# Overview of FY-3 Payload and Ground Application System

Zhongdong Yang, Naimeng Lu, Jinmin Shi, Peng Zhang, Chaohua Dong, and Jun Yang

***Abstract*—The payload on board the FengYun 3 (FY-3) satellite series has been providing critical observations to the Earth, and the observation data have been processed and distributed to various users by the corresponding ground application system. In this paper, the FY-3 payload and its future development plan are presented, and its ground system is introduced. The major characteristics of the FY-3 instruments and the requirement on the instruments for major applications are discussed as well. There are nine new instruments, including the Microwave Temperature Sounder (MWTS), Microwave Humidity Sounder (MWHS), Infrared Atmospheric Sounder (IRAS), Medium-Resolution Spectral Imager (MERSI), Microwave Radiation Imager (MWRI), Solar Backscatter Ultraviolet Sounder, Total Ozone Unit, Solar Irradiation Monitor, and Earth Radiation Measurement. The data quality from the IRAS, MWTS, MWHS, and MWRI has proved to be good, and according to our evaluation at the European Centre for Medium-Range Weather Forecasts (ECMWF), the data have a very high availability. The MERSI has 20 visible (VIS) and infrared (IR) channels, of which three are VIS channels with a 250-m spatial resolution, one is a near-IR channel with a 250-m spatial resolution, and one is a long-wave IR channel with a 250-m spatial resolution. The global data at a 250-m spatial resolution are very useful in weather, disaster, and environmental monitoring. Compared with the ground observations, the ozone products derived from the FY-3 series are highly accurate. We have completed the calibration and validation of these sensors and most products.**

***Index Terms*—FengYun 3 (FY-3), ground application system, remote sensor.**

## I. Introduction

On MAY 27, 2008, and November 5, 2010, the China Meteorological Administration sequentially launched two of its second-generation polar-orbiting environmental and meteorological satellites under the FengYun 3 (FY-3) series. The first one is referred to as FY-3A, and the second is referred to as FY-3B. With the capability to provide global, all-weather, multispectral, 3-D, and accurate observations of atmospheric, oceanic, and land surface states, the FY-3 satellite series can make valuable contributions to improving weather forecasts and natural-disaster and environmental monitoring in China, the rest of Asia, and the whole world.

Manuscript received November 16, 2011; revised February 22, 2012; accepted March 24, 2012. Date of publication May 30, 2012; date of current version November 22, 2012. This work was supported in part by the National Development and Reform Commission, China, and in part by the Ministry of Finance.

The authors are with the National Satellite Meteorological Center, China Meteorological Administration, Beijing 100081, China (e-mail: yangzd@cma.gov.cn).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TGRS.2012.2197826

Both FY-3A and FY-3B have 11 sensing instruments on board. These instruments are the Visible and InfraRed Radiometer (VIRR), Medium-Resolution Spectral Imager (MERSI), Infrared Atmospheric Sounder (IRAS), Microwave Temperature Sounder (MWTS), Microwave Humidity Sounder (MWHS), Microwave Radiation Imager (MWRI), Solar Backscatter Ultraviolet Sounder (SBUS), Total Ozone Unit (TOU), Solar Irradiation Monitor (SIM), Earth Radiation Measurement (ERM), and Space Environment Monitor (SEM). Using these sensing instruments to gather observational data, FY-3 satellites have made valuable contributions to weather forecasting, particularly to numerical weather prediction (NWP), as well as severe weather warning and environmental monitoring [1], [2].

FY-3A/B's atmospheric sounding instrument package is composed of the IRAS, MWTS, and MWHS. Combined with FY-3's other optical and microwave instruments, it has obtained global vertical temperature and humidity soundings, having effectively filled the gaps in the conventional radiosonde ground observations in desert and marine areas. The root-mean-square error of FY-3B atmospheric temperature profiles is 2–3 K, while the average deviation of FY-3B atmospheric humidity profiles is $\pm 8\%$ within a standard deviation of 20%–30%. These profile products are obtained from FY-3B's IRAS, MWTS, and MWHS package using a statistical inversion method. The error rate is referenced in an FY-3 ground-application-system operational technique report (interior) that is validated by radiosonde data.

The application of meteorological satellite data assimilation in NWP can greatly improve the accuracy of weather forecasts. Based on the ECMWF NWP platform, we evaluated the quality and the availability of data from the FY-3 atmospheric sounder suite and MWRI. The results showed that the data from the four instruments in FY-3 meet the requirements for application in NWP assimilation, and preoperational testing has shown that the FY-3A data deliver measurable positive forecast improvements in the ECMWF model [3]. The sounder data quantify that more improvements in the FY-3 series will be realized in FY-3D, which is expected to be launched into afternoon orbit in the middle of 2015.

Typhoons are one of the main weather events that considerably impact China's eastern coasts in summer, sometimes causing very severe damage to life and property. "Sanda" was the first severe typhoon (on May 21, 2011) in the Pacific Northwest. Based on FY-3B's MWRI data, the structure of the typhoon rainfall distribution was successfully retrieved and used in estimating the typhoon precipitation and intensity, as well as in forecasting its path (see Fig. 1).

