# State-of-the-art of the China Seismo-Electromagnetic Satellite Mission

SHEN Xuhui, ZHANG Xuemin, YUAN Shigeng, WANG Ianwei,
CAO Jinbin, HUANG Jianping, ZHU Xinghong,
PIERGIORGIO Picozzo, DAI Jianping

1 (Institute of Crustal Dynamics, CEA, Beijing, 100085)
2 (Institute of Earthquake Science, CEA, Beijing, 100036)
3 (DFH Satellite Co. Ltd. Beijing, 100094)
4 (School of Space and Environment, Beihang University, Beijing 100191)
5 (Italian National Institute of Nuclear Physics, Roma, 100133)
6 (Beijing Special Engineering Design and Research Institute, Beijing 100028)

E-mail: shenxh@seis.ac.cn

## Abstract

The China Seismo-Electromagnetic Satellite (CSES) mission was proposed in 2003 and approved in 2013 after ten years' scientific and engineering demonstrations. To meet the requirement of scientific objectives, the satellite is designed to be in a sun-synchronous orbit with an altitude of 507 km and descending node time of 14:00 LT. The CSES satellite carries 8 instruments, including Search-Coil Magnetometer (SCM), Electric Field Detector (EFD), High Precision Magnetometer (HPM), GNSS Occultation Receiver (GOR), Plasma Analyzer Package (PAP), Langmuir Probe (LAP), High Energetic Particle Package (HEPP) and Detector (HEPD), and Tri-Band Beacon (TBB), among which HEPD is provided by Italian Space Agency. The CSES satellite was launched successfully on Feb.2, 2018, and is planned to operate for 5 years. The CSES mission is the first satellite in China to measure geophysical fields, which will have a lot of application prospects in the study of seismology, geophysics, space science and so on.

## Key words

China Seismo-Electromagnetic Satellite, Seismo-ionospheric disturbance, Lithosphere-Atmosphere-Ionosphere coupling, Geomagnetic fields, Ionosphere

## 1. Introduction

On Feb. 2, 2018, the China Seismo-Electromagnetic Satellite (CSES), also called ZHANGHENG-1 in honor of an ancient Chinese earthquake scientist Zhang Heng about 2000 years ago, was launched successfully. CSES is the first space-based platform in China for both earthquake observation and geophysical field measurement. It was first proposed early in 2003 and was approved in 2013 by China National Space Administration (CNSA) after ten years' scientific and engineering demonstration. During the past 15 years, the pre-studies and development of CSES have been continuously funded by CNSA, the Ministry of Sciences and Technologies (MOST) and China Earthquake Administration (CEA).

Back to the cross point of the century, there occurred a hot scientific dispute in the literature about whether an earthquake is predictable accompanied with a series of devastating earthquakes including the 2001 China Kunlunshan M8.1, 2004 Indonesia M9.2, 2008 China Wenchuan M8.0 and 2011 Japan M9.0 and so on [1-3]. Regarding that earthquake prediction is a natural science based on observations, at the beginning of 2003, Chinese government made the decision to develop space-based observation system so as to help to develop new methods and theories on earthquake prediction, and to improve the understanding of physical processes in the preparation, occurrence, and development of earthquake.

After 10 years' pre-studies on science and engineering, the mission was finally initiated in 2013. In the middle of 2014, works were finished such as the development of Electrical Model which was used to demonstrate the hardware and software design of the platform and payloads, verify the compatibility between the platform and payloads, test the payload performance, validate the structure and mechanical designs as well as the satellite thermal control design, the DC/AC magnetic cleanliness control validation and the compatibility between Satellite and EGSE/MGSE, and so on. In the middle of 2015, Qualification Model was developed for the purpose of qualifying all newly-built units and calibrating all payloads. The results show that the satellite platform and scientific payloads fulfill all the specifications. In the middle of 2017, the Flight Model was developed and performed as required for flight operation. At this moment, the commission test is being carried out and the scientific payloads started to operate successively since Feburary13, 2018.

## 2. Scientific Background

### 2.1 Seismo-ionospheric Perturbations

#### 2.1.1 Perturbations in the Electromagnetic Field

Both the ground-based and satellite observations have shown that the wide-frequency band ElectroMagnetic (EM) signals can be detected around strong earthquakes[4]. These EM perturbations continue much longer on the ground but are always imminent in space within a few days or even a few hours prior to earthquakes. In last century, many cases of the EM perturbations related to earthquakes observed by satellites (e.g. Intercosmos-19 and -24, GEOS-2, DE2, Aureole 3, and ISIS 2) at topside ionosphere have been reported[5]. Furthermore, in the 21st century, the related researches were carried out in the frequency bands from DC to LF by using the data of DEMETER satellite, in which both the case studies and the statistical studies exhibited significant EM anomalies around strong earthquakes[6-13].

