Earthq Sci (2013) 26(6):427–437
DOI 10.1007/s11589-013-0053-9

RESEARCH PAPER

Progress and development on multi-parameters remote sensing application in earthquake monitoring in China

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Received: 6 January 2013 / Accepted: 2 December 2013 / Published online: 31 December 2013

Abstract In this paper, the progress and development on remote sensing technology applied in earthquake monitoring research are summarized, such as differential interference synthetic aperture radar (D-InSAR), infrared remote sensing, and seismo-ionospheric detecting. Many new monitoring data in this domain have been used, and new data processing methods have been developed to obtain high-precision images about crustal deformation, outgoing longwave radiation (OLR), surface latent heat flux (SLHF), and ionospheric parameters. The development in monitoring technology and data processing technique largely enriches earthquake research information and provides new tools for earthquake stereoscope monitoring system, especially on the space part. Finally, new developing trend in this area was introduced, and some key problems in future work were pointed out.

Keywords Remote sensing monitoring · D-InSAR · Infrared remote sensing · Seismo-ionospheric detecting

1 Introduction

Earthquake Science is an observational science, so rich observing information is a key factor in earthquake research. Earth observation by space technology is unmatchable for ground-based detecting technology, which has the features of global observation, high-dynamic-range, all-time, unlimited by natural conditions on ground, and can increase greatly checking chance of earthquake events and enrich the information content of earthquake precursors. These advantages can help to test effectively and develop methods and theory on earthquake prediction, to improve the understanding the laws in earthquake preparation, occurrence, and development. Remote sensing monitoring has developed into a new hotspot in earthquake monitoring and prediction research (Gokhberg et al. 1983; Massonnet et al. 1993; Parrot 1995; Hayakawa 2001; Tronin et al. 2002; Ouzounov and Freund 2004; Shen et al. 2007).

2 General situation of remote sensing technology application in earthquake science in China

The application research begins from 1970s, of the earth observation technology by satellite in earthquake prevention and disaster mitigation. By using mobile satellite system (MSS) satellite images of USA at that time, national investigation on active structures was carried out, and *The Album of typical Satellite Imagery of Active structures of China* (1982) with 1:4,000,000 was edited since 1978. Taken account of the requirements of development in earthquake prevention and disaster mitigation, studies on rapid earthquake disaster assessment methods started since later stage of 1980s by satellite and aerial remote sensing technologies. In 1988, West Yunnan Earthquake Test Site took the lead in GPS observation experiment, and then satellite thermal infrared earthquake monitoring technology and technique research were developed gradually since 1990 (Qiang et al. 1990).

Since the Tenth Five-Year National Science and Technology Development Program in China (2001–2005), in order to the implementation of related national research plans and major scientific projects, earthquake remote sensing application research and application system construction were paid high-level attention, deployed, and developed