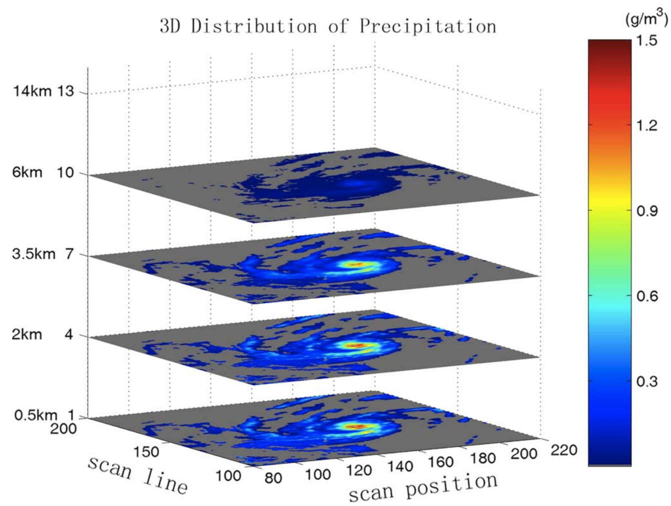


Fig. 1. Three-dimensional distribution of precipitation of "Sanda" from FY-3B/MWRI (Provided by Hu Yang).

In spring 2011, a strong low-ozone event happened over the Arctic region that was clearly revealed by FY-3A/B's TOU and SBUS products. The mean and the maximum ozone contents decreased by 100 and 193 DU, respectively, in March over the Arctic from the upper troposphere to the stratosphere (10–100 hPa), and the magnitudes of change were 83% and 77% compared to the corresponding period in the previous years. The low center of the area's daily average total ozone was about half over the same period in many past years [4] (see Fig. 2).

This paper gives an overview of the mission of the FY-3 satellite series, the FY-3 spacecraft and payloads, the plans for future FY-3 satellites, and the FY-3 ground application system.

## II. Missions of the FY-3 Satellites

The FY-3 satellite series has three missions, involving weather forecasting, climate monitoring, and natural-disaster monitoring. The first entails obtaining global temperature and humidity profiles and cloud, radiation, and other meteorological parameters to improve the accuracy of weather forecasts, particularly that of NWP products. The second involves global climate monitoring, including radiation balance, snow cover, sea surface temperature, greenhouse gases, and ozone monitoring for short-term climate-prediction research. The third entails global remote sensing and monitoring of natural, ecological, and environmental disaster events.

The FY-3 series as the Chinese second-generation polar-orbiting meteorological satellites aims to achieve the operational level. We will make FY-3 satellite applications that are stable and reliable, by using products with known quantitative precision, providing information that can be openly shared and establishing services that are efficient and of good quality.

NWP is the backbone of modern weather forecasting. The influence of and restrictions in the accuracy and timeliness of forecast products lie in the precision with which the initial fields of physical and chemical atmosphere processes are described. The FY-3 remote-sensing data include information on wind, temperature, humidity, clouds, precipitation, and aerosols, as well as other related information on the atmospheric state. The observations are critical for improving precision in the initial fields of numerical prediction.

Climate change leads to changes in the survival conditions for humans. Observations and studies have shown that carbon dioxide ($CO_2$), methane ($CH_4$), and other greenhouse gases, as well as ozone ($O_3$) and aerosols, are the key factors affecting climate change [5]. Using the future FY-3-satellite remote-sensing tools will be an effective way to make continuous observations and assessments of sensitive factors of global climate change. Capabilities for the operational monitoring of greenhouse gases can provide an objective scientific basis for understanding and grasping the truth regarding climate changes.

There are many kinds of disasters with a wide geographic distribution and a high frequency in China, usually causing serious economic losses. "China's Mitigation Actions" (May 2009) [6] clearly points out that one of the main tasks for disaster prevention and mitigation in China is to build monitoring satellite remote-sensing systems and form a 3-D natural-disaster-monitoring system. As the main means of monitoring weather disturbances and their consequent disasters, FY-3 satellites play an irreplaceable role, particularly when it comes to macro dynamic large-scale natural disasters associated with events like typhoons, storms, floods, droughts, snow, dust storms, and fog, as well as agriculture, forestry, marine, ecological, and environmental disasters. The monitoring of vegetation, drought, and crop growth requires meteorological satellite remote-sensing data. The multispectral data provided by FY-3 satellites at a global spatial resolution of 250 m are critical to the remote sensing of global vegetation dynamics, crop growth, and yield assessment of the world's major food crops. With the rapid economic and social development, the application of agricultural monitoring and assessment models will require satellite remote sensing of more types of agricultural products.

## III. FY-3 Satellites and Their Payloads

### A. Spacecraft

FY-3 satellites are sun-synchronous polar-orbiting environmental meteorological satellites with an orbit altitude of about 830 km. FY-3A is in a morning orbit, while FY-3B is in an afternoon orbit. Each satellite occupies a hexahedron-shaped volume of $4.4\ m \times 2.0\ m \times 2.0\ m$ (see Fig. 3) and has a total weight of about 2500 kg. A solar panel is mounted on one side of the main satellite body, making the span length of the satellite about 10 m in flight. The attitude control of the satellite is three-axis stabilized with a measuring precision of 50 m using two onboard star sensors. Table I presents the major orbital parameters of the satellite.