#### 2.1.2 Plasma Disturbances

The study of plasma disturbances related to earthquakes was first carried out around the Alaska earthquake in 1964, and then, ionospheric parameters mainly including foF2, foEs and TEC are widely used, which are obtained from ground-based observational instruments such as ionosondes and GPS receivers[14]. After the launch of DEMETER in 2004, many papers based on plasma parameters obtained by satellite have been published and they all show more or less correlation of plasma disturbances with strong earthquakes[15-17]. Recently, Yan *et al*.[18] illustrated that although the in-situ plasma observations showed a statistical correlation with earthquakes, they alone could not be used directly in earthquake prediction, and they might be useful in earthquake warning. Both ground stations and satellite can provide the plasma parameters of the ionosphere, which enables us to study the ionospheric variations at different altitudes and their evolution processes and to obtain a better understanding of their coupling mechanism[19-24].

As for the energetic particles, the statistical studies based on in-situ data acquired by satellites (e.g. Mir orbital station, Mir orbital station, Meteor-3, Gamma, and SAMPEX) show that there appear energetic particle bursts about several hours before earthquakes[25-27]. However, case studies using the data of NOAA and DEMETER showed longer time precursors in energetic particles, i.e. a few days prior to strong earthquakes[28-29]. Thus the relations of energetic particles with seismic activities still need further investigations.

### 2.2 LAIC Coupling Mechanism

Pulinets and Boyarchuk [30] suggested that Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) has three ways: (1) EM wave propagation; (2) acoustic gravity wave propagation; (3) DC electric field coupling excited by geochemical factors. The relevant quantitative models have been continuously developed trying to make theoretical results to coincide with the ground and satellite observations.

#### 2.2.1 EM Wave Propagation

These evidence verified that EM waves from the epicentral area can penetrate up into the topside ionosphere directly. To simulate this penetration process of EM waves from the ground into the ionosphere, the full-wave propagation model has been developed[31]. In this model, the main controlling factors are the electron density and the collisional frequency profiles in the ionosphere, and the geomagnetic field distribution at the incident point. So the variations in electron density in the ionosphere will significantly influence the penetration power of EM waves. According to the simulations, the main attenuation of EM wave from the ground to ionosphere always occurs in the D/E layers with the first electron density peak at the lower ionosphere [32]. This model is utilized not only in earthquake-related researches[33-34], but also in the simulations of terrestrial VLF transmitters[35-36] and their effects to plasma parameters[37] and ELF EM signals[38].

#### 2.2.2 Effects of Overlapped DC Electric Field

Sorokin *et al*.[39-40] for the first time gave the theoretical model of DC electric field coupling and exhibited consistent variation amplitudes of a few mV/m in an electric field with satellite observations. With the development of the numerical simulations by considering the overlapped currents at the ground and their effects on plasma parameters in the ionosphere with both SAMI-2 or SAMI-3 models[41-43], it has become a widely accepted model to explain the ionospheric precursors related to strong earthquakes. At present, the main problem of this model is the initial conditions from the source, where still exists great differences between model results and actual ground and atmospheric observations in an electric field or other parameters.

#### 2.2.3 Acoustic Gravity Wave Propagation

Acoustic-gravity waves are widely detected and verified by TEC variations induced by seismic waves, tsunami and typhoon etc. The waves shown in TEC have a propagation velocity ranging from a few to ten hundred m/s, similar to the propagation velocity of gravity wave, acoustic wave, etc. And they are always well consistent with seismic waves, Doppler shift, geomagnetic field variations[44], which helps us to further understand their propagation processes after earthquakes or other disaster events. However, till now, these waves are rarely observed before earthquakes, which means that it is questionable for the existing of pre-seismic AGW waves. In addition, some scientists connected these waves to the variations in VLF/LF transmitter signals before earthquakes, and think that the acoustic-gravity waves first disturbed the electron density distribution and then affect the VLF/LF EM wave propagation in the ionosphere[7]. However, this theory has not yet been verified by simultaneous perturbations in $N_e$ and VLF signals, or by the numerical simulations.

