (4 band) and 11.50–12.50 μm (5 band). The sensors collect thermal infrared information of surface features and use it to identify features and invert surface parameters such as temperature, humidity, and thermal inertia. A typical, relatively stable algorithm is the split window algorithm developed from research of NOAA weather satellites in the 1980s and further improved by NOAA-AVHRR.

(3) Microwave soil moisture detection. In the 1980s to 1990s, microwave technology was used to detect surface dielectrics and estimate soil moisture and groundwater reserves. In the field of passive microwave remote sensing, NASA carried out a test flight with a microwave radiometer detecting soil moisture in farmland in the early 1970s. With the development and application of microwave remote sensing data, statistical products have been established for soil moisture indicators such as the Antecedent Precipitation Index (API) and the Microwave Polarization Difference Index, and soil temperature brightness. EOS-Aqua, which started providing soil moisture products on a global scale in 2002, is an Advanced Microwave Scanning Radiometer for EOS (AMSR-E). AMSR-E has 12 channels and realizes surface horizontal and vertical polarization measurements at 6.925 GHz, 10.65 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, and 89.0 GHz and vertical polarization measurements. The radiative transfer model is the theoretical basis of AMSR-E soil moisture retrieval algorithms, which produce three main feature parameter products: soil moisture, vegetation moisture content, and surface temperature.

(4) Combined thermal, infrared and microwave synergistic soil moisture inversion technology. The algorithm uses high-resolution thermal infrared ASTER data, medium-resolution thermal infrared MODIS data, and passive microwave AMSR-E data. The inversion algorithms using passive microwave AMSR-E data and thermal infrared remote sensing data collaboratively compute for thermal infrared and microwave data. For statistical algorithms or physical models, no matter which technological path is taken, the physical meaning, lifting scale, and validation for soil moisture inversion products are the key consideration in the collaborative computing framework.

2.2.4 New Theories and Models for Estimating Groundwater Resource Changes

In recent years, detection methods for groundwater resources have made great progress, mainly reflected in two aspects: methods for surface process modeling with data assimilation, and inversion of groundwater reserve changes using satellite gravity data.

(1) Surface process model and data assimilation methods. Soil moisture is an important parameter reflecting the energy flow and material exchange of the soil-vegetation-atmosphere system. It is also an important factor in the energy balance of the Earth's surface and the greenhouse effect, so it needs an effective application of different areas of expertise from various professional backgrounds to explore and obtain soil moisture information. Using surface process modeling with data assimilation and soil moisture observation data improves the reliability and stability of groundwater products for groundwater resource management.

After 2000, a number of assimilation methods were developed for estimating groundwater storage by using the surface hydrology models in the Land Data Assimilation System (LDAS), including the VIC hydrology model, basic parameters driving the models, data assimilation algorithms, remote sensing observation data, and ground-based observation validation data. The VIC hydrological model and Bayesian network assimilation algorithm can be combined to estimate water storage changes not only on the surface but also 50 cm and 100 cm below the surface. The estimated depth depends largely on the depth of the surface observation data and the accuracy of remote sensing observation data.

(2) Groundwater resource change inversion using

satellite gravity data. The Gravity Recovery and Climate Experiment (GRACE), a twin satellite gravity mission jointly sponsored by NASA and the German Aerospace Center (DLR), was launched in March 2002. Its main scientific goal is to obtain high-precision, long-wave measurements of the gravitational field and its varying characteristics globally. It is also meant to improve the understanding of the Earth's variation. GRACE satellite technology provided a new tool for studying the Earth's gravitational mass transfer and hydrological issues, and also has significance for in-depth understanding and effective simulation of the water cycle and great changes in Earth's climate and ecological systems.

(3) GRACE data applications in groundwater resource inversion. In the previous ten years of GRACE data collection, the measurement of groundwater was only on the Earth's surface in America, including 1,383 geological survey observation wells using real-time sounding, 5,908 reading points daily, plus hundreds of thousands of wells, trenches, and caves taken as supplements for water level measurements across the country.

Another example is groundwater retrieval results in northern India being drastically reduced, affecting over 100 million people (NASA Satellites Unlock Secret to Northern India's Vanishing Water, 2012). In 2009, the online edition of *Nature* published a report pointing out that the water level in northern India was reducing sharply, and agriculture and drinking water for more than 100 million people in the region would likely suffer a major blow if no measures were taken. A research team from NASA detected groundwater reserves in northern India and concluded it led to a significant reduction in over-exploitation using seven years' gravity field data. Satellite data observed in two regions, Rajasthan and Punjab in northern India, indicate that the water level in the region fell by an average of 4 cm per year, a total loss of 109 cubic kilometers of groundwater from 2002 to 2008.