The links of the spacecraft communications system are at the S-, L-, and X-bands. Commands are via the S-band only. Command and telemetry links are active simultaneously. The S-band section of the communications subsystem provides primary telemetry and command service to and from the FY-3 ground stations. The L- and the two X-band sections of the communication subsystem provide the downlinks of

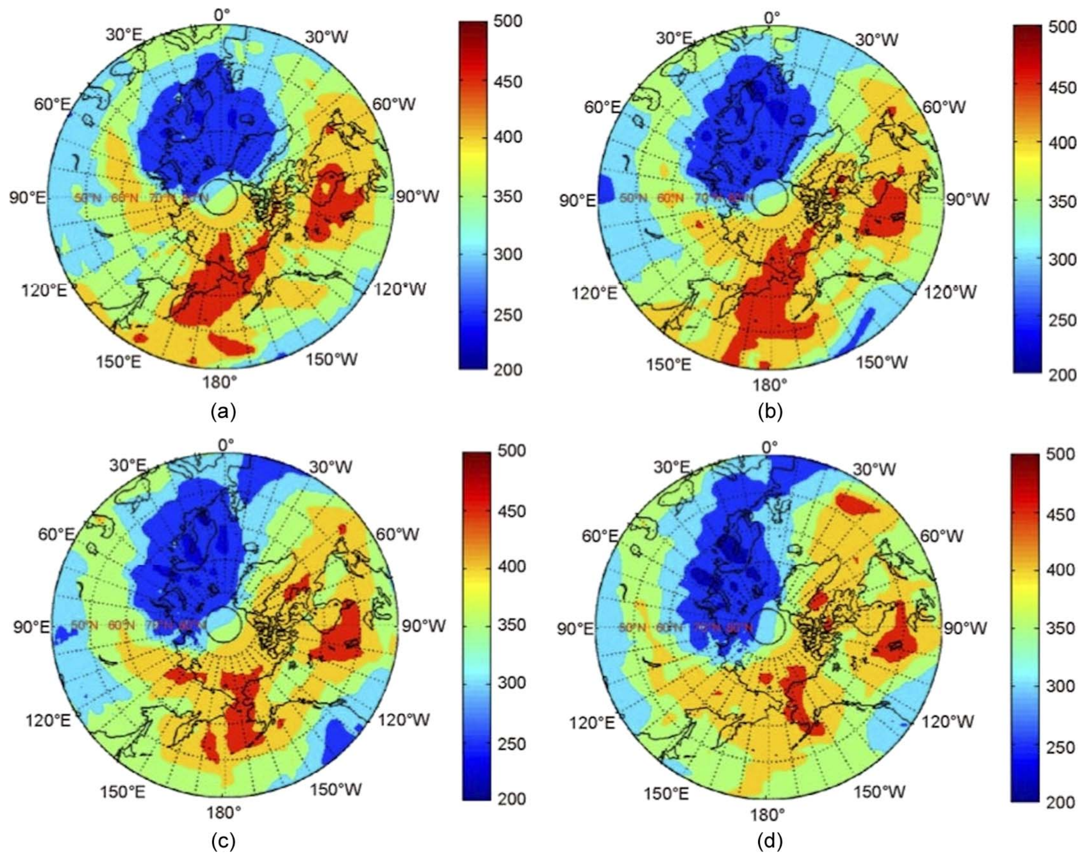


Fig. 2. Movement of the area of ozone reduction at the North Pole during March 28–31, 2011 (Dobson Units; provided by Fuxiang Huang; (a)–(d) refer to March 28–31, respectively).

scientific and engineering data for the FY-3 common spacecraft. Users around the world can directly receive data from the MERSI and the other instruments on the spacecraft in real time. The downlink of satellite scientific data follows the space data system standards offered by the Consultative Committee for Space Data Systems, which makes the FY-3A/B data format compatible with other meteorological operational satellite data transmissions. Table I shows a summary of the primary FY-3A/B spacecraft and its orbital characteristics.

### *B. FY-3A/B Payload*

There are 11 instruments on FY-3A/B, including three sounding instruments (one optical and two microwave sensors), two ozone instruments, two earth radiation budget instruments, three imaging remote sensors (one microwave and two optical instruments), and one space environment monitoring unit. The payload has nearly 100 remote-sensing channels in the spectral range, from ultraviolet to visible (VIS), infrared (IR), and microwave. Table II presents the primary payload characteristics of FY-3A/B.

*1) Sounding-Instrument Suite:* The IRAS is the primary sounder on FY-3A/B. It is a High-Resolution Infrared Radiation Sounder (HIRS)/3-like instrument but with a total of 26 channels. The first 20 channels are almost the same as the HIRS/3, while the other six enable the IRAS to measure aerosols, carbon dioxide content, and cirrus. The IRAS instantaneous field of view (IFOV) is 17 km at nadir. Its products include atmospheric temperature profiles, atmospheric humidity profiles, and outgoing long-wave radiation.

The MWTS is a four-channel passive scanning microwave sounder capable of temperature sounding in cloudy regions. It has four channels around 50 GHz. Its products are atmospheric temperature profiles and surface emissivity.

The MWHS is similar to the Advanced Microwave Sounding Unit-B and has the primary purpose of moisture sounding in cloudy regions. The MWHS has five higher frequency channels (150–183 GHz), with the 150-GHz channel polarized in both vertical and horizontal directions. The MWHS has a nominal IFOV of 15 km at nadir. Its products are atmospheric humidity profiles and precipitation intensity and cloud-ice-water thickness.

The IRAS, together with the MWTS and MWHS, provides global atmospheric temperature and moisture profiles in all weather conditions for global NWP models and climate data records.