The coupling process between signals induced by an earthquake (preparation and occurrence) and ionospheric perturbations is complicated and involves various parameters observed from lithosphere to atmosphere and ionosphere. CSES carries eight scientific payloads and will output tens of parameters and components, which cover all the possible ionospheric parameters associated with earthquakes shown in previous researches. The CSES observations afford us a very useful tool to connect all the observations in the electromagnetic field and plasma parameters in a stereo monitoring system. The comprehensive multi-parameter measurements by CSES can provide an effective way to verify the real correlation between seismic activity and ionospheric perturbations, and further improve the LAIC coupling theoretical models.

## 3. Mission Objectives and Contents

### 3.1 Scientific Objectives

The CSES mission is the first satellite of Chinese space-based geophysical field observation system and will have a lot of application prospect in earthquake science, geophysics, space sciences and so on. The scientific objectives of the mission are as follows:

- To obtain global data of the electromagnetic field, plasma and energetic particles in the ionosphere, especially those real-time data when the satellite passes over the Chinese territory.
- To monitor and study the ionospheric perturbations which could be possibly associated with seismic activity, especially with those destructive ones.
- To monitor and study the near-Earth space environment, and its disturbance caused by human activities.
- To analyze the features of seismo-ionospheric perturbations, therefore to explore the possibility for short-term earthquake forecasting in terms of satellite observation and to search the new approaches for short-term and imminent prediction.
- To support the researches on geophysics, space science as well as radio science and so on.
- To provide the data sharing service for international cooperation and scientific community.

### 3.2 Mission Contents

According to the scientific objectives, the CSES is designed to measure various physical parameters including electromagnetic field, electromagnetic waves, ionospheric plasma parameters, and high energy particle, etc.

These parameters are as following:

(1) Magnetic Fields

- 3-components of the magnetic field in the frequency band of DC-15 Hz.

(2) Electromagnetic Waves

- 3-components of the magnetic field in the frequency band of 10 Hz-20KHz;
- 3-components of the electric field with the frequency band of 0-3.5MHz.

(3) Plasma Parameters

- Electron and ion temperatures;
- Electron and ion densities;
- Total Elertronic Content (TEC).

(4) Energetic Particles

- Energetic particle energy spectrum from 200keV~200MeV;
- Pitch angle of energetic particles.

## 4. Satellite

### 4.1 Orbit Parameters

The main orbit parameters of CSES are as following (Table 1):

**Table 1** Main orbit parameters of the CSES

| Parameter | Design Value |
|---|---|
| Orbit type | Circular Sun Synchronous Orbit |
| Orbit altitude | 507km |
| Inclination Angle | 97.4° |
| Local time of descending node | 14:00 |
| Revisit Period | 5 days |

The distance between neighboring tracks is around 2650 km in one day and is reduced to 530km in a revisit period of 5 days (see Figure 1).

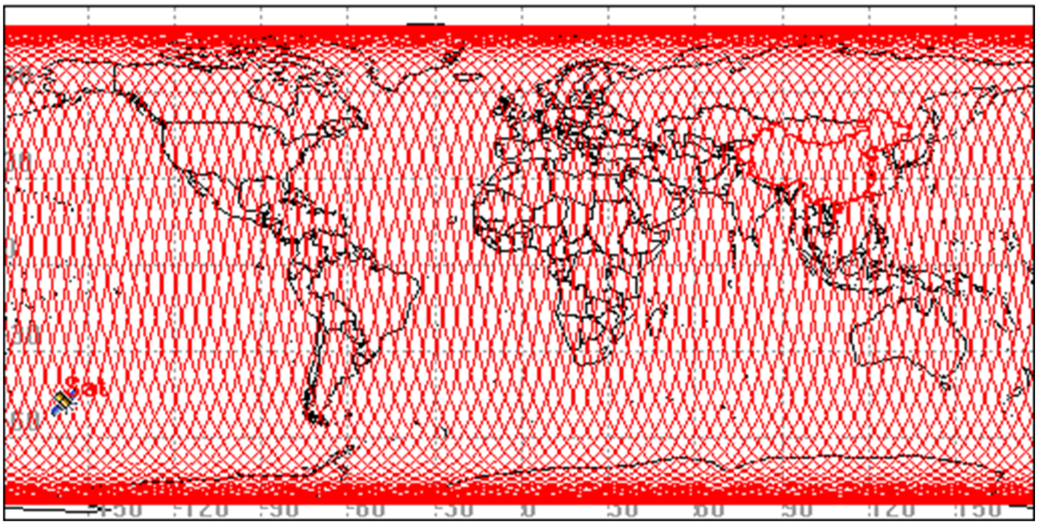

**Fig. 1** Sub-Satellite footprint track in 5 days

### 4.2 Structure of the Platform

The platform of CSES was redesigned upon the CAST2000. CAST2000 offered a standard multi-mission platform at a very attractive cost. Technically, the platform architecture is generic, and adaptations are limited to relatively minor changes in several electrical interfaces and software modules.

