Environment Satellite 1 and its application in environmental monitoring

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Abstract: Environment Satellite 1 (HJ-1), the first new kind satellite developed by China used for environment and disaster monitoring, was launched in September 2008. This satellite is the milestone of China's environmental technology development and application. This article focuses on the application key technology research and business operations of HJ-1. First, it introduces and analyzes HJ-1 technologic parameters and provides HJ-1 data examples of CCD camera, infrared camera and hyper-spectral imager. Furthermore, it analyzes and evaluates HJ-1 data quality in the aspects of geometric accuracy, radiance characteristic and so on. Second, this article proposes the HJ-1 application demand in the fields of large water body environmental remote sensing (RS) monitoring, regional air quality RS monitoring and macro eco-environmental satellite RS monitoring. Based on the demand, this article also designs the HJ-1 application scheme which includes operation flow and data product definitions. Finally, this article uses environmental parameter RS reversing methods to reverse aerosol optical thickness in Beijing-Tianjing- Tanggu (BTT) area and to monitor chlorophyll-a concentration in Chaohu lake.

Key words: environment Satellite, HJ-1, application, monitoring

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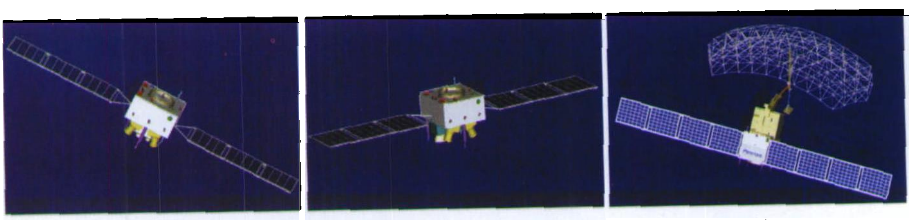
1 GENERAL INTRODUCTION OF ENVIRONMENT SATELLITE 1

1.1 Environment Satellite 1 system

Chinese government attaches much importance to satellite remote sensing application in eco-environment monitoring. In 2003, the government proved the establishment of Environment and Disaster Monitoring and Forecasting Small Satellite Constellation (Environment Satellite 1, HJ-1), which is the special satellite project for eco-environmental monitoring. In the first phase of this project, research and development has been done to establish the constellation comprised of two optical satellites and one radar satellite (Fig.1). The second phase is to develop four optical satellites and four radar satellites. On September 6th 2008, two optical satellites were launched successfully. The launch of radar satellite will be completed in 2010. Examination of the feasibility of the second phase of this project will be on the way by then. The main mission of HJ-1 Satellite is to monitor pollution, ecosystem destruction and natural disaster in large-scale dynamically and around the clock. In the meantime, it also forecasts development and changes of eco-environment and natural disaster and evaluates environmental quality and disaster damage immediately and scientifically (Wang & Wang, 2006; Wang *et al*., 2008).



(a) (b) (c)

Fig. 1 Sketch of HJ-1 satellites
(a) HJ-1A; (b) HJ-1B; (c) HJ-1C

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The launch of HJ-1 Satellite is the limestone that China has began to hold the advanced environmental remote sensing monitoring system with middle-high space resolution, high temporal resolution, high spectral resolution, wide monitoring coverage and comprehensive observing capability using visual optical, infrared and microwave. It also signals the possibility that China will establish the eco-environmental monitor system to realize large-scale, all-weather and all-day eco-environment dynamic monitoring (Wang *et al.*, 2005).

1.2 The effective loads of Environment Satellite 1

The effective loads of HJ-1 Satellite include a wide-coverage multi-spectral visual optical camera, a hyper-spectral imager, an infrared camera and a S-band SAR. The main techno-parameters are shown in Table 1—Table 4.

2 ENVIRONMENT SATELLITE 1 DATA AND QUALITY ANALYSIS

2.1 Environment Satellite 1 data examples

After the launch of HJ-1 A/B, Satellite Environment Center, Ministry of Environmental Protection (SEC, MEP) immediately carried out the work of data processing and application evaluation. Fig. 2—Fig. 4 show the first batch of HJ-1 data processing results, reflecting the basic condition of HJ-1 data in the aspects of environmental objects' spectra, texture and geometric characters.

Table 1 Main techno-parameters of wide coverage multi-spectral CCD camera

Parameters	Capability			
Width/km	360 (mosaic of two CCD≥700)			
Sub-satellite point resolution/m	30			
Bands/μm	0.43—0.52	0.52—0.60	0.63—0.69	0.76—0.90
Whole view MTF of each band	≥0.20	≥0.20	≥0.20	≥0.14
Dynamic range /($W \cdot m^{-2} \cdot Sr^{-1} \cdot \mu m^{-1}$)	316/197	334/195	246/145	246/163
Signal to noise (*S/N*)/dB	≥48			
Gain control	Each band has 2 level gains adjustable respectively			
Matching precision of central pixel/pixel	±0.3			
Quantitative value/bit	8			
Calibration precision	Relative calibration 5%, absolute calibration 10%			

Table 2 Hyper-spectral imager main techno-parameters

Parameters	Capability
Width/km	≥ 50
Bands/μm	0.45—0.95
Average spectral resolution/nm	5
Space resolution/m	100
Lateral visual field angle/(°)	±30
Bands number	110—128
Quantitative value/bit	12
Signal to noise (*S/N*)	50—100 between 0.45—0.95μm
Dynamic range/($W \cdot m^{-2} \cdot Sr^{-1} \cdot \mu m^{-1}$)	134
System MTF	≥0.2
Radiance calibration precision	Relative calibration 5%, absolute calibration 10%

Table 3 Infrared camera main techno-parameters

Parameters		Capability			
Width/km		720			
Sub-satellite point resolution/m		300m (10.5—12.5μm), 150m (other bands)			
Bands/μm		0.75—1.10	1.5—1.75	3.50—3.90	10.5—12.5
MTF		≥0.28	≥0.27	≥0.26	≥0.25
Radiance resolution Ne $\Delta\rho$ or Ne ΔT		0.5%	0.5%	≤1K (@400K)	≤1K (@300K)
Radiance scene of each band	MAX	9.32mW /($cm^2 \cdot Sr$)	0.89mW /($cm^2 \cdot Sr$)	500K	340K
	MIN			300K	200K
Calibration precision		Ground Relative calibration 5%, absolute calibration 10%		On-board calibration 2K	
Matching precision/pixel		±0.3			
Quantitative value/bit		10			

Table 4 S-SAR main techno-parameters

Parameters	Capability
Polarization type	Vertical launch and vertical receiving (VV)
Band	S
Resolution/ width	SCAN mode: 15—25m/95—105km (4 views in distance, single view in bearing) Strip mode: 4—6m/35—40km (single view)
Radiance resolution/dB	3
Minimum valid scattering area σ_0 /dB	−18
Radiance stableness/dB	One scene ≤0.6
Dynamic range/dB	≥30
BAQ quantitative value/bit	3

2.2 Environment Satellite 1 data quality analysis

During HJ-1 in-orbit testing period, China Resources Satellite Center and SEC analyzed the quality of satellite data from the geometric accuracy, precision of radiation and other aspects, using evaluation indicators such as average gray, gray variance, angular second moment, contrast, correlation coefficient, definition, entropy, information capacity, details of the energy, edge energy, and power spectrum. The comprehensive evaluation results showed that: In the default gain status, the each band energy of HJ-1 CCD is low and the equilibrium between the various bands is good. In the aspect of distribution of image gray level, DN range is concentrative and the band gray range is narrow. In the aspect of the information redundancy between bands, HJ-1A CCD1 and HJ-1B CCD2 have good correlation. In the aspect of texture, the angular second moment is too large;

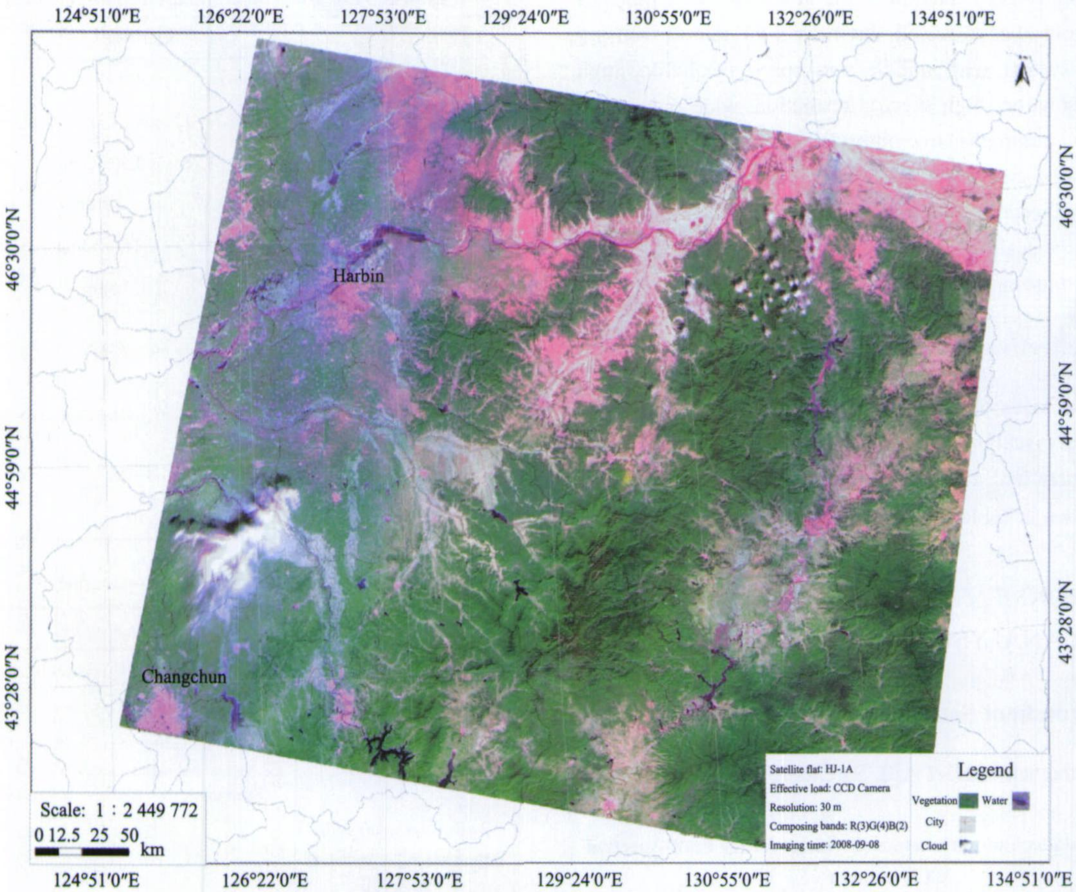

Fig. 2 HJ-1 CCD camera data example

(Eco-environmental RS monitoring HJ-1 CCD image in northeast part of China)