*2) Ozone-Instrument Suite:* Two of the instruments on board FY-3A/B, the SBUS and the TOU, are new sensors for measuring atmospheric ozone distribution. The TOU is a six-channel spectrometer with wavelengths from 308 to 360 nm and a resolution of 50 km at nadir. The profiler SBUS is a 12-channel spectrograph with wavelengths ranging from 252 to 380 nm. The spatial resolution of the ozone profile is around 200 km at nadir. The typical products of the SBUS and TOU are global vertical ozone profiles and total column ozone.

Fig. 3. FY-3 spacecraft before it was launched.

*3) Earth-Radiation-Instrument Suite:* The ERM is like the Earth Radiation Budget Experiment instrument on board the National Oceanic and Atmospheric Administration satellites. It has separate wide-FOV and narrow-FOV observation units, each with two channels. The broadband channel covers the spectrum ranging from 0.2 to 50 $\mu$m, while the narrowband channel covers 0.2–4.3 $\mu$m. The ERM products are solar radiation flux and outgoing long-wave radiation flux.

The SIM provides long-term constant solar observations, offering reliable scientific data for studying variations in the solar energy output at various time scales. It has an irradiance measurement range of 100–1400 $W \cdot m^{-2}$, a spectral range of 0.2–50 $\mu$m, 0.2-$W \cdot m^{-2}$ sensitivity, and 0.5% calibration error rate. Its primary product is the solar constant.

*4) Imaging Instruments:* The VIRR is a commonly used instrument in the Multichannel Visible and Infrared Scanning Radiometer (MVISR), a ten-channel radiometer that makes operational observations on board the FY-1C/D satellites. For the purpose of risk reduction, an instrument similar to the MVISR is used on FY-3A/B. Its primary uses include recording the cloud amount, cloud classification, cloud physical properties, fog, fire spots, aerosols, outgoing long-wave radiation, snow/ice, sea surface temperature, land surface temperature, atmospheric precipitable water, surface albedo, vegetation index, leaf area index, and net primary productivity.

TABLE I
FY-3A/B SATELLITE SPECIFICATIONS AND MAJOR ORBITAL PARAMETERS

| | |
|---|---|
| Satellite Mass | ~2500 Kg |
| Launch Size | 4380mm×2000mm×2000mm (X.Y.Z Spacecraft coordinate) |
| Size in Flight | 4440mm×10000mm×3790mm (X.Y.Z Spacecraft coordinate) |
| Orbit type | Sun-synchronous orbit |
| Orbit altitude | 831Km |
| Orbit inclination | 98.81°/98.64° |
| Orbit period | 101.5 minutes |
| Orbital eccentricity | 0.00012/0.00013 |
| Revolutions/day | 14 |
| Quasi-repeat time | 5.5 days |
| Local time at Descending/Ascending point | 10:05/13:40 (UTC) |
| Remote sensing instruments (payloads) | VIRR, IRAS, MWTS, MWHS, MERSI, SBUS, TOU, MWRI, SIM, ERM, SEM. |
| Real time data transmission: | L band; QPSK modulation; Bit rate: 4.2 Mbps<br>X band; QPSK modulation; Bit rate: 18.7 Mbps |
| Delayed data transmission: | X band; QPSK modulation; Bit rate: 93Mbps |
| Onboard data storage | 144 Gbits |
| Atitude directing error rate | ≤0.3°(X,Y,Z Spacecraft coordinate) |
| Atitude measurement error rate | ≤0.05°(X,Y,Z Spacecraft coordinate) |
| Atitude stability | ≤0.008°/s (X,Y,Z Spacecraft coordinate) |
| Designed life | 3 years |

The MERSI is a spectral imaging sensor with medium resolution. It is similar to the Moderate Resolution Imaging Spectroradiometer on board the Earth Observing System satellite series except that it does not carry the mid-IR channels. The MERSI has 20 channels that are mainly located in the VIS and the near-IR (NIR) spectral regions, while the VIRR has the complementary IR channels. Five of the MERSI channels (four VIS and one thermal IR) have a spatial resolution of 250 m, which can be used to create a high-resolution imagery of the earth in natural color during the day and high-resolution thermal IR imagery during the night. The remaining MERSI channels have a spatial resolution of 1 km. The MERSI products record the land surface reflectivity, high-resolution vegetation index, land-cover types, ocean color, aerosols, and atmospheric precipitable water.

The MWRI is a conical scanning microwave imager at five frequency points with dual polarization (ten channels). This sensor can measure microwave emissions from land and ocean surfaces and various forms of water in the atmosphere, including cloud. The microwave imager with wavelengths longer than 1 mm in some channels can penetrate clouds and provides forecasters with all-weather measurements. At higher frequency channels, such as 89 GHz, the scattering signatures from clouds and precipitation are also good indicators for detecting rainfall over both land and ocean. The spatial resolutions are from 12 to 80 km, depending on the wavelength. The typical products of the MWRI are precipitation and cloud water, atmospheric precipitable water, sea surface temperature, soil moisture and temperature, and snow cover [7].