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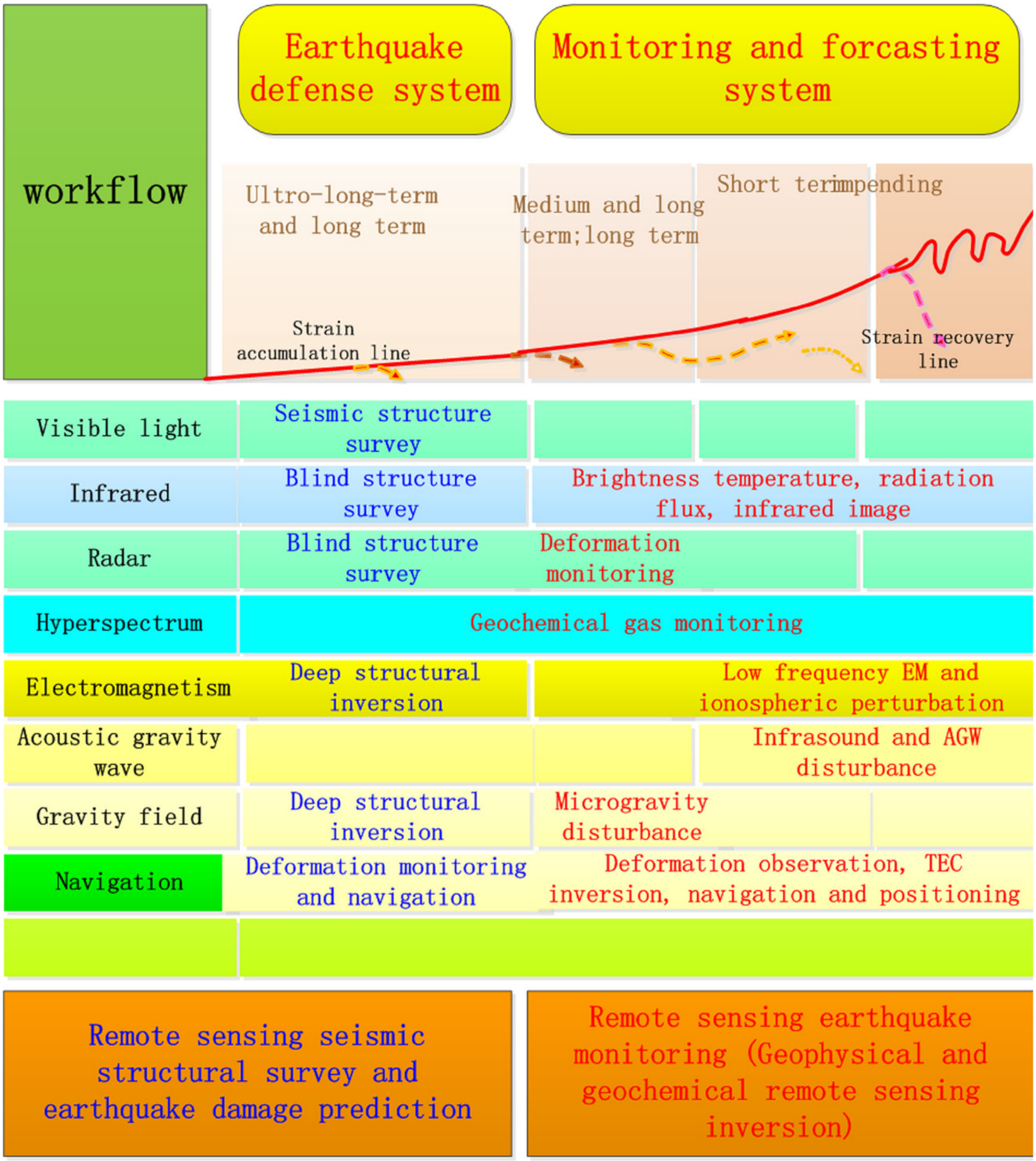

Fig. 1 The main application field of space technology in earthquake prevention and disaster mitigation

systematically and comprehensively. Focused on construction requirements in earthquake monitoring capability, the key techniques in earthquake monitoring and prediction were developed systematically and achieved remarkable progress by satellite electromagnetism, satellite infrared, and InSAR technology. The statistical research was promoted on historical earthquakes, and the space precursory characters were summarized initially in electromagnetism, infrared, deformation, and other information, which laid the foundation for gradually promoting the practical use. On the basis of these works, argumentation on the first space-based platform has been finished in earthquake stereoscope observation system in China, and integrated earthquake remote sensing application system has been designed comprehensively.

At present, space technology has been applied in all works of earthquake prevention and disaster mitigation (Fig. 1). Remote sensing geology has become the basic tool for earthquake research, and satellite technologies represented by satellite infrared, InSAR, and global navigation satellite system (GNSS) have played significant role in earthquake monitoring and prediction. Relied on high-resolution optical remote sensing, the capability on earthquake disaster assessment has been improved greatly. As, GNSS and satellite communication serve as the fundamental guarantee in earthquake emergency response and field seismic work.

