Development, application, and prospects for Chinese land observation satellites

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The launching of CBERS-01 (China Brazil Earth Resource Satellite) in 1999, China’s first land observation satellite, signifies an unprecedented milestone in Chinese satellite remote sensing history. Since then, a large number of applications have been developed that drew upon solely CBERS-01 and other Chinese land observation satellites. The application development evolves from one satellite to multiple satellites, from one series of satellites to multiple series, from scientific research to industrial applications. Six aspects of the Chinese land observation satellite program are discussed in this paper: development status, data sharing and distribution, satellite calibration, industrial data applications, future prospects, and conclusion.

Keywords: Chinese land observation satellite; data sharing and distribution; satellite calibration; industrial data applications

1. Development status

1.1. An introduction to Chinese land observation satellites

Currently, there are five series of Chinese land observation satellites, the CBERS (China Brazil Earth Resource Satellite), HJ, ZY, SJ, and GF series. The CBERS was jointly developed by China and Brazil. The other four series were named by the first pinyin character, e.g. HJ/ZY/SJ/GF, respectively standing for Chinese phases (HuanJing, ZiYuan, ShiJian, and GaoFen) meaning environment, resource, experiment, and high-resolution Satellite. Up to the present, 11 land observation satellites have been launched by China, among which eight are still in orbit and working: HJ-1A/1B, ZY-1 02C, ZY-3, SJ-9A/B, and GF-1 (Figure 1). They are managed by CRESDA (China Center for Resources Satellite Data and Application). CRESDA is tasked with the processing, archiving, and distribution of data from all Chinese land observation satellites.

The following provides a brief overview of different satellites that have been launched since 1999. The CBERS-01, launched in 1999, is China’s first land observation satellite, ending a history of complete dependence on foreign satellite data (1). Launched in 2004, the data quality from the CBERS-02 has been continuously refined. Meanwhile, the scope of data applications has expanded correspondingly. The CBERS-02B, launched in 2007, is the first satellite with a high-resolution 2.36 m camera that opens up new avenues for high-resolution data applications. In addition, the HJ-1A/1B launched in 2008, are environmental and disaster reduction satellites, equipped with wide-scope CCD cameras and China’s first hyper spectral cameras. It should be noted that HJ-1A/1B satellites are capable to revisit the same study site within two days. In 2012, the first Chinese SAR satellite: HJ1-C was launched with intension to acquire data under different weather condition. The ZY-1 02C, launched in 2011, is China’s first operational satellite for land resource surveys, to further meet user’s demand for high-resolution satellite data. Its data acquisition capability was substantially improved compared to aforementioned satellites. The ZY-3 satellite, launched in 2012, is China’s first satellite for capturing three-dimensional geometric information. The SJ-9A/B, launched in 2012, was equipped with a variety of experimental sensors, which primarily aim for disaster monitoring and early warning, emergency response, and disaster assessment. The success of SJ-9A/B has laid a solid foundation for the development of the GF-1 in 2013, which is the first satellite for special projects in the high-resolution observation system, initiating a new era for high-resolution land observation data applications.

1.2. Sensors

The aforementioned satellites carry both panchromatic sensors that can acquire images at spatial resolutions ranging from 2 to 5 m, and multi-spectral sensors that acquire images at the spatial resolution of 6–150 m (2). The spectral coverage for the panchromatic camera ranges from 0.45 to 0.89 μm while the multi-spectral camera provides the visible, infrared, and thermal spectral bands. In addition, the hyperspectral imager targets the 0.45–0.95 μm range, with 115 bands (Figure 2).
With regard to temporal resolution, the revisiting period for any of the eight in-orbit satellites are three days. The average revisiting period for the multi-satellite combination is approximately eight hours.