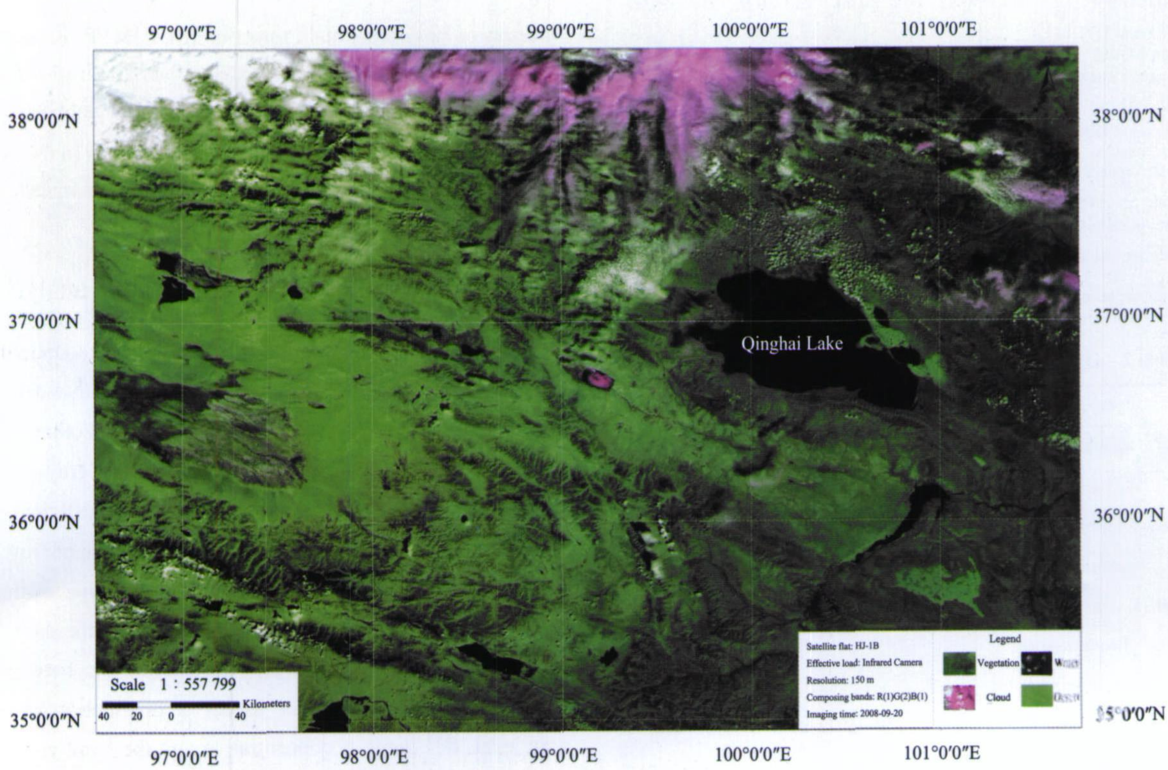

Fig. 3 HJ-1 infrared camera data example

(Eco-environmental RS monitoring HJ-1 IRS image in Qinghai Lake area)

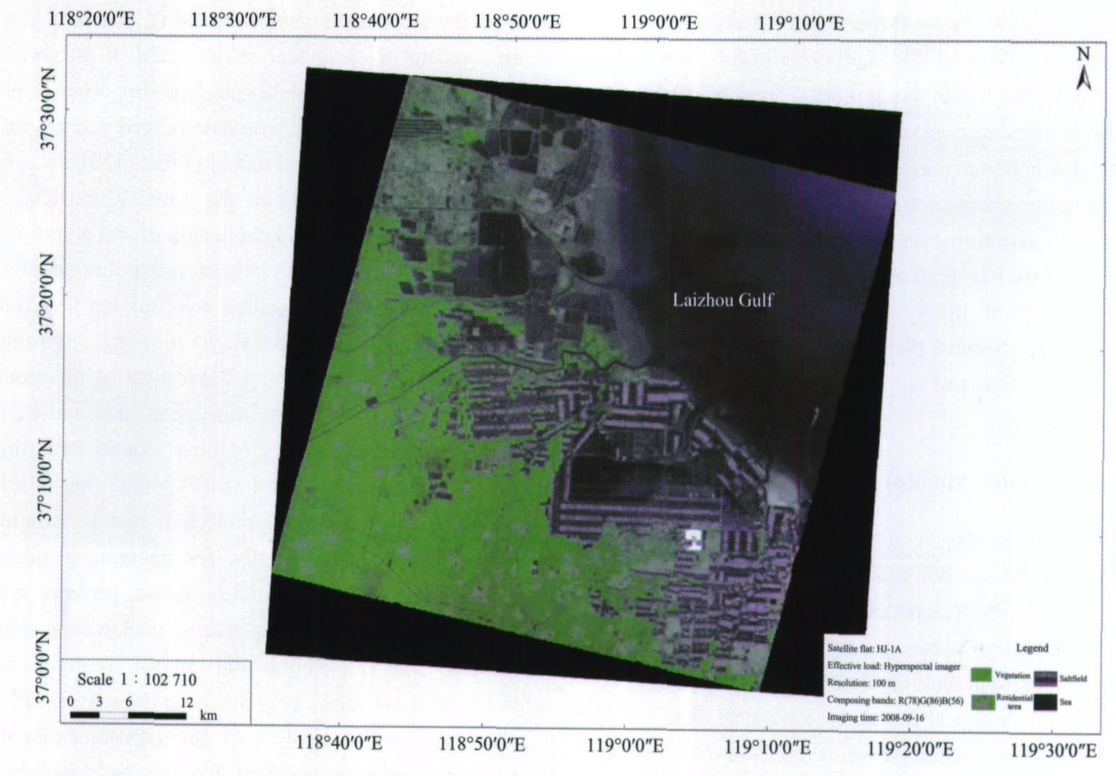

Fig. 4 HJ-1 hyper-spectral imager data example
(Eco-environmental RS monitoring HJ-1 HIS image of Laizhou Gulf, Shandong province)

the image is smooth but texture is coarse; the band texture vary greatly, generally decreasing according to band sequence. In the aspect of details of the signal and information capacity, the contrast of each band is good in general, but CCD entropy is low. In the aspect of the image clarity, the image is clear and power spectrum is good. The performing of image edge of signals is good, too. In short, the energy of CCD data is low and energy balance is good between bands. Radiation quality (entropy value, texture, details of the energy, etc.) and other parameters are good, too. DN values of infrared cameras are comparatively stable and in normal range. Infrared camera's energy, gray-level distribution as well as clarity have good performance and are relatively stable. We analyzed the 4 bands of hyper-spectral data (10, 39, 68 and 103). The results show that the mean and variance of infrared camera's DN values have decreasing trends, and texture is stabile basically except the 10^{th} and 103^{rd} bands. To the objects which have small variance, their contrast, clarity and energy are low. The 10^{th} band often appears low relativity and its angular second moment is quite different from other bands. Therefore, the overall quality of HJ-1 data is relatively stable and achieves the design targets basically.

3 APPLICATION DEMANDS OF ENVIRONMENT SATELLITE 1

Regarding the tasks of national eco-environmental monitoring, the application demands of HJ-1 satellite currently focus on three areas: regional air quality, large water body environmental quality and macro eco-environment.

3.1 Regional air quality remote sensing monitoring

Regional air quality RS monitoring has three aspects: (1) City air quality monitoring, which focuses on monitoring respirable particulate matter. RS monitors, warns, and evaluates air quality in representative areas and city groups such as Yangtze River Delta, Pearl River delta, and Beijing-Tianjin-Hebei area. (2) Pollution of SO_2 and acid rain monitoring, which focuses on the emissions of SO_2 and nitrogen oxides from heavy industry areas. RS monitors, warns and evaluates conditions in large and middle city, in areas severely polluted by acid rain and SO_2, and in large coal-fired power plants. (3) Pollution source of industrial waste gas monitoring, which focuses on the 6000 national control pollution sources with large emissions of SO_2. RS monitors, warns and evaluates pollution source of industrial waste gas. (4) Green house gas monitoring, which focuses on monitoring of CO_2, CH_4, O_3. RS monitors, warns and evaluates the change of environmental air quality in areas sensitive to global climate change and sensitive eco-systems.

3.2 Large water body environmental quality remote sensing monitoring

Large water body environmental quality RS monitoring has three aspects: (1) Water quality monitoring of drainage area and coastal sea, which focuses (Lee *et al.*, 2007) on remote sensing monitoring of chlorophyll-a, suspended matter, CDOM, surface temperature, transparency, etc. RS monitor warns and evaluates the water quality in important sea and rivers like Huaihe River, Haihe River, Niaohe River, Songhuajia River, Three Gorges reservoir, Xiaolangdi reservoir and water resource of

South-to-North Water Diversion Project, Taihu Lake, Dianchi Lake, Chaohu Lake and Bohai. (2) Monitoring of drinking water source, which includes planning protected areas of drinking water source with assistance of satellite RS technology, investigating drinking water source area by RS; monitoring conservation of water resource area, non-point source pollution monitoring; dynamically monitoring and controlling the construction of large scale industries in protected upstream areas of water source. (3) Emission of industrial dust waters monitoring, which focuses on the chemical plants near rivers, and dynamically monitors the resources of harmful substances and outfalls of industrial dust waters.