The platform includes eight units, Data Transmission subsystem (DTs), Structure and Mechanism subsystem (SMs), Thermal Control subsystem (TCs), Attitude and Orbital Control subsystem (AOCs), Power Supply subsystem (PSs), Telemetry and Tele-Command subsystem (TTCs), On Board Data Handling subsystem (OBDHs) and scientific payloads.

Satellite structure construction uses the dual-layer cabin design: payload layer cabin and platform layer cabin. While in-orbit, satellite is flying in the direction of Satellite *X* axis, satellite *Z* axis is pointing nadir, Satellite *Y* axis is then decided by right-hand rule. Solar panel locates on the +*Y* side of the satellite with 12° offset angle and could rotate around satellite *Y* axis.

Housekeeping data exchange onboard CSES uses CAN bus, OBDH center computer is used as a host and all other equipment are guests. Onboard telemetry use TM package to communicate. Launch and flight status of CSES are shown in Figure 2

Satellite AOCs uses earth oriented 3-axis stabilization. 3-star trackers, 2 group of gyros and 1 digital sun sensor are used to measure the attitude. Reaction wheel and magnetic torque are used to maintain the zero-momentum control. A propulsion system is used for attitude complementary control and orbit maintenance. A S Band Telecommunication system assisted by GPS positioning is used for TMTC subsystem.

Power supply subsystem is composed of 80Ah Li-ion battery and GaInP2/GaAs/Ge Solar Cell Panel. Main Specifications of the satellite platform are shown in Table 2.

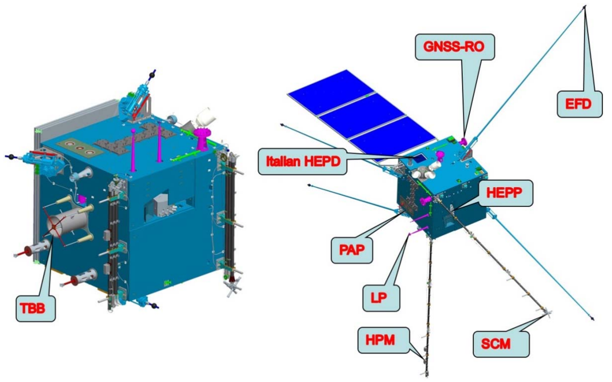

**Fig. 2** Launch (left panel) and flight (right panel) status of CSES

## 4.3 Payloads Assemble and Working Modes

The scientific payloads include Search-Coil Magnetometer[45-46], Electric Field Detector, High precision Magnetometer, GNSS occupation Receiver, Plasma Analyzer, Langmuir Probe, Energetic Particle Detector, and Three-frequency Transmitter. Table 3 lists their main parameters.

**Table 2** Main Specifications of the satellite platform

| Item | Specification | |
|---|---|---|
| Mass | ~700kg | |
| Data Transmission | Band | X |
| | DownLink Rate | 120Mbps |
| | Codec | RS |
| | Mass Memory Size | 160Gbit |
| | EIRP | 19.3dBW |
| TMTC/ OBDH | System | USB |
| | Uplink Rate | 2000bps |
| | Downlink Rate | 16384bps |
| | Time Sync Precision | 3ms |
| AOCS | Three-Axis Stabilized Attitude Control | |
| | Pointing Accuracy: better than 0.1°(3-Axis,3σ)<br>Knowledge Accuracy: better than 0.03°(3-Axis,3σ)<br>Stabilization Accuracy: better than 0.001°/s(3-Axis,3σ) | |
| | With Orbit Maintenance Capability | |
| Life Span | ⩾5 Years | |
| Reliability | ⩾0.6 at end of life | |