1.3. The satellite application development stage
Over the past 14 years, the development of Chinese land observation satellite applications can be divided into three stages (Figure 3). The first stage, the experimental stage, can be traced back from 1999 to 2006. During this period, work has been mainly focused on the launch, operation, and application of CBERS-01/02. Between 2007 and 2011 is the second stage, which shifted focuses from experimental to industrial data applications, denoted by the operation and application of the HJ-1A/1B and ZY-02C, ZY-3, and GF-1 satellites. Since 2011, the third stage concentrates on industrial applications, epitomized by the launch, operation, and application of the ZY-1 02C, ZY-3, and GF-1 satellites. It is apparent that the satellite application industry has a bright future with these improvements in observation capability.

2. Data sharing and distribution
2.1. Architecture of data distribution service system
CRESDA has established a “three-in-one network” data distribution service system to ensure that the rapid growth of satellite data can meet for users’ requirements. The data distribution system was transitioned from a single CD-ROM (magnetic media)-based distribution to network-based distribution, followed by a transition from single network to multiple networks, including a special network, the e-government network, and the Internet, at different levels and for different users (Figure 4). For primary users such as the Ministry of Land Resources, the Ministry of Environmental Protection, the Disaster...

Figure 3. The stages of Chinese land observation satellite application development.
Reduction Department, and the State Bureau of Surveying and Mapping, the data are distributed through an optical fiber network. For government users, data are distributed through the e-government network. As for the general public, data are distributed through the Internet. The International format standards, such as GeoTiff, JPEG 2000, are used for data distribution.

2.2. Rapid growth of data requirements

Data requirements are increasing rapidly and data application industries are continuously expanding (3, 4). This presents new opportunities and challenges for effective application of such data. As of September 2013, the annual amount of data distributed has already elevated from thousands of scenes to hundreds of thousands of scenes. Today, the total number of images distributed has reached 4.1 million scenes (Figure 5) while at the same time, data applications have expanded accordingly as well. In addition to the traditional land resource users, such as agriculture, forestry, water conservancy, environmental protection, disaster prevention and reduction, and the urban planning industries, data acquired by these Chinese Satellites are used in the fields of electricity generation and distribution, coal, petroleum, transportation, civil aviation, tourism, and electronic navigation (Figure 6). Furthermore, the data application areas have expanded; as registered institutional users have reached nearly 4000 from across the whole country of 34 provinces, autonomous regions, municipalities, and special administrative regions.

2.3. International data distribution

In December 2008, the CBERS-02B-receiving station was successfully built in South Africa as an aim to construct the China–Africa strategic cooperation framework, promoting the use of CBERS-02B satellite data resources.
throughout 13 countries in southern Africa (5). It is the “tipping point” for Chinese overseas station establishment, marking the point at which Chinese remote sensing satellite data formally entered the overseas remote sensing application market. Additionally, the CBERS-03-data receiving transformation in South Africa was completed. Thus, CBERS-03 data will be incessantly received and distributed in that country. CBERS-02B-receiving station in South Africa and data-receiving area are shown in Figure 7.

In April 2011, construction of the HJ-1A remote sensing ground station for Thailand was completed and officially delivered to Thailand, another “tipping point” as China extending from export of only-ground receiving systems to processing, storage, and distribution systems. In July 2011, the ground station was christened the “Princess Chulabhorn Remote Sensing Satellite Ground Station” (Figure 8).

During the Association of Southeast Asian Nations (ASEAN) Expo in September 2012, China, the Chinese government announced the CBERS-03 satellite free data-sharing project for ASEAN member countries. In this project, the CBERS-03 satellite, to be launched in late 2013, will be transmitting to a data-receiving station at the National University of Singapore, and the data relayed to a data center in Beijing. The CBERS-03 satellite data (ASEAN)-sharing service platform will be established by China for CBERS-03 data sharing among all ASEAN member countries.