*5) Space Environment Monitoring Unit:* The SEM on board FY-3A/B is a modified version of the FY-1 space environment monitoring instruments, with improved accuracy and

TABLE II
PRIMARY PARAMETERS OF THE FY-3A/B PAYLOADS

| Pay-loads | Spectral range | Chan. Num. | Swath | Resolution@nadir | Quanti-zation | Primary use |
|---|---|---|---|---|---|---|
| IRAS | 0.69~15.5 um | 26 | ±49.5° | 17.0 km | 13 bit | atmospheric temperature profile, humidity profile, OLR. |
| MWTS | 50~57 GHz | 4 | ±48.3° | 50 km | 13 bit | atmospheric temperature profile |
| MWHS | 150~183 GHz | 5 | ±53.35° | 15 km | 14 bit | atmospheric humidity profile, |
| SBUS | 252~340 nm | 12 | / | 200 km | 12 bit | vertical ozone profile. |
| TOU | 309~361 nm | 6 | ±54.0° | 50 km | 12 bit | total ozone |
| ERM | 0.2~3.8 um<br>0.2~50 um | 2 | ±50.0° | 35 km | 16 bit | reflected solar radiation flux, OLR. |
| SIM | 0.2~50 um | 1 | / | / | 16 bit | Solar constant |
| VIRR | 0.44~12.5 um | 10 | ±55.4° | 1.1 km | 10 bit | Cloud,VI,snow,LST/SST, aerosols, LAI,etc |
| MERSI | 0.41~12.5 um | 26 | ±55.4° | 0.25~1.0 km | 12 bit | land surface reflectivity, high resolution vegetation index, land cover types, ocean color, aerosol, atmospheric precipitable water. |
| MWRI | 10.65~89 GHz | 10 | FY-3B,conical@ 45.0°<br>FY-3A,conical@ 45.4° | 9~85 km | 12 bit | precipitation and cloud-water, atmospheric precipitable water, sea surface temperature and wind speed, soil moisture and temperature,snow cover |
| SEM | 3.0~300.0 Mev;0.15~5.7 Mev | / | / | / | 10 bit | high-energy particle |

measuring capacity for high-energy particles. The SEM can effectively monitor the space environment and the charged particle flux, record impacts of space weather events on the satellite, and provide important data for space weather monitoring and warning. It maps the occurrence and location of high-energy particles.

### C. Visions and Strategies for Future FY-3 Satellites

The FY-3 series is intended to offer at least four operational satellites in the future (the FY-3C, D, E, and F), two in a morning orbit and two in an afternoon orbit, with a design life of five years. FY-3C will be launched into a morning orbit in 2013. This FY-3 morning-orbit satellite's missions are mainly earth surface imaging and atmospheric sounding, and its observational data are to be used in weather forecasting, as well as disaster, ecological, and environmental monitoring. The FY-3 afternoon-orbit satellite's missions are atmospheric sounding and climate-change monitoring, and its data are to be used in weather forecasting, atmospheric chemistry, and climate-change monitoring. FY-3D will be launched into an afternoon orbit in 2015. The FY-3 satellites' core capabilities are optical imaging observations at global medium resolution and atmospheric temperature and humidity sounding using both high-precision optical and microwave instruments, which are essential for weather forecasting and disaster monitoring. The two orbital satellites have the capability to make more complete and integrated earth observations.

FY-3 satellites will have four observational capabilities in the near future. The first is global optical imaging at a 250-m resolution, four times per day; the second is global atmospheric temperature and humidity sounding using high-precision optical and microwave instruments in combination; the third is atmospheric-composition sounding of greenhouse gases and other climate-change factors; and the fourth is high-precision wide-angle imaging of the aurora.

A new global 250-m-resolution optical imager, the MERSI-II, will be mounted on FY-3D/E/F. This version of the MERSI-I has enhanced capability, with 25 optical channels from 0.47 to 12.5 $\mu$m, 15 solar reflective channels, and ten IR channels. Six of these channels have a 250-m spatial resolution, including two IR split-window channels, three solar reflective channels, and one NIR channel. All other channels have a spatial resolution of 1 km. The MERSI-II will primarily be used in the remote sensing of land, cloud, aerosols, ocean color, atmospheric water vapor, and surface and cloud temperatures.

The high-precision atmospheric sounding units of the assembled optical and microwave instruments, the MWTS-II and MWHS-II, will be mounted on FY-3C/D/E/F and the high-resolution IRAS (HIRAS) on FY-3D/E/F. The MWTS-II and MWHS-II will enhance the capabilities of the MWTS and MWHS. The MWTS-II temperature sounding channels will be increased to 13, providing temperature information for more atmospheric layers. The MWHS-II sounding channels will be increased to 15, the 118-GHz band will be added to the original MWHS, and the MWHS-II will mainly be used in precipitation detection as well as atmospheric temperature and humidity sounding. The HIRAS is a new high-spectral-resolution sounding instrument made up of 650–1136-, 1210–1750-, and 2155–2550-cm$^{-1}$ spectral bands, with spectral resolutions of 0.625, 1.25, and 2.5 cm$^{-1}$, respectively. The respective channel numbers are 778, 433, and 159. The HIRAS's basic uses are the same as those of the IRAS, mainly for atmospheric temperature and humidity sounding, but the HIRAS can obtain more accurate sounding information with better vertical resolution.