3 Space-air-ground Coordinated Observation System in Decision Support Applications

Earth observation applications in China have leapt from the testing application stage into the application operation stage. Earth observation technology can help our society to cope with various challenges, and play a supportive role in decision-making, such as ensuring food and water resource security, resisting natural disasters and emergencies, adapting to climate change, establishing new economic belts and urbanization, and safeguarding the sustainable development of the environment[12].

3.1 Establishing China's Cooperative Satellite and Drone System for Forensic Investigations of Environmental Policy Violations

Now socioeconomic development in China is facing the pressure of sustainable, environmentally conscious development. Although the state has the "Air Pollution Prevention Law", "Water Pollution Protection Law" and 20 other regulations and corresponding action plans, there are still air pollution (hazy weather days are increasing), soil pollution, and water pollution. Many environmental violations occurred in 2013, according to the Environmental Supervision Bureau of the Ministry of Environmental Protection, which used a cooperative satellite and drone system for forensics to monitor environmental violations.

The basic method is to use the satellite images obtained by the environmental satellite application center to determine the key area, and then use drones to take photos and get video evidence in real-time at the air pollution source, and ultimately collect a large amount of evidence of illegal activities. March of each year is the key period when most parts of the country suffer from unfavorable atmospheric diffusion conditions, and drinking water during the dry season must be protected. The Ministry of Environmental Protection sent 26 teams to carry out special inspections on environmental protection in 44 cities. The report includes the monthly atmospheric pollution problems since November 2013, and also includes the safety issues affecting drinking water that may be more prominent. For industrial pollution, after five consecutive months of rigorous rounds of inspection through law enforcement, the phenomena of environmental law violations have been constrained to a certain extent in the Beijing-Tianjin-Hebei region, though there were still 141 enterprises violating environmental law in the 20 provinces, areas, and cities inspected.

3.2 Large-scale Application of Satellite-air-drone Networks in Land Resource Management

There have been four Chinese resource remote sensing satellites, with two currently in orbit. That number will reach six in 2020. The application of remote sensing satellite data in the regulation of land and resources presents a prospect for new, systematic, large-scale applications. The operation of large-scale applications is continuously improving in the field of land and resource management.

(1) Remote sensing-based digital technology system for homeland resources. RS-GIS-GPS techniques and equipment are being fully applied to basic geology, mineral resources, the environment, and geological hazard surveys. They provide all-digital information collection and processing, and can generate national coverage of land use and mineral development once a year. They will help establish "One Map" of national homeland resources and maintenance mechanisms of annual land use, and build a number of different scale and national coverage databases for land, regional geology, mineral resources, and geological disasters. The four-level homeland resource departments have accumulated terabyte-level data, and built a three-level, national, provincial and municipal homeland resources data system.

(2) Continuing implementation of remote sensing in monitoring land changes. Governments organized to update national coverage remote sensing data for 2013, and produced remote sensing orthophoto maps of land use of counties (cities and districts). The 2012 land survey database and 2012 baseline of remote sensing maps were overlaid, extracting remote sensing figure spots for the year, tracing and verifying investigation-related polygon changes in the past years (including results of enforcement checks using satellite images). The update included remote sensing products of counties (cities and districts) for the year 2013.

(3) Implementing remote sensing for verifying damaged farmland. On the southeast coast of China, typhoons, rainstorms, and floods occur frequently and a large amount of farmland is damaged every year. Remote sensing technology plays a supportive role to help the affected farmers in terms of warning, restoring agricultural production, and minimizing losses. The figure spots verify the destruction from disasters. Analyzing pre-disaster and post-disaster IKONOS images and Resource-2 images help interpret and verify disaster destruction, find suspicious figure spots, and undertake a field review for part of the suspicious figure spots. Area statistics for the verified destruction data can be compared with the report data to produce a diagram of the disaster distribution. The results were analyzed comparatively and reviewed using different image data sources. The best data sources and methods were identified for disaster-damaged farmland assessment in the future.

3.3 Space-air-sea Coordinative Searching for the Lost MH370

At 02:40 on March 8, 2014, Malaysia Airlines said a Boeing 777-200 carrying 239 people, flight number MH370, lost contact with the control center. The aircraft should have arrived in Beijing at 06:30 on March 8, 2014. Now the space-air-sea coordinated search is still underway until the flight is found.