3.3 Macro eco-environmental satellite RS monitoring

Macro eco-environmental satellite RS monitoring has five aspects: (1) Regional eco-environment monitoring. It focuses on monitoring of biophysical parameters, surface vegetation parameters, eco-evaluation factors and eco-classification factors. It investigates changes of land-use, ecological composition, ecological structure, ecological functions, ecological degeneration and bio-diversity. At the same time, it monitors the regions like the national natural reservations and important ecological function reservations dynamically. (2) National ecological security warning. It monitors and evaluates the change of ecological environment such as vegetation destruction, soil erosion, land degeneration and grassland desertification caused by resource exploitation. It also monitors and warns the main eco-environmental problems and ecological fragile regions, ecological interlaced zones, changes of ecological sensitive regions types, space distribution and ecological system's service functions. Further more, it monitors and evaluates the environmental influence of critical national projects (including Three Gorges Dam Project, South-to-North Water relocation and railway road project in Qinghai and Xizang) dynamically. (3) Regional eco-environmental quality evaluation. RS synthetically evaluates regional and drainage area eco-environmental quality in the aspects of ecological security, health of ecological system, bearing of ecological environment. It also warns the ecological trend of national key regions, important ecological function zones and natural reservations, and reflects the ecological security condition and trend in time. (4) The eco-environmental quality monitoring in the country districts, which includes RS investigation and evaluation of soil pollution, macroscopic RS monitoring of types of soil pollution in typical regions (such as sewage irrigating area, mining area, oil field and abandoned industrial area), monitoring environmental changes in farm produce area, RS investigating non-point pollution in key drainage regions and countryside and RS monitoring environmental changes of area around farm products base and farm producing factories. (5) Monitoring of effect of national ecological protection project. It mainly monitors the ecological projects dynamically, for example protection of natural forest, recovery of natural grassland, projects of returning farmland to forest, returning grazing land to grass, returning farmland to lake, prevention and control of desertification, water-soil conservation, prevention and recovery of rocky desertification. (6) Monitoring of environmental disaster and environmental pollution accident. It tracks and monitors unexpected environmental disaster and accidents (for example sand storm, flood, earthquake, fire, red tide, oil leakage, algae blooming, heat pollution and eutrophication), and reflects the distribution, type, area, level and space-time change, and then warns and predicts the trend.

4 OPERATION APPLICATION DESIGN OF ENVIRONMENT SATELLITE 1

4.1 Integral operation flow

HJ-1 operation flow begins with gaining and processing data, followed by environmental information reversing, then analyzing and evaluating, finally producing and issuing data (Fig. 5).

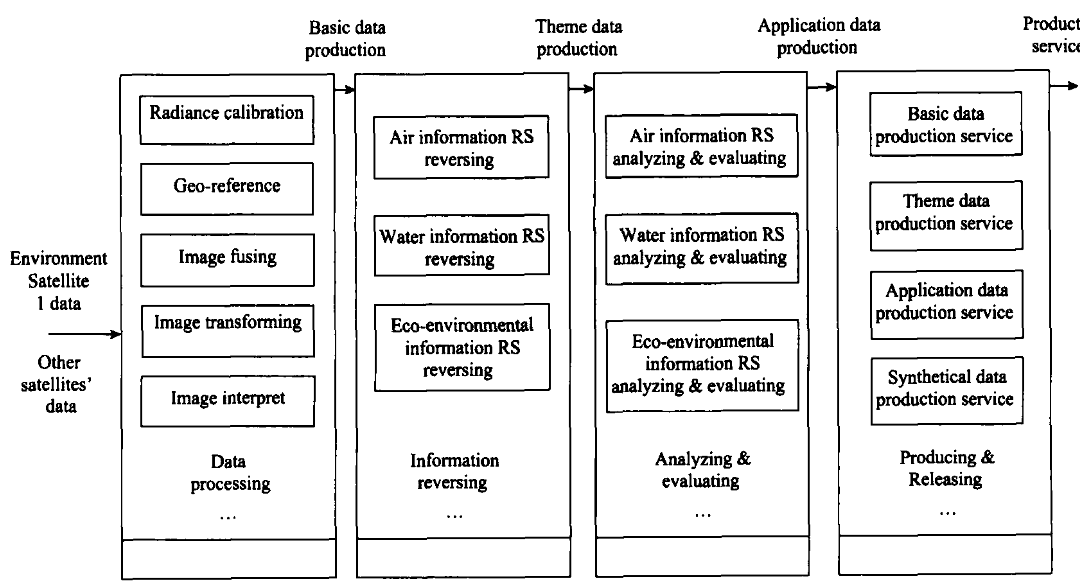

Fig. 5 Integral operation flow

According to the requirements of environmental RS monitoring tasks, we first collect basic supporting data, such as HJ-1 images, other useful satellite images, geometric spatial data, environment background data, field water environment data and social-economic data. Data processing includes radiance calibration, geometric correction, image fusion, image mosaic, image enhancing, image transform and image interpretation. After these processing procedures, we can get environmental RS monitoring basic data products. The next step is environment feature information extracting and parameters reversing, including air quality RS monitoring information, water environmental quality RS monitoring information, bio-physical parameters, land surface physical parameters and nature eco-environmental RS monitoring information (Gordon *et al.*, 1994; Jiménez-Munoz & Sobrino, 2003). Such information and parameters consist of the specific environment RS monitoring products. With the environmental background data and environmental monitoring data, we use RS technology to analyze and evaluate eco-environmental quality, air quality and water quality according to environmental protection requirement, in order to get environment RS monitoring application products. Finally, we get comprehensive data products of HJ-1 satellites through synthetic analysis, maping and report with field data. With web service, we can provide basic data products, specific theme data products and application data products for various kinds of users.

4.2 Operation application data product design

Considering HJ-1 capability and demand of environmental monitoring, we design the HJ-1 data product in 10 levels. Raw data, 0 level data, level 0 data products, level 1 data products (system radiance calibration products), level 2 data products (system geometric correction products), level 3 data products (high precise geometric correction products), level 4 data products (orthorectification products), level 5 data products (image processed data products), level 6 data products (theme data products), level 7 data products (application products). The level 7 data products direct to application synthetical reports, which combine monitoring, analysis, evaluation. In product form, level 7 data products combine remote sensing maps, thematic maps, statistical charts and a written report on the whole. The detail scheme of operation application data products is shown in Table 5.

Table 5 The scheme of operation application data products for HJ-1

Product name			Product introduction
Raw data			Received satellite down-stream raw code data files.
Level 0 data			Raw data after decompression, frame synchronization, formatting.
Standard Data Products	Level 0	Level 0 data products	Standard scene product obtained through level 0 data framing.
	Level 1	System radiance calibration products	Based on optical level 0 data, carrying out allocation between bands and system radiation calibration.
		SAR geographic referenced products	Based on radar sensor level 0 product, formating geo-referenced products after imaging step. Products include single-look complex type (SLC) image products and single-look geo-referenced images (strip mode), multi-look (MLC) image products and multi-look geo-referenced products (strip and scan mode).
	Level 2	System geometric correction products	Based on optical sensor level 1 product, after geometric correction. Based on radar sensor level 1 products, after systematic geometric correction processing. They have map projection information and include strip mode products and scan mode products.
Advanced Data Products	Level 3	High precise geometric correction products	Based on level 2 data product, after geo-correcting based on ground control points and satellite orbit information.
	Level 4	Orthorectification products	Based on high precise geometric correction products, after geo-correcting based on satellite orbit information, ground control points and ground elevation model information.
	Level 5	Image processed data products	Based on high precise geometric correction products, after image process methods such as masic, fusing, filtering, sharpening, etc.
Thematic Data Products	Level 6	Landuse and ecological classification data products	Based on landuse and ecosystem classification system, after automatic classification and manual interpretation.
		Biophysics parameters products	Vegetation index, leaf area index, primary productivity data products, etc.
		Surface physic parameters products	Surface evapotranspiration, soil moisture, surface reflectance data products, etc.
		Landscape ecology index products	Landscape fragmentation, landscape richness index, landscape dominance index, biological abundance index products, etc.
		Water environmental RS monitoring thematic products	Chlorophyll-a, suspended matter, transparency, water surface temperature and other data products.
		Air environmental RS monitoring thematic products	Aerosol optical thickness, water vapor content, respirable particulate matter and other data products.
Application Data Products	Level 7	Ecological RS application products	Ecological RS monitoring and assessing application products.
		Water environmental RS application products	Water environment RS monitoring and evaluating application products.
		Air environmental RS application products	Air environment RS monitoring and evaluating application products.

5 EXAMPLES OF ENVIRONMENT SATELLITE 1 APPLICATION

5.1 Reversing aerosol optical thickness in Beijing-Tianjing- Tanggu (BTT) area based on Environment Satellite 1 data

We used four scenes Environment Satellite 1 data on 20th Sep. 2008 to reverse aerosol optical thickness in BTT area. The data path-row number is (2, 64), (1, 68), (453, 65), (453, 69). The technology flow is as Fig. 6 and results are shown in Fig.7 and Fig.8 (Remer *et al.*, 2006).

In order to evaluate the reversing precision, we compare the reversing result with MODIS aerosol product. After images mosaic processing, we unify two pictures' project into Equal Geographic Project and resample them as the same resolution Fig.9 and Fig. 10. After these processes, we get 486 corresponding point pairs. Between these pairs, the absolute error is

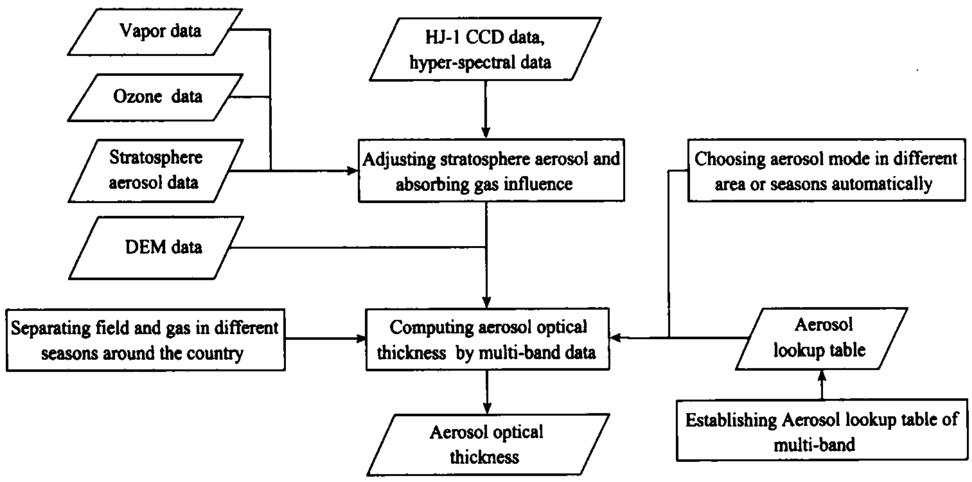

Fig. 6 Aerosol optical thickness reversing flow based on HJ-1 data

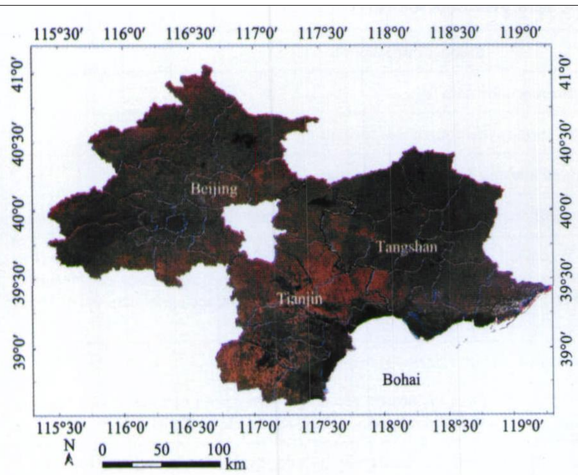

Fig. 7 CCD pseudo color picture of HJ-1A in BTT area (2008-09-20)