The Greenhouse Gas Absorption Spectrometer (GAS) is a new VIS and NIR high-spectral atmospheric-composition sounding instrument composed of 0.76-, 1.61-, 2.01-, and 2.30-$\mu$m spectral bands with spectral resolutions of 0.6, 0.27, 0.27, and 0.27 cm$^{-1}$, respectively. The respective spectral bandwidths are 20, 160, 160, and 180 nm, while the spatial resolution is 10 km. The GAS performs sounding of atmospheric $CO_2$, $CH_4$, CO, $N_2O$,$O_2$, and aerosols.

The Ozone Mapping Spectrometer (OMS) is a new enhanced high-spectral sounding instrument with the same main uses as those of the TOU and SBUS, basically for the sounding of total ozone and ozone vertical profiles. The OMS consists of one 250–310-$\mu$m and two 300–500-$\mu$m spectral bands, with spatial resolutions of 34 $\times$ 60 km and 15 $\times$ 25 km, respectively. The spectral resolution is 0.4 nm.

## IV. FY-3 Ground Application System

All the functions of the FY-3A/B meteorological satellite ground application system were completed in November 2010. The computing platform of this system comprised a high-performance computer cluster, a local area network storage serving as the data management center, and a server and storage device using a fiber-optic network for high-speed data exchange. This database system is based on distributed data management applications. The ground application system uses backup equipment to increase its stability and reliability, enhance its data-processing capabilities, and improve the service levels for product processing and monitoring. The FY-3-meteorological-satellite ground application system works 24 h for 365 days continuously, with a high level of automation to provide stability. The ground application system can be divided into three large segments, namely, data acquisition, product generation, and application service based on the data flow features.

### A. Data-Acquisition Segment

The front segment of the FY-3 ground application system consists of a satellite-to-earth link through ground stations that have been established in five cities: Beijing, Guangzhou, Urumqi, Jiamusi, and Kiruna and many local X-band direct broadcasting stations. According to the FY-3 timetable for each base ground station produced by the Operation and Control Subsystem (OCS), the ground station receives data from three transmission channels of FY-3: High Resolution Picture Transmission (HRPT), Medium resolution Picture Transmission (MPT), and Delayed Picture Transmission (DPT). Then, the data are decoded, unpacked, quality checked, and transmitted to the data-processing and service centers simultaneously. The ground station has the capacity to store raw data for more than a week, as well as independent operational capacity in case of a communication interruption or other abnormal circumstances.

### B. Product-Generation Segment

This is a big segment covering the OCS, Data Preprocessing Subsystem (DPPS), and Product Generation Subsystem (PGS). The basic functions of the OCS are to command, control, and plan task schedules for the five ground stations and the command center. The compilation of a timetable using satellite orbital elements is the basis for every subsystem and ground station operation. There is a hotline between this segment and the satellite Tracking, Telemetry and Control (TT&C) center, which is used to transmit satellite orbital elements and control commands.

The DPPS's task is the preprocessing of raw data from the FY-3 remote-sensing instruments, including geographical location, radiometric calibration, satellite and solar zenith, and azimuth calculations, channel registration, image geometric correction, and the conduct of quality checks for every pixel of each sensor, producing level-1 (L1) data. The FY-3 geolocation operational software algorithm is based mainly on GPS data, but the orbital data numerical integration algorithm and software are used as hot backup.

The PGS input L1 data produced by the DPPS generate level-2 (L2) and level-3 (L3) products through automatic business scheduling at the OCS. These L2 and L3 products are atmospheric physical parameters, clouds, land surface parameters, and sea and space environmental parameters. The atmospheric and geophysical parameters are derived using scientific algorithms based on the L1 data. The L2 products are used mainly in weather analysis and forecasting and disaster and environment monitoring. The L3 products are statistical and analysis products of the time series of daily L2 products in ten-day, one-month, and one-year compilations, used mainly in climate research. All of the products are constructed in hierarchical data format and are easy for users to extract and display. The atmospheric and cloud products include temperature and humidity profiles, atmospheric stability index, total precipitable water, cloud mask, cloud-top temperature, cloud type, and cloud optical thickness. The land and sea surface products include the vegetation index, land cover (vegetation type), snow cover, land surface reflectivity and temperature, flooding index, global fire, sea surface temperature, ocean color/chlorophyll, and sea ice cover. The space weather products include solar proton, solar ion, solar electron, potential radiant dose, and single-event observations (see Table III for details).

### C. Application-Service Segment

This segment is composed of the Archival and Retrieval Service Subsystem (ARSS), Monitoring Analysis and Service Subsystem (MAS), and User Demonstration Subsystem (UDS). The ARSS's tasks are data archiving, data retrieval, data customization, and user management. The ARSS is responsible for the quality control of data products, format specifications, and catalog archive management; it provides online download services according to user online search, ensures the safety of stored data, and maintains and manages online and near-line storage devices.