3 Earthquake-related deformation monitoring by SAR remote sensing

3.1 Co-seismic deformation measurement by D-InSAR

The D-InSAR technique offers new possibilities to observe and study coseismic and postseismic deformation and even inter-seismic deformation. The main advantage of D-InSAR for studying coseismic deformation is the low cost and high spatial resolution of the observations. And it is often the only measurement available for the coseismic deformation field in the Tibetan Plateau where no conventional geodetic measurement networks exist.

The first earthquake studies using D-InSAR were on the 1992 Landers $M_w7.3$ earthquake obtained by the Massonnet et al. (1993) and Zebker et al. (1994), and these studies clearly demonstrated the power of this technique to observe coseismic deformation. Many studies followed and some authors have made important contributions to earthquake science. D-InSAR measurements have also allowed researchers to estimate the fault slip distribution of large earthquake, for example, the Jonsson et al. (2002) had inversed the seismic slip distribution of the 1999 Hector Mine earthquake, and Shen et al. (2009) obtain the slip distribution and rupture feature of the 2008 Wenchuan earthquake by the D-InSAR and GPS measurement. The D-InSAR technique has been used in many other earthquakes which happed in China, such as the 1997 Manyi $M_w7.6$ earthquake by Shan and Zhang (2006), Xu and Wen (2008) and Sun et al. (2007a), the 1998 Zhangbei-Shangyi $M_s6.2$ earthquake by Shan et al. (2003), the 2001 Western Kunlunshan $M_w7.9$ earthquake by Shan et al.(2004) and Wang and his co-workers (2008), the 2008 Gaizhe $M_w6.4$ earthquake by Sun et al. (2008) and Feng et al. (2009), the 2008 Yutian $M_w7.1$ earthquake by Hong et al. (2010a, b) and Zhang et al. (2011), the 2008 Dangxiong $M_w6.3$ earthquake by Feng et al. (2010) and Sun et al. (2011), and 2010 Yushu $M_w6.9$ earthquake by Hu et al. (2012) and Qu et al. (2013).

3.2 The measurement of small crustal deformation

After the deformation field of Landers $M_w7.3$ earthquake obtained by the Massonnet et al. (1993) by European remote sensing satellite (ERS-1) data, the D-InSAR technology caused great concern of the international seismological community. Due to the atmospheric effects, digital elevation model (DEM) error, incoherence, etc., the measurement accuracy of D-InSAR can only achieve centimeter-level, and cannot be suitable for long-term and slow crustal deformation monitoring. In order to overcome the error sources of the conventional D-InSAR, Ferretti et al. (2001) firstly developed the Permanent Scatters (PS) measurement method, which can achieve mm-level accuracy. Afterward, the Small Baseline InSAR (SBAS InSAR), Multi-temporal InSAR (MT-InSAR), Multicale InSAR Time Series (MInTS), and Distributed Scatterers (DS) that was developed based on PS method, have obtained the success of small crustal deformation monitoring (Hooper 2008; Ferretti et al. 2011; Hetland et al. 2012).

Supported by the GPS-2 Project and the Eleventh Five-Year Science and Technology Development Program of China (2006–2010), China Earthquake Administration has a system launched PS/CR-InSAR technology research work. At present, we have built about 106 artificial Corner Reflectors(CR) around the Haiyuan fault, Liupanshan fault, and north edge of XiqinLing fault, which in the northern section of north–south seismic belt; and also built dozens of CR in the Yangbajing basin, Yanhuai basin northwest of Beijing, and Lijiang basin. And by the deformation monitoring, we found: eastern of Haiyuan fault displays a left lateral slip rate about 6–7 mm/a, the average cumulated displacement of these points in 2003–2009 is about 4.2 cm, which is roughly in agreement with that from GPS measurements and geological investigations (Qu et al. 2011); the land subsidence in the areas of geothermal wells is up to 25 mm/a, while the subsidence in the basin is less than 1 mm/a (Li et al. 2012).