(1) Searching for the lost MH370 using imagery from Chinese satellites. On the morning of March 8, 2014, the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, launched a rapid emergency response, inquired about satellite reconnaissance tasks after the incident, coordinated satellite data for domestic and international users, and submitted the access applications of emergency satellite data in the next 2□3 days. Researchers used satellite data of March 8 and March 10, found three traces of oil in the area where Malaysian Airlines lost contact, and quickly analyzed the results and submitted them to relevant departments, which provided supporting information for the search and rescue. At 11:00 on March 12, Xi'an Satellite Control Center announced that 10 satellites were urgently called together for supporting this search and rescue action. China employed various satellites and used high-resolution Earth imaging and visible light cameras, and other Earth observation technology. It was reported in Chinese military networks that Xi'an Satellite Control Center employed four kinds of satellite, including ocean satellites, FY satellites, high-resolution satellites and remote sensing satellites, totally 10 satellites to provide technical support. Some of these satellites adjusted their original work plan, suspended their original tasks and were devoted to the mission in order to strengthen meteorological monitoring, communication, navigation, and search and rescue in the area of the lost plane. On March 13, the China Resources Satellite Application Center observed three suspected floating objects in the area where MH370 lost contact from the satellite images of High-resolution Satellite No.1 at 11:00 on March 9, 2014, located within 20 km radius of the central region (105.63°E, 6.7°N), and the approximate size of the three suspected floating objects were 13 m × 18 m, 14 m × 19 m, and 24 m × 22 m.

(2) Searching for the lost MH370 using foreign satellites. On March 19, the Terra/MODIS satellite of NASA took an image with 250 m resolution in relevant waters, around 104.6°E, 6.1°N, close to the suspected crash site of flight MH370. On March 23, a French satellite captured some objects in the search area, probably related to MH370. On March 20, the Australian Maritime Safety Administration announced radar satellite images suspected to contain the lost plane, and show suspected "massive" objects underwater.

4 Entering the Coming Era of Earth Observation Big Data

Two conferences related to big data were held in Beijing in February and March 2014. One was the scientific data NSC Congress Conference with the theme "Big Data and Data Science Research" at Huairou, Beijing. The other was the Xiangshan meeting with the theme "The Era of Data-Intensive Scientific and Technical Information". The two meetings jointly considered that a global network of big data will drive the traditional paradigm shift in technology and changes in the way data services represent a new round of technological revolution.

Data is the information carrier. A large network of global interoperability of data is an enormous resource. In order to master the use of large data in knowledge discovery and information services, and use large data scientifically and efficiently, scientific research must be taken in a new direction, toward data-intensive science. In Earth observation, the use of a large data network has bidirectional characteristics, mutually providing data sources to the internet and also using data from the internet. This is effectively a national remote sensing data infrastructure and information system. In order to further explore the wealth of data, large data-intensive computing will be needed for multi-regional, multi-domain, and multi-disciplinary studies, with increased complexity of the architecture and security.

After nearly 50 years of accumulation, Earth observation has entered a petabyte-class "big data" stage, exhibiting compute-intensive characteristics of throughput, speed, diversity, value enhancement, processing and synchronized feature rendering, representing the future direction of development. The traditional form of data processing and application service models is apparently unable to meet discovery and application service requirements of large, scientific Earth observation data. The big data era is opening a major transformation that will change human life as well as our understanding of the world. Big data has become a manifestation of the sovereignty of information, and will be another space beyond the border, coastal, and air defense power game. In 2012, the U.S. government started big data research and development programs and invested 200 million dollars to set up a number of projects. The European Union (EU) open data strategy was proposed in 2011 to promote economic growth. In 2013, the EU also held the EU Big Data Forum. Australia issued a big data strategy report in 2013, promoting open data and big data as one of the major areas of development. In China, government departments have also started different big data projects one after another. The essential characteristics of the era of big data and large data computing are the shift from a model-driven to data-driven paradigm, and the establishment of data-intensive scientific methods. Traditionally, the scientific experiments are a primary means to describe natural phenomena. Afterwards, there was theoretical research using models and methods of reasoning. Then there was a scientific computing branch for simulating and modeling complex phenomena. Today, the advent of the era of big data will unify theoretical, experimental and computational simulation to form a new scientific paradigm—data-intensive science.

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