**Table 3** physical parameters measured by CSES

| Detecting content | Physical parameters | Frequency and scope | Payload |
|---|---|---|---|
| Electromagnetic field | Magnetic field | DC–15Hz | HPM |
| | | 10Hz–20kHz | SCM |
| | Electric field | DC–3.5MHz | EFD |
| Plasma in-situ | Ion density | $5\times10^{2}cm^{-3}$–$1\times10^{7}cm^{-3}$ | PAP |
| | Ion temperature | 500–10000K | |
| | Ion component | $O^{+}$, $H^{+}$, $He^{+}$ | |
| | Electron density | $5\times10^{2}cm^{-3}$–$1\times10^{7}cm^{-3}$ | LAP |
| | Electron temperature | 500–10000K | |
| Energetic particle | Proton energy spectrum | 2MeV–200MeV | HEPP/HEPD |
| | Electron energy spectrum | 100keV–50MeV | |
| | Pitch angle | – | |
| Ionospheric structure | TEC; electron density; atmosphere density | GPS; BD | GOR |
| | TEC; electron density | 150,450,1066 kHz | TBB |

To assure the accuracy of scientific data for all the payloads and avoid electromagnetic interference and plasma contamination, Solar Panel Rotation and AOCS adjustments (Magnetic Torquer, Thruster) are suspended while payloads are working.

Normally all payloads are supposed to work successively in the region within the latitude range [–65°, 65°].

According to the monitor requirement of Chinese territory and two main international earthquake belts, Burst Mode Region is shown in Figure 3 using a 5° mesh.

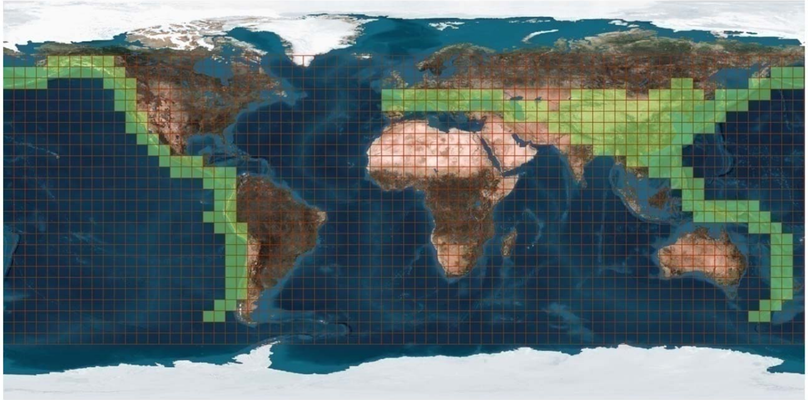

**Fig. 3** Satellite burst mode region

According to Figure 3, payloads with two operation modes will work in burst mode for ~2h and in survey mode for ~15.6h in a day while the working time of those payloads with only unique working mode will work 17.6h in a day.

## 5. Ground Segment of the Mission

The ground segment of CSES consists of science and application center, satellite ground networks, field verification bases and comparison system for satellite-ground measurement.

The science and application center, which will be in charge of mission operation and control, data management and service, as well as earthquake science application, is constructed in China Earthquake Administration (see Figure 4 and 5).

### 5.1 Framework of the Ground Segment

The tasks of ground segment are as follows:

- To receive and process the data from CSES and TBB receiving station.
- To make the observational schedules of CSES Mission.
- To operate & control the operation of data application system.
- To store and manage the data products.
- To verify and evaluate the data.
- To provide the data sharing service.

### 5.2 Main Data Output

The data products of CSES are classified into raw data, scientific data, and seismic event data. The main types of data are as follows

- Multi-band waveform and spectrum of electromagnetic field;
- In-situ plasma parameters including electron and ion density, temperature;
- Electron density profiles and tomography;
- Energetic particle flux and energy spectra;
- Seismic event data, i.e. the data associated earthquakes with their magnitudes are larger than Ms6 in China or Ms7 outside China;
- Geomagnetic field model, ionosphere model, and other related scientific research products.