The MAS is an operational FY-3 remote-sensing monitoring and analysis service platform that includes a database, image processing and display, and thematic mapmaking tools, as well as remote-sensing information extraction and information product generation and analysis using automatic or human–computer interaction. The task of the MAS is remote-sensing monitoring, assessment, and early warning of environmental disasters. Using L1, L2, and L3 products, combined with geographic information systems, the MAS monitors, assesses, and warns of weather events, natural disasters, and environmental changes, delivering such information to a variety

TABLE III
OPERATIONAL DATA PRODUCTS GENERATED FROM THE FY-3 GROUND APPLICATION SYSTEM

| No. | Name | Resolution (Km ) | Error Rate |
|---|---|---|---|
| 1 | Cloud Mask | 1 | 5%-20% |
| 2 | Cloud Top Temperature | 5 | 0.5-2.0K |
| 3 | Cloud Top Height | 5 | 50hpa |
| 4 | Cloud Optical Thickness | 5 | 5%-20% |
| 5 | Cloud Type | 5 | 5%-20% |
| 6 | Cloud Cover(total amount, high cloud) | 5 /10 | 5%-20% |
| 7 | Outgoing Long-wave Radiation | 5/17/50 | 3-8 $W/m^2$ |
| 8 | Aerosol over Ocean | 1/10 | 15%-30% |
| 9 | Fog Detection | 1 | RMS < 0.25 |
| 10 | Total Precipitable Water | 1 / 5 /50/27x45 | 15%-25%/10%-20% |
| 11 | Precipitation Rate at the ground | 18x30 | 30% |
| 12 | Atmospheric Temperature Profile(1000-10hPa) | 50 | 1.5-2.5K |
| 13 | Humidity Profile (1000-300hPa) | 50 | 15%-25% |
| 14 | Geopotential Height(1000-10hPa) | 50 | TBD |
| 15 | Atmospheric Stability Index | 50 | TBD |
| 16 | Total Ozone | 50/17 | 8-15% |
| 17 | Ozone Profile | 200 | 8-15% |
| 18 | Radiance Flux | 35 | LW:10$Wm^{-2}$ /SW:30$Wm^{-2}$ |
| 19 | NDVI | 0.25/1 | 5%-10% |
| 20 | Land Cover (Vegetation Type) | 0.25/1 | 15%-20% |
| 21 | Snow Cover | 1/5 | 10%-20% |
| 22 | Land Surface Reflectivity | 0.25/1 | TBD |
| 23 | Land Surface Temperature | 1/25/50x85 | 1.0-2.0K |
| 24 | Flooding Index | 50x85/25 | TBD |
| 25 | Global Fire Area | 1 | 5% |
| 26 | Sea Surface Temperature | 1/5/50 | 1.0-1.5K |
| 27 | Ocean Color/Chlorophyll | 1/10 | 15%-20% |
| 28 | Sea-Ice cover | 0.25/1 | 5%-15% |
| 29 | Solar Proton | 20 | 15% |
| 30 | Solar Ion | 50×50 | 20% |
| 31 | Solar Electron | 50×50 | 20% |
| 32 | Potential | 50×50 | 20% |
| 33 | radiant dose | 50×50 | 20% |
| 34 | Single event | 50×50 | 20% |
| 35 | Aerosol over land | 5/10 | TBD |
| 36 | Leaf Area Index | 1 | 15%-20% |
| 37 | Net primary production | 1 | TBD |
| 38 | BRDF | 1 | TBD |
| 39 | Drought Index | 5/25 | 25% |
| 40 | Surface Soil Moisture | 50x85/25 | 15%-30% |
| 41 | Surface MicroWave Emissivity | 75 | TBD |
| 42 | Wind Speed over Sea Surface | 30x50 | TBD |

of users through the Internet, television, and other means to provide decision support services. The MAS consists of individual modules that accomplish the following: business management, integrated database management, integrated monitoring and analysis, environmental disaster diagnoses and early warning, and integrated information dissemination.

Through adequate resource sharing, the UDS aims to push meteorological satellite remote-sensing applications to a variety of users in the national system. The system uses a three-level structure, namely, national, regional, and provincial. The demonstration fields consist of weather analysis and NWP, climate-change research and prediction, and environmental, disaster, and space weather monitoring.

## V. SUMMARY

FY-3A has been successfully launched on May 27, 2008, and is in extended service beyond its design life of three years; eight of the 11 sensors on board remain in operation. FY-3B has been successfully launched on November 5, 2011, and all 11 sensors on board are operating. The calibration and validation of these sensors and most of their products have been accomplished. The FY-3 ground application system has been distributing operational standard products since 2009.

The FY-3 series is divided into two phases, one of which is experimental, and the other is operational. The first two satellites (FY-3A/B) are experimental satellites whose purpose is the reduction of risks in the space and ground application systems, including the systems engineering, product algorithm development and validation, and data utilization demonstration. There are four satellites in the second phase. The satellite constellation for the operational phase (FY-3C/D/E/F) is planned with enhanced sounding and imaging capabilities. Two groups of FY-3-series polar satellites will be put into operation, one in a morning orbit and the other in an afternoon orbit. The payloads on board these two satellites will be a little different. The sensors for weather monitoring will be on board both the morning- and afternoon-orbit satellites, while the atmospheric component sensors will only be on board the latter. In addition, one low-inclination orbit satellite is being planned, mainly for precipitation measurement using an onboard radar and a passive microwave sensor. China will continue to develop two types of meteorological and environmental satellites (low earth orbit and geostationary satellites) to address meteorological requirements. It is believed that the Chinese satellites benefit not only China but also the international communities that are engaged in meteorological, hydrological, and environmental operations.

## ACKNOWLEDGMENT

The authors would like to thank all those who have made contributions to the FY-3 project and its ground-segment development during the past 12 years. The authors also sincerely would like to thank the two reviewers for their valuable comments and suggestions.

## REFERENCES

[1] C. Dong, J. Yang, W. Zhang, Z. Yang, N. Lu, J. Shi, P. Zhang, Y. Liu, and B. Cai, "An overview of a new Chinese weather satellite FY-3A," *Bull. Amer. Meteorol. Soc.*, vol. 90, no. 10, pp. 1531–1544, 2009.