3. Satellite calibration

3.1. Absolute radiometric calibration

Absolute radiometric calibration obtains the calibration coefficient to transform the digital counts (DCs) output from a sensor to a radiance value. Radiometric characterization and calibration is a prerequisite for creating high-quality scientific data, and consequently, higher level downstream products. CRESDA executed satellite in-orbit radiometric calibration in 1999 when the CBERS-01 satellite was launched. Since then, CRESDA has published on a yearly basis the absolute radiometric calibration coefficients of all in-orbit land satellites for users, which has greatly promoted quantitative applications of Chinese land observation satellite data. Through constant practice and improvement during the past decade, CRESDA has developed a series of standards and norms for absolute radiometric calibration.

At present, China has built several absolute radiometric calibration sites to meet satellite radiometric calibration requirements (Figure 9(a)). The Dunhuang and Qinghai Lake sites are used for the satellite sensors calibration for the medium and low spatial resolution, visible – shortwave infrared, and thermal infrared regions (Figure 9(b)). A Songshan site and planned Yunnan site will meet higher spatial resolution sensor calibration and calibration frequency requirements. Results from a decade of applications have proved that these calibration sites played an important role for Chinese satellite sensor in-orbit calibration and comprehensive performance testing.

3.2. Geometric calibration

On-board geometric calibration is a critical step in the pre-processing of such remotely sensed satellite images with improved spatial resolution (6), especially since ZY-3, China’s first high-resolution stereo mapping satellite that was launched in 2011. A high-resolution geometric calibration field is the foundation for on-board calibration (7, 8), and the basis for high accuracy reference data resources, such as highly accurate ground control points (GCPs), digital ortho-photo maps (DOMs), and digital elevation models (DEMs).

To this end, the Songshan Mountain district in Henan Province was chosen as the most satisfactory area for geometric calibration. The Songshan Calibration Field is 100 km from east to west and 100 km from south to north. An Aerial image with 20 cm ground sample distance was acquired by the ADS40 with an extent of 60 km × 60 km. DOM and DEM (see Figure 10) were produced after aerial triangulation with a planar accuracy of 1 m and an elevation accuracy of 2 m. DOM and
DEM are composed of abundant high-accuracy three-dimensional reference data as each pixel can be considered as a GCP.

The positioning accuracy both with and without control have gained significant refinement after geometric in-orbit calibration for ZY-3 three-line array images became available. For ZY3, the average positioning error without control was boosted from 900 m or so before calibration to approximately 10 m after calibration. Further, the stereo accuracy with control is refined to 3 m in plane and 2 m in elevation only using two or three control points. Moreover, the accuracy with control is improved from 6–7 pixels before calibration to 1–2 pixels after calibration.
4. Industrial data applications

China Land Observation Satellite data have been widely used in the field of land resources monitoring, disaster prevention and reduction, agriculture, forestry, water conservancy, environmental protection, urban planning, and transportation.

For land resource monitoring in China, land observation satellite data were applied to a survey project once a year. This data played an important role in provincial land resource surveys (Figure 11).

In agriculture, land observation satellite data are widely used for crop growth monitoring, agricultural yield evaluation, and crop acreage surveys, providing timely and unbiased information for decision-making departments. Figure 12 shows the winter wheat monitoring results for Dezhou city, Shandong province, based on CBERS-02B.

In water conservancy, HJ satellite data were transmitted to the Water Information Center of the Ministry of Water Resources in real time through a special data transmission channel, which played an important role in water investigation, drought monitoring during the first national water census. As shown in Figure 13, the deep blue color, red color, and blue stand for the water area on 19 December, 11 December, and 11 November in 2011, respectively, illustrating the water area changes in Dongting Lake based on HJ-1A and HJ-1B satellite data (9).

In forestry, the domestic land observation satellite provided important data support for forest resources and wetland resources surveys and desertification monitoring. For example, Figure 14(a) and (b), shows the CBERS-01 satellite data.
satellite image of Nyingchi in Tibet and also the forest type distribution map in Nyingchi.

For environmental protection, land observation satellite data were widely used in the monitoring of red tides, sea ice, and oil spills. Figure 15 shows the oil spill area in the Gulf of Mexico, which was portrayed on the HJ-1B data collected on 10 May 2010.