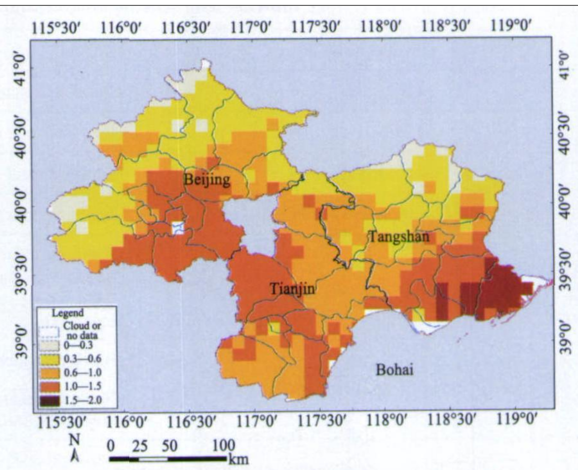

Fig. 9 HJ-1A aerosol monitoring picture after re-sampling (2008-09-20)

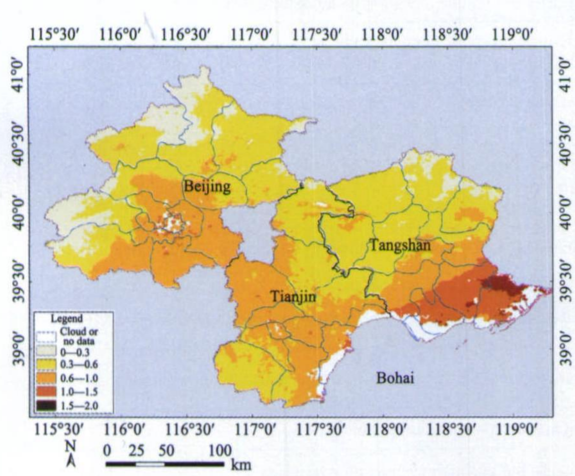

Fig. 8 Aerosol optical thickness distribution based on HJ-1A (2008-09-20)

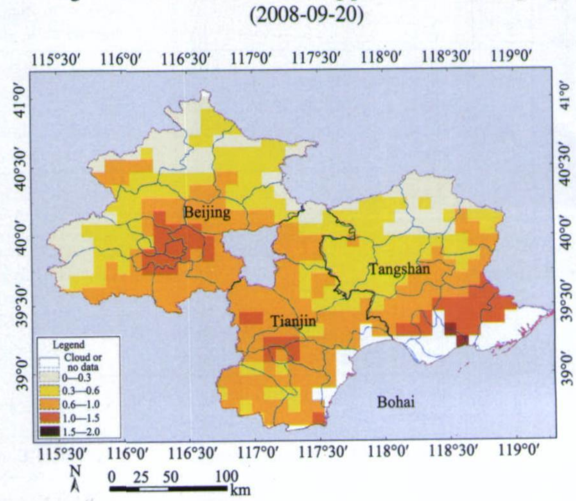

Fig. 10 MODIS aerosol monitoring picture (2008-09-20)

0.104, average error is 0.148, and correlative index is 0.890. Because the aerosol arithmetic of MODIS is mature, the comparing result above shows the reliability of HJ-1A aerosol product to certain extent (Liou, 2002; Bendix *et al.*, 2003).

5.2 Reserving chlorophyll-a in Chaohu lake based on Environment Satellite 1 data

We use HJ-1B CCD data on Jun.4th 2009 to reverse chlorophyll-a in Chaohu lake. The technology flow and monitoring result are demonstrated in Fig. 11 and Fig. 12. The result shows 29.19% of the water area is on level 3, 43.87% on level 4 and 24.73% on level 5. In the area near the north bank, algae bloom area is 35.72km^2, which is 4.69% of the total lake area. The chlorophyll-a concentration of northwest area is higher than that of east area and chlorophyll-a concentration in north area is higher than in south area. The average concentration of chlorophyll-a is 62.70 mg/m^3.

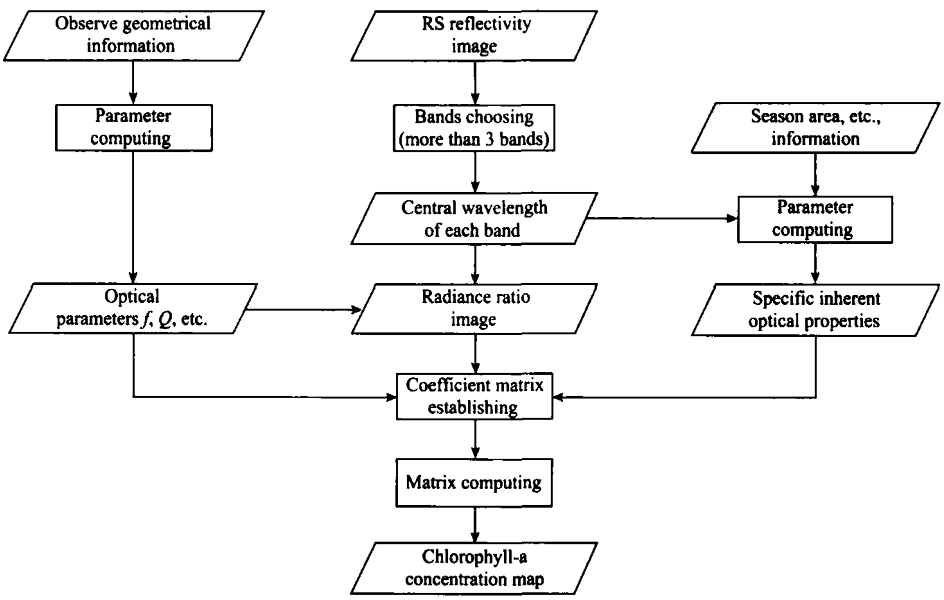

Fig. 11 Chlorophyll-a reversing flow based on HJ-1 data

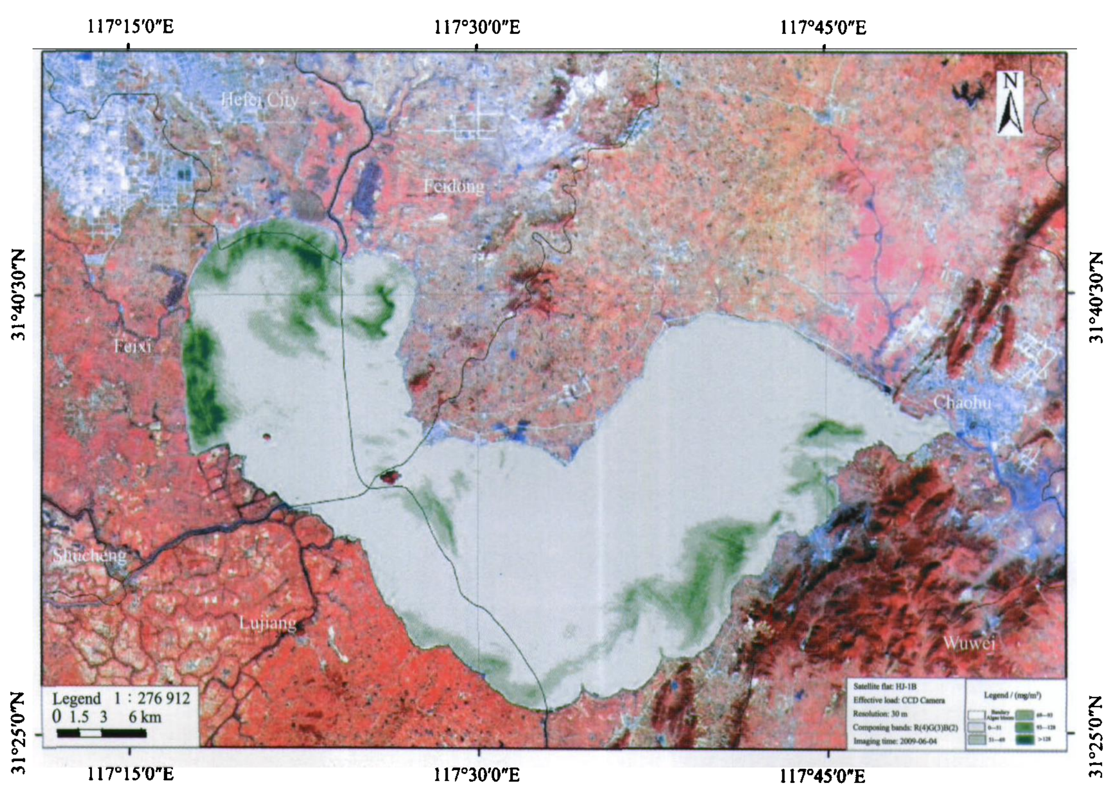

Fig. 12 Chlorophyll-a distribution map of Chaohu lake in Jun.4th, 2009

6 PROSPECT

Successful launch and application of Environment satellite 1 indicates that the environmental monitoring technology in China has entered a new era of "heaven and earth integration". However, the environmental RS in China still has a lot of problems to solve, such as problems with effective sensor research, key techniques of environmental RS and operation system construction of environmental monitoring. In the future, we will establish Environment Satellite 2 system including 4 optical satellites and 4 radar satellites and develop multi-spectral polarization imager, water environmental hyper-spectral imager with programming ability, atmospheric environmental infrared hyper-spectral imager and multi-polarization synthetic aperture radar in C band. These sensors will satisfy the needs of environmental monitoring of multi-bands multi-characteristics, high spatial resolution, high spectral resolution, high temporal resolution, high precision monitoring and realize large-scale, all-weather and all-day eco-environment dynamic monitoring.

Meanwhile, our goal in the new era is to provide information service of national environmental RS dynamic monitoring. This indicates that lots of work should be done in the future in order to form operation system of environment RS monitoring. Such work includes developing technology of environmental RS data processing, information product producing and service, developing key RS reversing techniques of water, atmosphere and ecological environmental parameters, developing environment RS monitoring and evaluating methods, construction of information service system of environment RS dynamic monitoring based on Chinese satellites data such as Environment satellites, enhancing application n of environment RS monitoring in some fields such as important drainage water environment, regional atmospheric environment, important ecological function regions and natural reserve regions. These will largely contribute to the realization of "heaven and earth integration".