3.3 3D deformation solving methods

One of the limitations of InSAR is that it only measures one component of the surface deformation—in the satellite's line of sight (LOS), but not the real surface deformation in the west–east, north–south, and vertical directions, and this question is named "LOS Ambiguity". It is important for overcoming this problem to transfer the LOS deformation to real surface 3D deformation. By the Multi-LOS InSAR measurement, combined with deformation simulation, Offset-tracking and GPS technology, Hong et al. (2010a, b) had built up a 3D deformation solving model to obtain the 3D deformation field of 9th and 16th January 2008 Gaizhe $M_w6.4$ and $M_w5.9$ double earthquake, 21st March 2008 Yutian $M_w7.1$ earthquake and 26th December 2003 Bam $M_w6.9$ earthquake. The analysis of 3D deformation shows that the $M_w6.4$ Gaizhe main shock was mainly ruptured by normal and left-lateral striking with a little rotation to east, and Gaizhe $M_w5.9$ after shock was mainly ruptured by normal faulting with a little right-lateral striking (Fig. 2); Yutian earthquake is mainly ruptured by normal faulting and left-lateral striking, and spatial distribution of the three-segment seismic rupture is featured by left step en echelon; the Bam earthquake was ruptured mainly by right-lateral

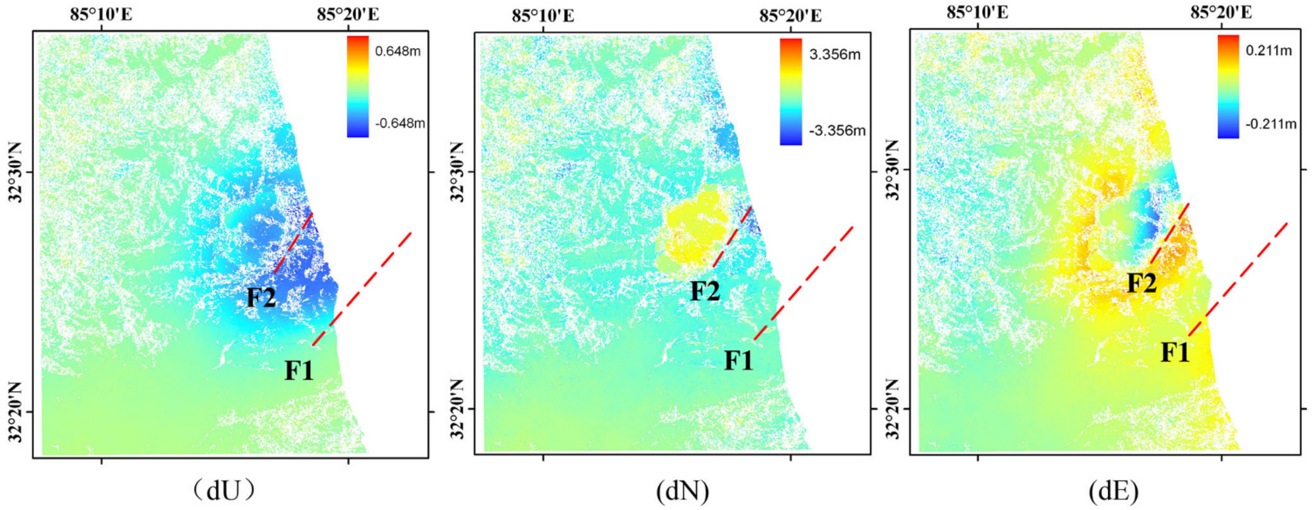

Fig. 2 3D deformation field of Gaize earthquake (by Hong et al. 2010a, b) (dU, dN, dE are respectively referring to the up, north, east orientation deformation; the movement toward upward, northern, and eastern is positive deformation, and toward downward, southern, and western are negative deformation; the *red dashed-lines* are the seismic faults F1 and F2)

striking mechanism, with a little left-lateral horizontal rotation in the east–west direction.