Also, HJ satellite data has been continuously used since 2009 for forest fire monitoring. As such, more than 30 fires have been monitored. In 2009, more than 70 scenes were provided to the Australian fire monitoring program, demonstrating an important decision support for fire disaster reduction, known as the “model of Sino-Australian cooperation in science and technology” (Figure 16). China land observation satellite data also contributes to mitigating natural disaster situations, such as Wenchuan earthquake (Figure 17), the Zhouqu mudslides, Yaan earthquake, etc.
applications for economic construction and social development; we will further strengthen international cooperation and exchanges, to promote international marketing of domestic land observation satellite data, and provide data services for more countries and regions. We are committed to making important contributions to global resource monitoring and environmental protection.

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References
(1) Chen, Y.; Chen, Q. China Brazil Earth Resources Satellite (in Chinese). Spacecraft Eng. 2001, 11 (2–3), 129–135.
(2) Yue, T.; Huang, Y.; Liu, P.; Hou, Y.; Zhou, Y. Analysis of China’s Future Satellite Remote Sensor Development (in Chinese). Spacecraft Eng. 2008, 17 (4), 77–82.
(3) Guo, H.; Liu, Z.; Zhu, L.W. Digital Earth: Decadal Experiences and some Thoughts. Int. J. Digital Earth 2010, 3 (1), 31–46.
(4) Li, D.; Gong, J.; Shao, Z. From Digital Earth to Smart Earth (in Chinese). Geomatics Inf. Sci. Wuhan University 2010, 35 (2), 127–132.
(5) Xu, G. “Digital Earth” Construction to Promote the Sustainable Development of China and the World (in Chinese). Aerosp. China 2000, 26 (1), 6–9.
(6) Gong, D. Models and Algorithms on Processing of High-resolution Satellite Remote Sensing Stereo Images. Ph.D. Thesis, The PLA Information Engineering University, Zhengzhou, China, 2003.
(7) Gruen, A.; Kocaman, S.; Wolff, K. Calibration and Validation of Early ALOS/PRISM Images. J. Jpn. Soc. Photogrammetry Remote Sens. 2007, 46 (1), 24–38.
(8) Poli, D. Orientation of Satellite and Airborne Imagery from Multi-line Pushbroom Sensor with a Rigorous Sensor Model. Int. Arch. Photogrammetry Remote Sens. 2004, 35 (B1), 130–135.
(9) Wang, Q.; Wu, C.; Li, Q. Environment Satellite 1 and its Application in Environmental Monitoring. J. Remote Sens. 2010, 14 (1), 104–120.

5. Future prospects
5.1. More satellites launched in the future
The CBERS-03/04 and a number of other high-resolution satellites will be launched in the near future. During the timeframe of “The Twelfth Five-Year Plan” more than 10 satellites are to be launched, and 8–10 satellites will be operating in-orbit concurrently every year going forward (Figure 18).

5.2. Grid-based distribution system
Distribution will be evolved from a network-based system to a grid-based one. A grid-based data sharing system will establish an interconnected infrastructure composed of many nodes based on high-speed transmission networks (e-government, Internet VPN, and networks). An upper grid software platform, in normal use cases, will integrate and permit data sharing of heterogeneous resources from different units. Users access the system through a one-stop grid portal and can harness various resources provided by different departments, obtaining information such as catalog index, data products, grid resource statistics, etc. In emergency situations, data can be converged and transmitted for fast response through a special, designated channel.

6. Conclusions
With the rapid development of Chinese remote sensing technology and the progressively increasing number of remote sensing satellites, a long-term, stable, continuous spatial information infrastructure for land observation is now being established. CRESDA, as the National Land Observation Satellite data center, will continue to routinely provide users long-term, stable, and continuous access to satellite data, products, and services. We will further promote the comprehensive use of Chinese Land Observation Satellite data in commercial and industrial