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环境一号卫星及其在环境监测中的应用

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摘　要: 2008年9月发射的环境一号卫星是中国自主研发的首颗专门用于环境与灾害监测的新型卫星, 对中国环境遥感监测技术发展与应用具有里程碑意义。围绕环境一号卫星应用关键技术研究与业务运行, 首先对在大量研究基础上形成的环境一号卫星技术性能指标进行了介绍和分析, 给出了环境一号卫星 CCD、红外和超光谱数据的实例, 并从几何精度和辐射特性等多个方面对环境一号卫星数据质量进行了分析和评价; 然后从大型水体环境遥感监测、区域环境空气遥感监测、宏观生态环境遥感监测的角度, 系统提出了环境一号卫星的应用需求; 在此基础上设计了包括业务流程和数据产品定义在内的环境一号卫星应用方案; 最后将所建立的基于环境一号卫星的环境参数反演方法用于京津塘地区气溶胶光学厚度及巢湖叶绿素 a 浓度反演, 显示了环境一号卫星应用的作用和效果。

关键词: 环境一号卫星, HJ-1, 应用, 监测

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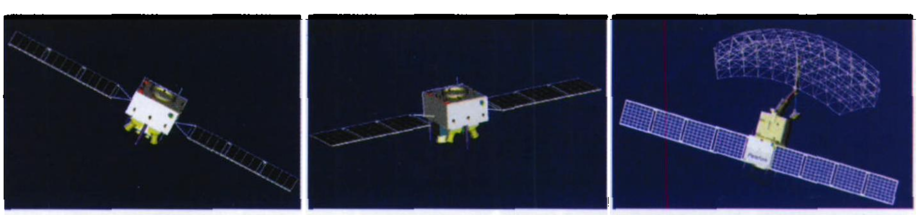
Wang Q, Wu C Q and Li Q . 2010. Environment Satellite 1 and its application in environmental monitoring. *Journal of Remote Sensing*. 14(1): 104—121

1　环境一号卫星概况

1.1　环境一号卫星系统

中国政府高度重视卫星遥感技术在生态环境监测中的应用, 于 2003 年批准建设专门用于生态环境监测的卫星系统——环境与灾害监测预报小卫星星座系统(代号环境一号卫星, HJ-1)。该系统一期工程研发由 2 颗光学卫星和 1 颗合成孔径雷达卫星组成的星座(图 1); 二期工程将发展由 4 颗光学卫星和 4 颗合成孔径雷达卫星组成的新型星座系统。目前一期工程已开始顺利实施, 2008-09-06 成功完成了 2 颗光学卫星(HJ-1A 和 HJ-1B)的发射, 2010 年将完成合成孔径雷达卫星(HJ-1C)的发射, 同时环境卫星二期工程也已进入论证阶段。HJ-1 卫星的主要任务是对环境污染、生态破坏和自然灾害进行大范围、全天候、全天时动态监测, 同时对生态环境和自然灾害的发展变化趋势进行预测, 对环境质量和灾害情况进行快速和科学的评估(王桥 & 王文杰, 2006; 王桥等, 2008)。

环境一号卫星的成功研制和发射标志着中国开始独立拥有具有中高空间分辨率、高时间分辨率、高光谱分辨率、宽观测带宽性能, 能综合运用可见



(a)　(b)　(c)

图 1　环境一号卫星示意图

(a) HJ-1A; (b) HJ-1B; (c) HJ-1C

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光、红外与微波遥感等观测能力的先进的环境遥感监测手段，也标志着中国通过构建天-地一体化的生态环境监测体系实现生态环境的大范围、全天候、全天时动态监测成为可能(王桥等, 2005)。

1.2 环境一号卫星有效载荷

环境一号卫星有效载荷包括宽覆盖多光谱可见光相机、超光谱成像仪、红外相机、S 波段合成孔径雷达，其主要技术指标如表 1—表 4。

2 环境一号卫星数据及其质量分析

2.1 环境一号卫星数据举例

环境一号 A/B 卫星发射后，环境保护部卫星中心立即开展了数据处理和应用评价工作，图 2—图 4 给出了对环境一号卫星第一批 CCD、红外和超光谱数据处理的结果，可真实的反映环境一号卫星数据在环境地物光谱特征、纹理特征和几何特征方面的基本状况。

表 1 宽覆盖多光谱可见光相机主要技术指标

指标	性能			
幅宽/km	360(2 台组合≥700)			
星下点地面像元分辨率/m	30			
谱段/μm	0.43—0.52	0.52—0.60	0.63—0.69	0.76—0.90
系统各谱段全视场的 MTF	≥0.20	≥0.20	≥0.20	≥0.14
动态范围/($W\cdot m^{-2}\cdot Sr^{-1}\cdot \mu m^{-1}$)	316/197	334/195	246/145	246/163
信噪比(*S/N*)/dB	≥48			
增益控制	每个谱段设置 2 档增益控制，各谱段分别可调			
中心像元配准精度/像元	±0.3			
量化值/bit	8			
定标精度	相对定标精度 5%，绝对定标精度 10%			

表 2 超光谱成像仪主要技术指标

指标	性能
幅宽/km	≥50
工作谱段/μm	0.45—0.95
平均光谱分辨率/nm	5
地面分辨率/m	100
侧向可视视场角/(°)	±30
谱段数	110—128
输出信号量化/bit	12
系统信噪比(*S/N*)	0.45—0.95μm 间，*S/N*: 50—100
动态范围/($W\cdot m^{-2}\cdot Sr^{-1}\cdot \mu m^{-1}$)	134
系统 MTF	≥0.2
辐射定标精度	相对定标精度 5%，绝对定标精度 10%

表 3 红外相机主要技术指标

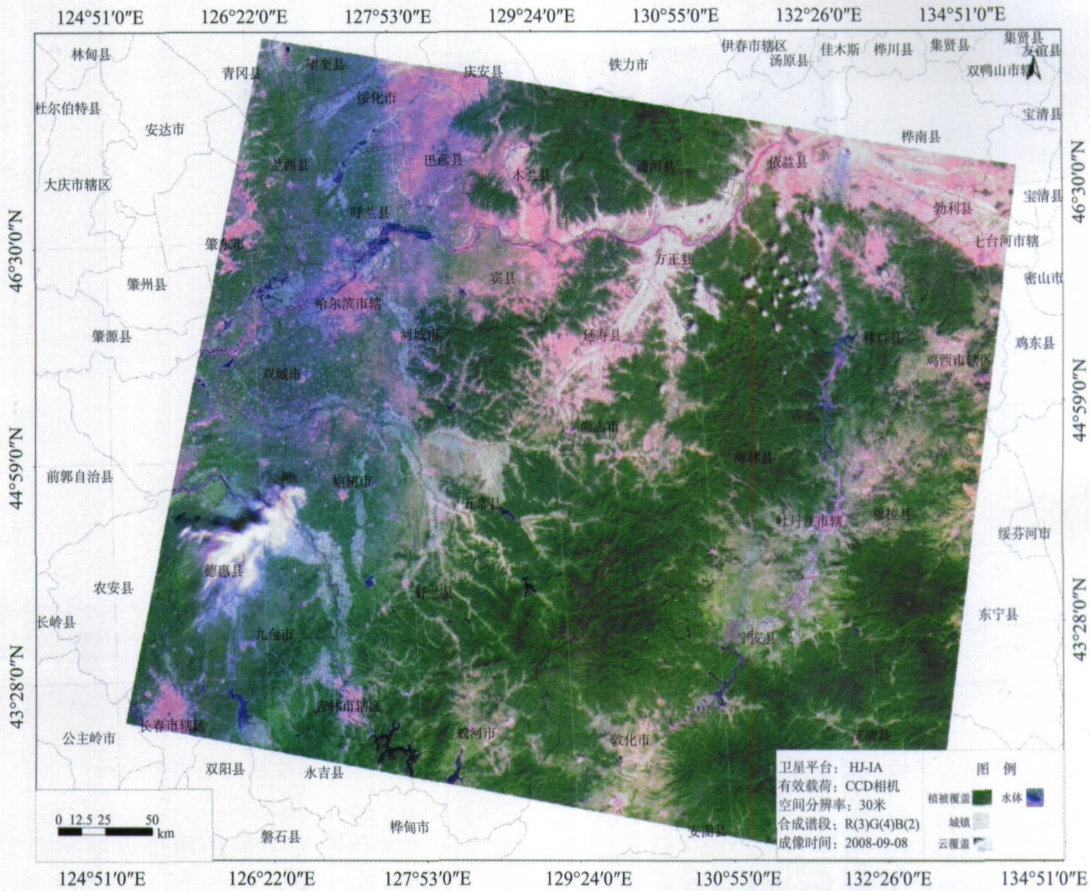
指标		性能			
幅宽/km		720			
星下点地面像元分辨率		300m(10.5—12.5μm), 150m(其他谱段)			
谱段/μm		0.75—1.10	1.5—1.75	3.50—3.90	10.5—12.5
MTF		≥0.28	≥0.27	≥0.26	≥0.25
辐射分辨率 $Ne\Delta\rho$或 $Ne\Delta T$		0.5%	0.5%	≤1K(@400K)	≤1K(@300K)
谱段辐射景	最大值	9.32mW/($cm^2\cdot Sr$)	0.89mW/($cm^2\cdot Sr$)	500K	340K
	最小值			300K	200K
定标精度		地面相对定标精度 5% 绝对定标精度 10%		星上定标精度 2K	
配准精度/像元		±0.3			
量化比特数/bit		10			

表 4 S 波段合成孔径雷达主要技术指标

指标	性能
极化方式	垂直发射-垂直接收(VV)
谱段	S 波段
分辨率/幅宽	SCAN 模式: 15—25m/95—105km(距离向 4 视，方位向单视), 条带模式: 4—6m/35—40km(单视)
辐射分辨率/dB	3
最小有效散射面积σ0/dB	−18
辐射稳定度/dB	单景内≤0.6
动态范围/dB	≥30
BAQ 量化值/bit	3