[2] J. Yang, C. Dong, N. Lu, Z. Yand, J. Shi, and P. Zhang, "FY-3A: The new generation polar orbiting meteorological satellite of China," *Acta Meteorol. Sinica*, vol. 67, no. 4, pp. 501–509, Apr. 2009.

[3] Q. Lu, W. Bell, P. Bauer, N. Bormann, and C. Peubey, "An evaluation of FY-3A satellite data for numerical weather prediction," *Q. J. R. Meteorol. Soc.*, vol. 137, no. 658, pp. 1298–1311, Jul. 2011.

[4] N. Q. Liu, F. X. Huang, and W. H. Wang, "Monitoring of the 2011 spring low ozone events in the Arctic region," *Chin. Sci. Bull.*, vol. 56, no. 27, pp. 2893–2896, 2011.

[5] *ESA SP-1282, Report GAW No.159 (WMO TD No.1235)*, Sep. 2004.

[6] PRC State Council Information Office, China's Mitigation Actions, White Paper, May 2009.

[7] H. Yang, F. Z. Weng, L. Q. Lv, M. N. Lu, G. F. Liu, M. Bai, Q. Y. Qian, J. K. He, and H. X. Xu, "The FengYun-3 microwave radiation imager on-orbit verification," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, pt. 2, no. 11, pp. 4552–4560, Nov. 2011.

**Zhongdong Yang** was born in China in 1964. He received the B.S. and M.S. degrees in geology of remote sensing from Xinjiang University, Xinjiang, China, in 1987 and 1990, respectively, and the Ph.D. degree in remote sensing science from the Beijing Institute of Geology, Beijing, China, in 1997.

He is a Senior Scientist with the National Satellite Meteorological Center (NSMC), Chinese Meteorological Administration, Beijing. He takes a leading role in data processing of the meteorological satellites, algorithm developments for remote-sensing information products, and development of the ground application system engineering of FengYun 3 (FY-3) at NSMC. He is in charge of the FY-3 Polar-orbiting Meteorological Satellite program and its ground application systems.

**Naimeng Lu** received the B.S. degree from the Nanjing Meteorological University, Nanjing, China, in 1985.

He is currently the Deputy Director of the National Satellite Meteorological Center, China Meteorological Administration, Beijing, China, where he is a Research Fellow and Director of the Science and Technology Committee, a member of the State Earth Observation and Navigation Committee and International Precipitation Working Group, the Principal Scientist for the State Satellite Calibration Laboratory, and the Chief Program Manager of the FengYun 3 ground-segment project.

**Jinmin Shi** was born in China on May 19, 1954. She received the B.S. degree in computer science from the University of Electronic Science and Technology of China, Chengdu, China.

She is a Senior Scientist with the National Satellite Meteorological Center, China Meteorological Administration, Beijing, China, where she is currently the Deputy Chief Designer for the ground application system of the FengYun 3 meteorological satellite. She has more than 30 years of solid experience in software and information technology facility architecture design. Her major field of study focuses on the overall architecture of the ground application system of the meteorological satellite.

**Peng Zhang** was born in China in 1970. He received the M.S. degree in atmospheric optics from the Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences (CAS), Hefei, China, in 1995 and the Ph.D. degree in atmospheric physics from the Institute of Atmospheric Physics, CAS, Beijing, China, in 1998.

From 1998 to 2001, he was with the Earth Observation Research Center, National Space Development Agency, Japan, with a postdoctoral position for the Global Imager/Advanced Earth Observing Satellite (GLI/ADEOS) project. Since 2001, he has been with the National Satellite Meteorological Center, China Meteorological Administration, Beijing, where he was an Associate Professor from November 2001 to November 2005, has been a Professor since December 2005, and is one of the leading Project Scientists of the Chinese meteorological polar-orbit-satellite FengYun 3 (FY-3) series since 2007. He is intensively involved in conceiving, developing, and operating the FY-3-satellite ground segment. His major field focuses on atmospheric remote sensing and satellite data assimilation.

**Chaohua Dong** was born in China on May 2, 1945. She received the B.S. degree in meteorology from the Nanjing Institute of Meteorology (now Nanjing University of Information Science and technology), Nanjing, China, in 1969.

From 1980 to 1982, she was a Visiting Scholar with National Environmental Satellite, Data, and Information Service (NESDIS), National Oceanic and Atmospheric Administration. In 1986, she was with the Bureau of Meteorology, Australia, for three months. She is currently the Senior Consultant of the National Satellite Meteorological Center, China Meteorological Administration, Beijing, China, where she was the Director-General and Chief Engineer and the Chief Designer of the FengYun 3-series ground-segment project. Her research interests include atmospheric radiation transfer computation and satellite meteorology.

**Jun Yang** was born in China in 1964. He received the B.S. degree from Tsinghua University, Beijing, China, in 1985 and the B.S. degree from the Chinese Academy of Meteorological Science, Beijing, in 1988.

Since April 2004, he has been the Director-General of the National Satellite Meteorological Center, China Meteorological Administration, Beijing, where he is responsible for the development of the Chinese FengYun 3 (FY-3) meteorological satellite series and was also the Chief Program Manager of the FY-3 ground-segment project from 2004 to 2009.