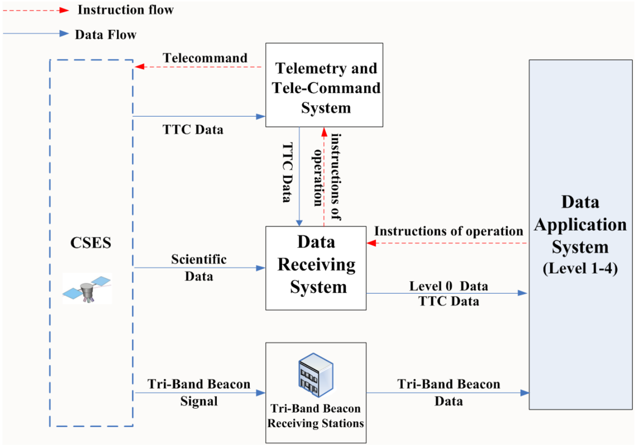

**Fig. 4** Data flow in the ground segment

### 5.3 Definitions of Data Levels

There are totally five levels of data, which are described as follows:

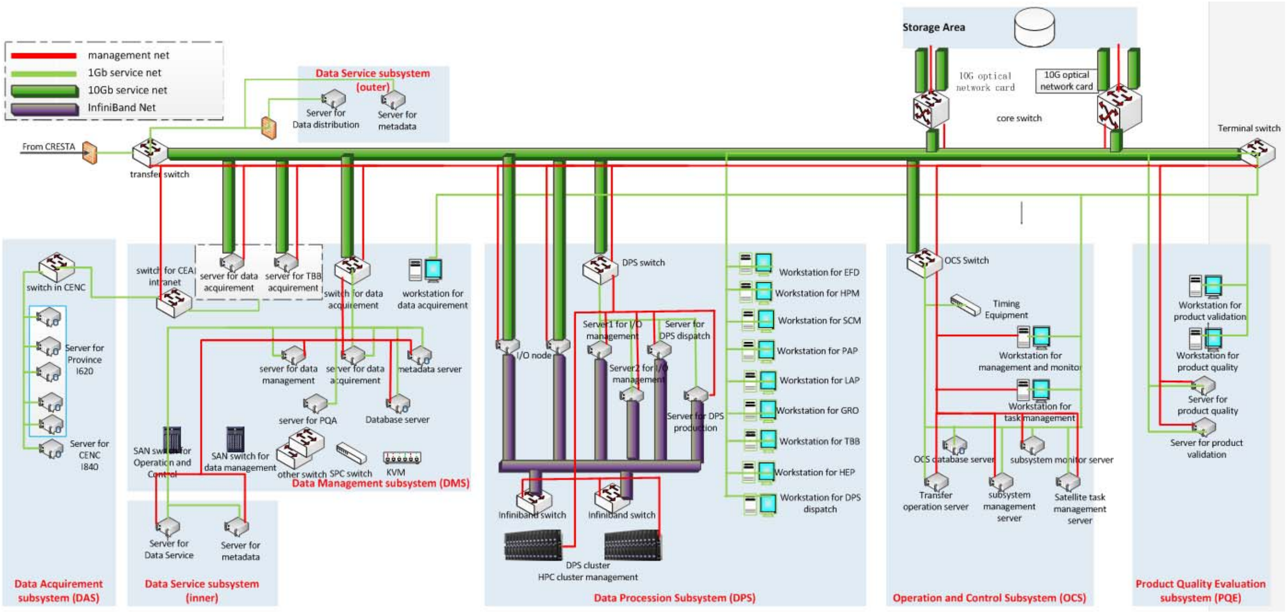

**Fig. 5** Logical Schemes of the CSES Mission Center

Level-0: The raw data of payloads generated after a series of process including frame synchronization, de-randomization, decoding, and de-formatting. All redundant data will be removed at this level.

Level-1: The data obtained after general error rejection, format conversion and calibration of Level-0 data.

Level-2: Physical quantity data with satellite orbit information after coordination system transformation and necessary data inversion of Level-1data.

Level-3: Time sequential data in the frame of satellite orbits generated after resampling, necessary spectral analysis based on Level-2 data.

Level-4: Global or regional dynamic observation data retrieved from level-2 and level-3 data, in terms of variation between recursive orbits and disturbance observed according to background field.

## 6. Conclusions and Remarks

CSES Satellite began its global observation since Feb.13, 2018, *i.e*. 10 days after its successful launch. According to the schedule, CSES will have 6 months' commission test in orbit and then turn into operation.

During its five years' operation time, CSES will acquire many kinds of data, such as multi-band waveform and spectrum of electric and magnetic fields; in-situ plasma parameters (including densities and temperatures of electron and ion), electron density profiles and tomography and energetic particle flux and energy spectra.

These data will benefit not only earthquake science but also geophysics, space science, radio wave science and space weather monitoring. A large number of case study results associated with earthquakes whose magnitudes are larger than Ms6 in China or Ms7 in the world will be acquired. In addition, the obtained data is also very helpful for improving global geomagnetic field model and ionosphere model.

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