2.2 环境一号卫星数据质量分析

环境一号卫星在轨测试期间，中国资源卫星中心和环境保护部卫星环境应用中心从几何精度和辐射精度等多个方面对卫星数据质量进行了分析，采用评价指标包括灰度均值、灰度方差、角二阶矩、对比度、相关性系数、清晰度、熵、信息容量、细节能量、边缘能量和功率谱等。综合评价结果表明：环境一号卫星 CCD 各波段在默认增益状态下的能量偏低，但各波段间的均衡性较好；在图像灰度分布层次方面，DN 范围较为集中，各波段的灰度范围较窄；波段间信息冗余方面，HJ-1A CCD1 和 HJ-1B CCD2 的相关性较好；纹理方面，角二阶矩偏大，图像纹理较粗，但图像较平滑，同时各波段的纹理差别较大，一般按波段顺序呈递减趋势；细节信号与信息容量方面，各波段的对比度总体上较好，但熵值较低；图像清晰程度方面，图像的清晰度和功率谱较好；边缘信号方面，表现良好。总之，CCD 数据的能量偏低，但各波段能量表现均衡，辐射质量(熵值、纹理、细节能量等)各项指标均表现良好。对于



环境保护部环境卫星中心筹备办公室制作

图 2　环境一号卫星 CCD 相机数据举例(东北地区生态环境遥感监测影像图)

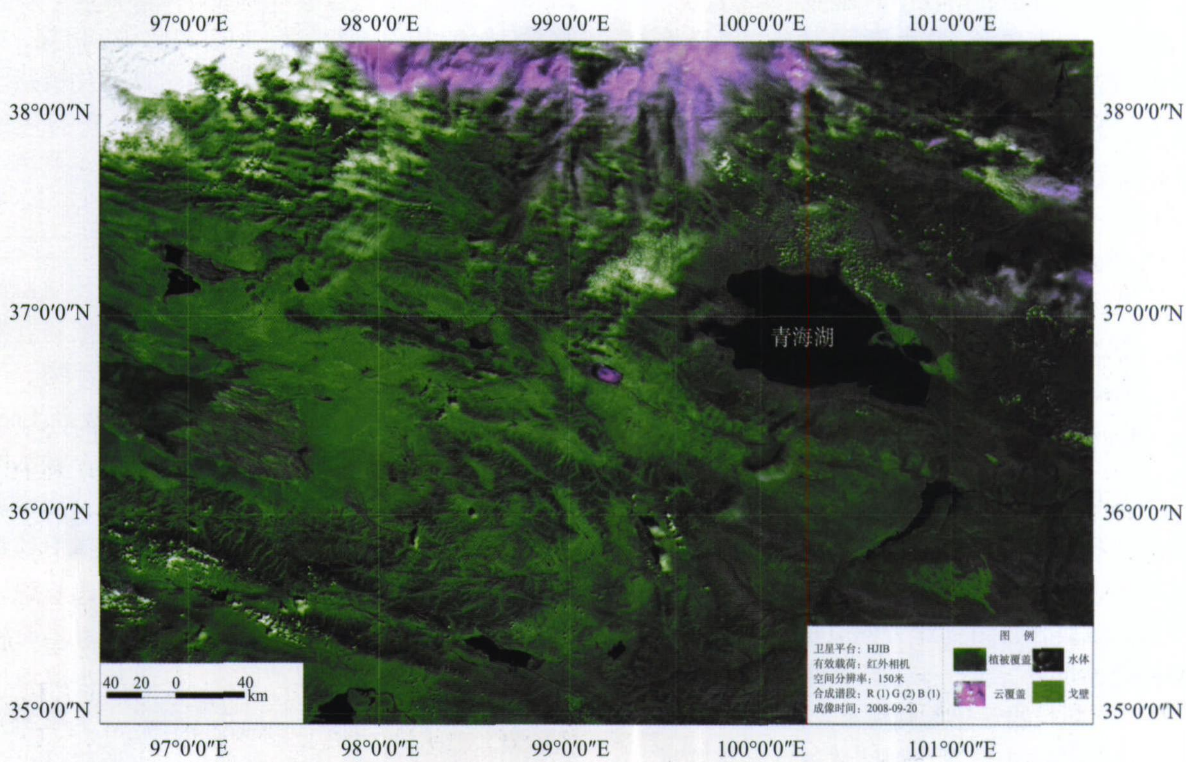


图 3　环境一号卫星红外相机数据举例(青海湖地区生态环境遥感监测影像图)

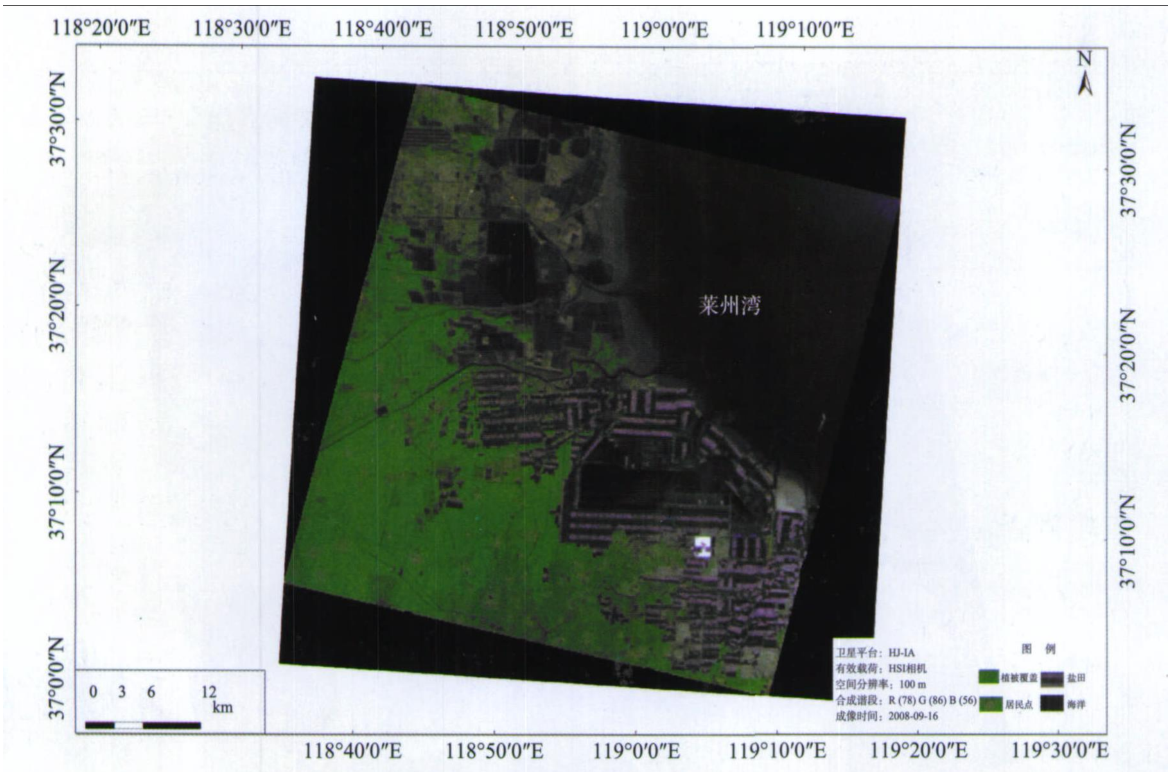


图 4 环境一号卫星超光谱相机数据举例(山东莱州湾地区生态环境遥感监测影像图)

红外相机DN值均较稳定，且属正常范畴；能量、灰度分布层次以及清晰度等各项指标表现良好，且较为稳定；对于超光谱数据，重点对典型的10, 39, 68, 103四个波段进行测试，结果表明DN均值和方差基本呈递减的趋势，纹理基本趋于稳定，第10、103波段的变化较大；对于方差较小的地物，其对比度、清晰度、能量等指标较低，其中第10波段常常会出现相关性很低的情况，而且其角二阶矩常常与其他波段的值相差较大，总之，第39、68、103波段较为理想，辐射质量表现良好，第10波段效果欠佳。因此总体上环境一号卫星数据质量比较稳定，基本达到了设计指标要求。

3 环境一号卫星应用需求

3.1 区域环境空气质量遥感监测

从国家生态环境监测任务角度看，环境一号卫星应用需求目前主要体现在区域环境空气质量卫星遥感监测、大型水体环境质量卫星遥感监测和宏观生态环境卫星遥感监测3个方面。在区域环境空气质量卫星遥感监测方面，一是城市环境空气质量监测，以可吸入颗粒物遥感监测为重点，对长三角、珠三角、京津冀等城市群及典型区域进行遥感监测、预警和评价；二是酸雨和二氧化硫污染监测，以重工业区二氧化硫和氮氧化物排放遥感监测为重点，对大中城市及其近郊、酸雨污染严重和大气二氧化硫浓度不达标地区及大型燃煤电厂建设进行遥感监测、预警和评价；三是工业废气污染源监测，以二氧化硫排放量较大的6000多家国控重点污染源监测为重点，对工业废气污染源进行遥感监测、预警和评价；四是温室气体监测，以二氧化碳、甲烷、臭氧等温室气体遥感监测为重点，对全球变化敏感区域与敏感生态系统的环境空气质量变化进行遥感监测、预警和评价。

3.2 大型水体环境质量卫星遥感监测

大型水体环境质量监测是目前国家环境监测工作的重点。卫星遥感监测方面，一是流域和近海海域水污染监测，以大型水体叶绿素、悬浮物、可溶性有机物、水温、透明度等遥感监测为重点(Lee 等, 2007)，对淮河、海河、辽河、松花江、三峡水库库区及上游、黄河小浪底水库库区及上游、南水北调水源地及沿线、太湖、滇池、巢湖以及渤海等重点海域和河口地区水环境质量进行遥感监测、预警和评价；二是饮用水源区环境监测，利用卫星遥感技术协助划定饮用水源保护区，开展饮用水源地环境状况遥感调查；开展水源地水土保持、水源涵养、面源污染遥感监测；对水源保护区上游建设水污染严重的化工、造纸、印染等类大型企业群进行遥感

动态监控；三是工业废水排放监测方面，以沿江沿河的化工企业为重点，对有毒有害物质的工业污染源及工业污水排放口进行动态遥感监控。

3.3　宏观生态环境卫星遥感监测

在宏观生态环境卫星遥感监测方面，一是区域生态环境监测，以生物物理参数、地表遥感参数、生态评价因子、生态分类要素等监测为重点，开展区域生态环境遥感调查，动态反映区域土地覆盖、生态组分、生态结构、生态功能、生态退化、生物多样性等时空变化；对国家自然保护区、重点生态功能保护区(重要水源涵养区、洪水调蓄区、防风固沙区、水土保持区、重要物种资源集中分布区等)等重点地区和重点生态问题进行动态监测；二是国家生态安全预警，主要是对资源开发活动引起的地表植被破坏、水土流失、土地退化、草原沙化等生态环境变化进行动态监控与评估；对生态脆弱区、生态交错带、生态敏感区的类型、空间分布、生态系统服务功能的变化、主要生态环境问题进行监控和预警；对国家重大工程和重大开发项目(如三峡工程、南水北调工程、青藏铁路工程等)的环境影响进行动态监控和评估；三是区域生态环境质量评价，主要从生态安全、生态系统健康、生态环境承载力等方面对区域和流域生态环境质量进行综合遥感评估；对全国重点区域、重要生态功能区、自然保护区生态变化趋势进行预警，及时反映生态安全状况及变化趋势；四是农村生态环境质量监测，主要开展土壤污染现状遥感调查与评价，针对不同土壤污染类型，选取有代表性的典型区(污灌区、固体废物堆放区、矿山区、油田区、工业废弃地等)开展遥感宏观监测；对农产品产地环境变化进行遥感监控；开展重点流域、区域农村面源污染遥感调查，摸清农村面源污染负荷及特征；开展农产品生产基地和生产加工企业周边地区的环境变化遥感监测。五是国家生态保护治理工程效果监测，主要对天然林保护、天然草原植被恢复、退耕还林、退牧还草、退田还湖、防沙治沙、水土保持和防治石漠化等生态治理工程进行动态监控；六是环境灾害与环境污染事故监测，对突发性环境灾害与事故(如沙尘暴、洪涝、地震、火灾、赤潮、溢油、水华、热污染、富营养化状况、水质性缺水等)等进行应急监测和跟踪，动态反映环境污染事故的分布、种类、范围、面积、程度等时空变化、预警和预测其发展趋势。

4　环境一号卫星业务应用方案

4.1　总体业务流程

环境一号卫星在环境监测中应用的业务流程总体上分为数据获取与处理、环境信息反演、分析评价、生产发布 4 个阶段(图 5)。

首先根据环境遥感监测业务需要，获取环境一号卫星数据、其他卫星遥感数据、基础地理空间数据、环境背景数据、地面环境监测数据和社会经济数据等，并对其进行数据处理，包括图像辐射校正、几何校正、图像融合、图像镶嵌、图像增强、图像变换和图像解译等(Gordon, 1997)，形成环境遥感监测基本数据产品；在此基础上进行环境特征信息提取及监测指标反演，包括区域环境空气质量遥感监测信息、大型水体环境质量遥感监测信息、生物物理参数和地表物理参数遥感信息、自然生态环境遥感监测信息等(Gordon 等, 1994; Jiménez-Munoz & Sobrino, 2003)，由此形成环境遥感监测专题数据产品；然后针对环境保护工作需要，结合地面环境背景和环境监测数据，对生态环境质量、环境空气质量和地表水环境质量进行遥感分析与综合评价，形

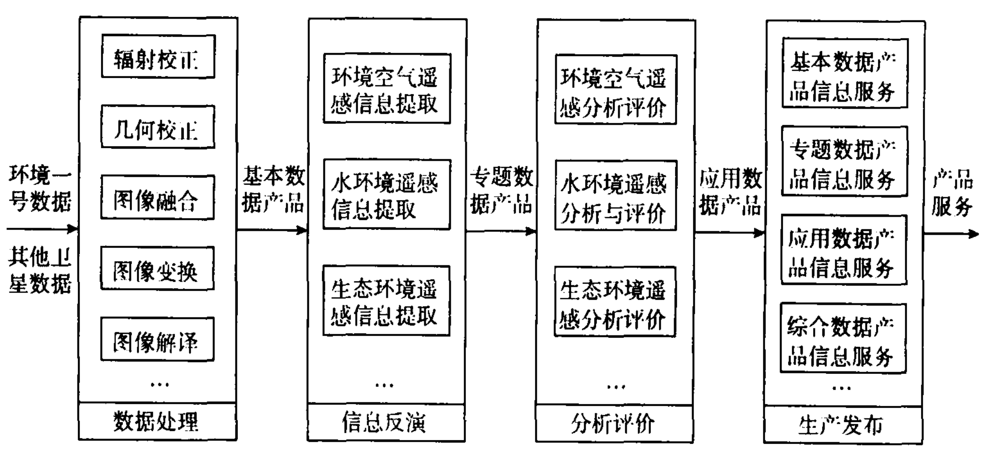


图 5　总体业务流程图

表 5 环境一号卫星业务应用数据产品方案

产品名称			产品基本说明
原始数据			卫星下行接收得到的原始码流数据文件
0 级数据			经过解压缩、帧同步、格式化处理后的原始数据
标准数据产品	0 级	0 级数据产品	0 级数据经分幅处理后得到的标准景数据产品
	1 级	系统辐射校正产品	基于光学传感器 0 级产品，进行谱段间的配准校正和系统辐射校正后的产品
		SAR 地理参考产品	在雷达传感器 0 级产品的基础上，经成像处理等步骤，形成的地理参考产品，包括单视复型(SLC)影像产品和单视地理参考图像(条带模式)；多视(MLC)影像产品和多视地理参考产品(条带和扫描模式)
	2 级	系统几何校正产品	基于光学传感器 1 级产品，经系统几何校正后的产品 基于雷达传感器 1 级产品，经系统几何校正处理，形成具有地图投影的图像产品，包括条带模式产品和扫描模式产品
高级数据产品	3 级	几何精校正产品	基于 2 级产品数据，利用卫星精轨数据和地面控制点，对图像进行几何精校正后的产品
	4 级	正射校正产品	基于几何精校正产品，利用卫星精轨数据、地面控制点和地面高程模型进行几何精校正后的产品
	5 级	图像加工数据产品	基于几何精校正产品，利用常用的图像处理方法(镶嵌、融合、滤波、锐化等)对图像进行处理后的产品
专题数据产品	6 级	土地利用与生态分类数据产品	基于土地利用和生态系统分类体系，利用自动分类与人工判读相结合方法生产的土地利用与生态系统分类产品
		生物物理参数产品	植被指数、叶面积指数、初级生产力等数据产品
		地表物理参数产品	地表蒸散量、土壤含水量、地表反射率等数据产品
		景观生态指数产品	景观破碎度产品、景观丰富度指数产品、景观优势度指数产品、生物丰度指数等各种产品
		水环境遥感监测专题产品	叶绿素、悬浮物、透明度、水温等数据产品
		环境空气遥感监测专题产品	气溶胶光学厚度、水汽含量、可吸入颗粒物等数据产品
应用数据产品	7 级	生态遥感应用产品	生态遥感监测与评估的各类应用产品
		地表水环境遥感应用产品	地表水环境遥感监测与评估的各类应用产品
		环境空气遥感应用产品	环境空气遥感监测与评估的各类应用产品

成环境遥感监测应用数据产品；最后经过与地面数据综合分析、制图、报告编写等生产出环境一号卫星综合数据产品，通过网络等方式对外发布，为各类用户提供基本数据产品、专题数据产品和应用数据产品等综合信息服务。

4.2 业务应用数据产品

根据环境一号卫星的特点和中国环境监测业务工作的实际需要，将环境一号卫星数据产品分为 9 个级别，即原始数据、0 级数据产品、1 级数据产品(系统辐射校正产品)、2 级数据产品(系统几何校正产品)、3 级数据产品(几何精校正产品)、4 级数据产品(正射校正产品)、5 级数据产品(图像加工数据产品)、6 级数据产品(专题数据产品)、7 级数据产品(应用数据产品)。其中 7 级数据产品是直接面向业务应用综合报告，从产品内容上集监测、分析、评价于一体，从产品形式上集遥感图、专题图、统计图和文字报告于一体。业务应用数据产品具体方案如表 5。

5 环境一号卫星业务应用示范举例

5.1 基于环境一号卫星的京津塘地区气溶胶光学厚度反演

采用 2008-09-20 的 HJ-1 A 星轨道号分别为(2, 64)、(1, 68)、(453, 65)、(453, 69)的 4 景数据，对京津塘地区气溶胶光学厚度进行监测，其技术路线及监测结果如图 6—图 8(Remer 等, 2006)。

使用 2008-09-20 的 MODIS 气溶胶产品与 HJ-1 A 星监测结果进行比对，将图像经过镶嵌处理，统一投影等经纬度投影，并重采样为同一分辨率(图 9、图 10)。共获得 486 个比对点，绝对误差为 0.104，均方根误差为 0.148，相关系数为 0.890。由于 MODIS 气溶胶算法比较成熟，上述比对结果在一定程度上说明 HJ-1 A 星获得的气溶胶产品的可靠性(Liou, 2002; Bendix 等, 2003)。

5.2 基于环境一号卫星的巢湖叶绿素 a 浓度反演

采用 2009-06-04 HJ-1B 数据对巢湖叶绿素 a 进行监测。其技术路线及监测结果如图 11、图 12。监

测结果表面约 29.19%水域处于 3 级水平，约 43.87%水域处于 4 级水平，5 级水域面积比例为 24.73%。西北部沿岸水域发生水华，水华面积为 35.72 平方公里，占水体总面积的 4.69%。西部水域叶绿素 a 浓度高于东部水域，近岸水域叶绿素 a 浓度高于湖心水域。总体平均 39.73mg/m^3。

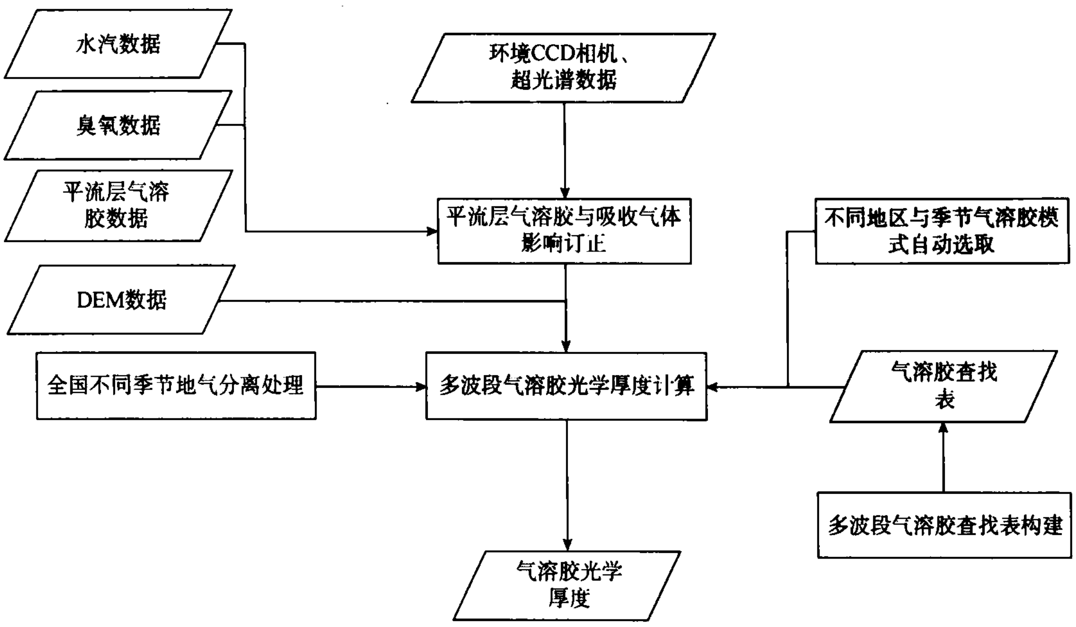


图 6　基于环境一号卫星的气溶胶光学厚度反演流程

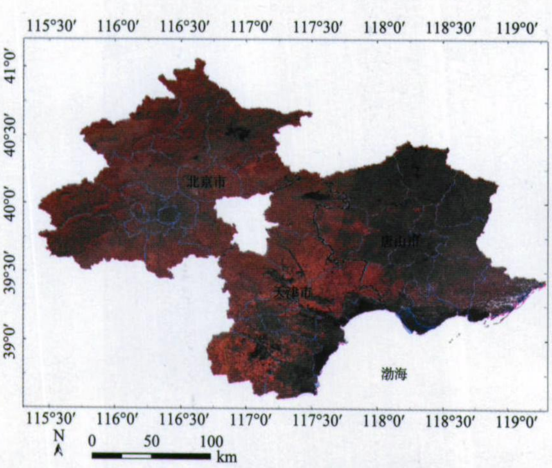


图 7　HJ-1A 京津塘地区 CCD 假彩色合成图 (2008-09-20)

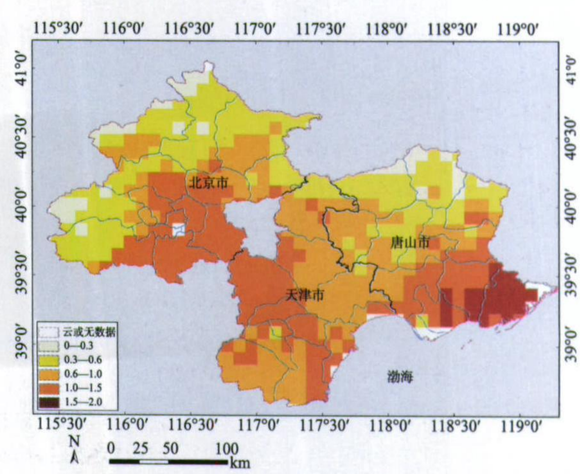


图 9　重采样后 HJ-1A 气溶胶监测图 (2008-09-20)

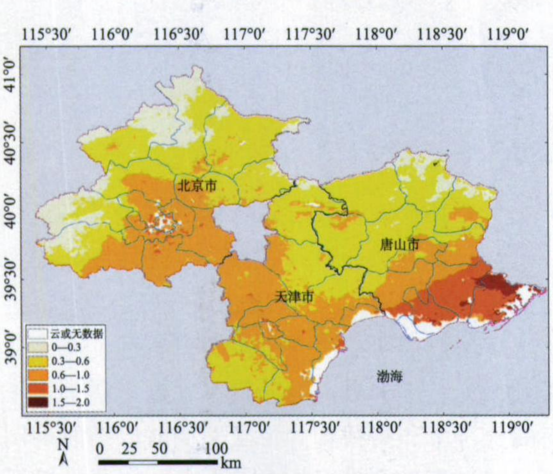


图 8　基于 HJ-1A 的气溶胶光学厚度图 (2008-09-20)

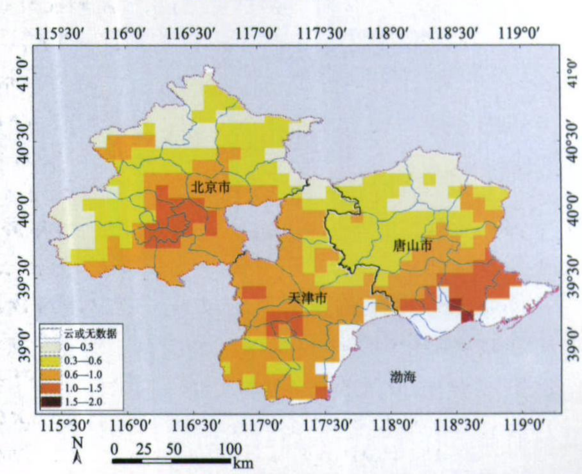


图 10　MODIS 气溶胶监测图 (2008-09-20)

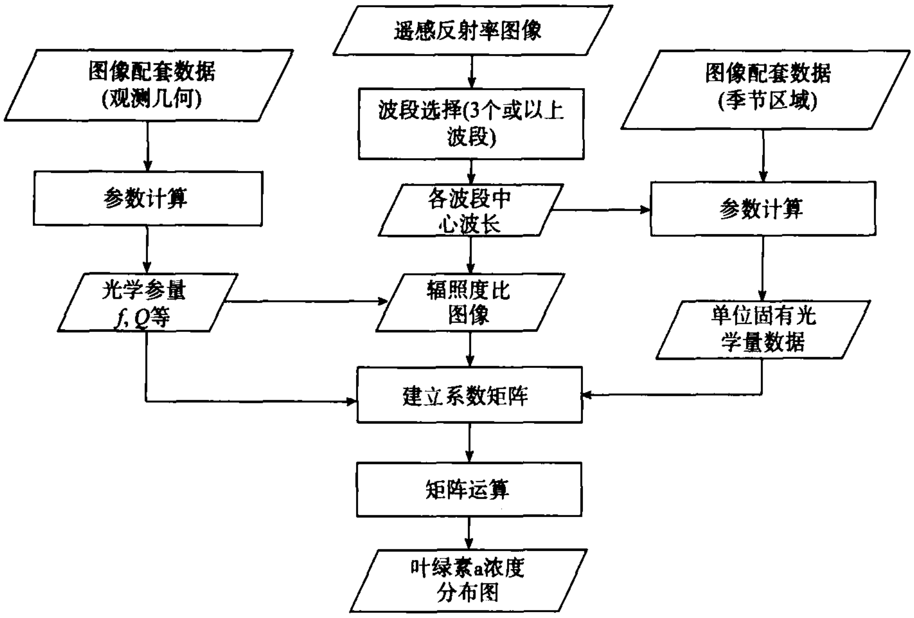


图 11 基于环境一号卫星的叶绿素 a 反演流程

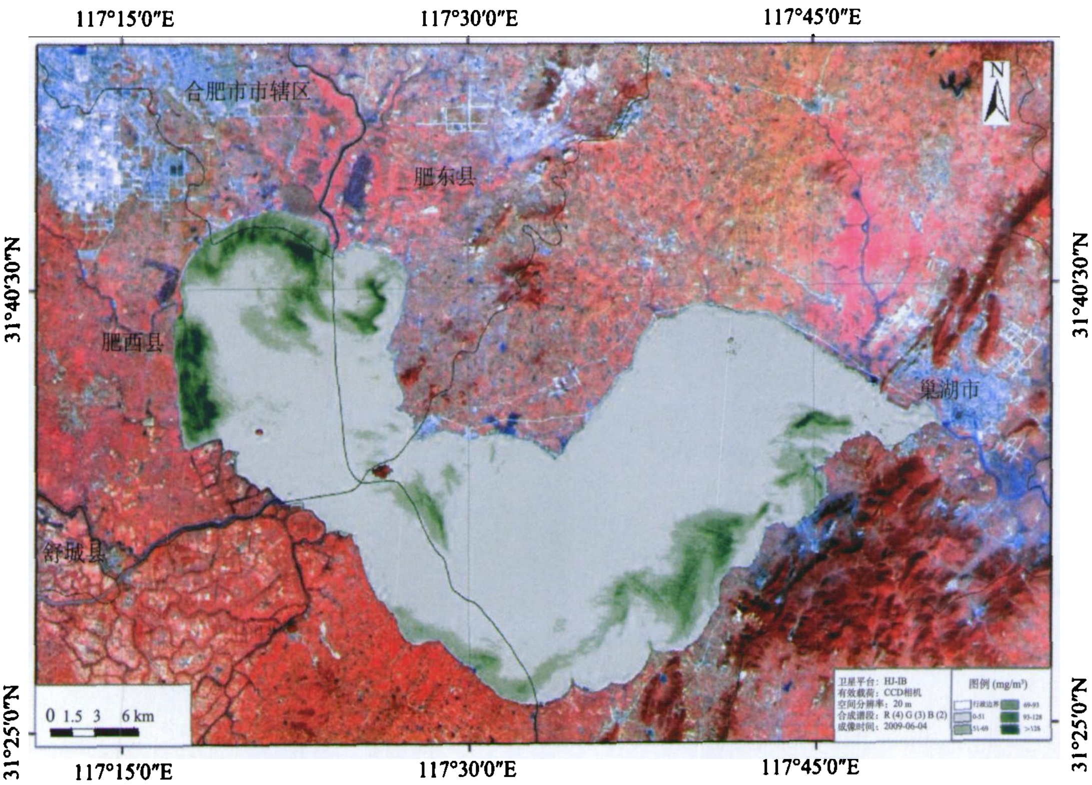


图 12 基于环境一号卫星的 2008 年 11 月巢湖叶绿素 a 浓度反演

6 结 语

环境一号卫星的发射和成功应用标志着中国环境监测跨入了“天-地一体化”的时代，但总体上中国环境遥感事业还处于起步阶段，从环境卫星有效载荷研制、环境遥感关键技术研究到环境应用业务系统建设还存在一定的问题，近期我们将进一步构建由 4 颗光学星和 4 颗雷达星组成的环境二号卫星“4 + 4”星座，研发多模式的偏振多光谱环境成像仪、可编程高光谱水环境成像仪，红外高光谱大气环境成像仪、多极化 C 波段合成孔径雷达，以进一步满足环境监测所需的多谱段、多特性、全天时、全天候、大范围、高空间分辨率、高光谱分辨率、高时间分辨率和高精度等要求。同时以新时期国家环境遥感动态监测信息服务为目标，完善环境遥感数据处理、信息产品生产与服务技术体系，攻克水、

大气和生态环境遥感参数定量反演关键技术，发展环境遥感监测与评价方法，加快建设基于环境卫星等国产卫星的环境遥感动态监测信息服务系统，加大重要流域水环境、区域大气环境、重要生态功能区和自然保护区等的环境遥感监测应用示范的力度，尽快形成中国天-地一体化的环境监测业务化运行技术体系。

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