3.4 Offset-tracking and MAI measurement

Due to the serious incoherent of time and space in the dense vegetation and mountain area and the unwrapped of the interferometer phase in the zone of extremely deformation gradient around seismic rupture, interferometry method is often unable to obtain the co-seismic deformation information of meizoseismal area. Offset-tracking measurement was proposed to make up this deficiency (Michel and Avouac 1999), which can obtain the two-dimensional deformation of Slant Range and Azimuth direction. The advantages of this method are fully reflected in the co-seismic deformation field extraction of the 12th May, 2008 Wenchuan M_w7.9 earthquake (Liu 2010), when the InSAR measurement cannot get the deformation information near the seismic ruptures. And, the Multiple Aperture Interferometry (MAI) technology proposed by the Bechor and Zebker (2006) can also effectively extract the two-dimension deformation field of Slant Range and Azimuth direction. The Sun et al. (2008) and Hu et al. (2012) have using the MAI technology to obtain the two-dimension cosesimic deformation fields, respectively, in the 2008 Gaize earthquake and 2010 Yushu earthquake.

4 Earthquake precursor monitoring technology using infrared remote sensing

The First application of thermal images in earthquake was carried out in 80th for Middle Asia by Gorny et al. (1988). The most outstanding IR anomalies are represented by *M*7.2 Gazli earthquake March 19, 1984. The anomalies appear 1 week before this earthquake, and the area of anomaly exceeds 100000 km^2. After that, the satellite thermal infrared anomaly related to earthquake has been demonstrated by many researchers, and Chinese scientists are important research team. Xu et al. (1993), Deng et al. (1997), and Qiang et al. (1990, 1997) make preliminary studies on the mechanism of earthquake infrared anomalies. The change of rock stress or atmospheric electric field, and the greenhouse effect are possible causes for thermal anomalies. Some case studies have been carried out by Liu and Kang (2005), Chen et al. (2006), Qu et al. (2006), Liu et al. (2007a, b), Kang (2008), and Jing et al. (2009). According to the data used, these cases studies can be classified into two categories: multi-parameter and multi-band.

4.1 Multi-parameter infrared variation related to earthquakes

Many kinds of infrared physics parameters can be used to study the anomalies associated with earthquakes, such as brightness temperature (BT), outgoing longwave radiation (OLR), and surface latent heat flux (SLHF). BT is defined as the temperature of a blackbody that emits the same intensity as measured. OLR is the emission to space of terrestrial radiation from the top of the earth's atmosphere and controlled by the temperature of the earth and the atmosphere above it, the water vapors in the atmosphere, and the clouds. SLHF is an atmospheric parameter, which can describe the heat released by phase changes and dependent on meteorological parameters such as surface temperature, relative humidity, wind speed, etc. The recent studies have demonstrated that these parameters may be as abnormal indicators as seismic precursor (Liu et al. 2007a, b; Xiong et al. 2010; Qin et al. 2011, 2012; Wu et al. 2012a; Jing et al. 2013).

Earthquake preparation is a complex process, it is difficult to identify anomaly just according to one parameter. The process of earthquake preparation is accompanied by the exchanges of mass and energy, which can change the energy budget in the earth-atmosphere system on the seismogenic zone. BT, OLR, and SLHF can reflect this variation. This theory may provide important support for the comprehensive analysis of infrared remote sensing multi-parameter in earthquake study. Therefore, infrared multi-parameter comprehensive study has important significance in the infrared seismic monitoring.

Different data processing methods have been proposed according to different parameters, such as standard deviation (STD) threshold, power spectrum estimation, background-deleted, which can be found in the related literatures (Jing et al. 2010; Guo et al. 2010; Li et al. 2010). Supported by the National Key Technology R&D Program of China, Over one hundred seismic cases have been analyzed using infrared multi-parameter. Taking Wenchuan earthquake, for example, BT, OLR, and SLHF show obvious variation (Fig. 3) for several days before this event. Since the physical meanings of these parameters are different, their respective anomalies performances on spatial and temporal characteristics are different. The area of BT anomalies is the largest than OLR and SLHF, and the position of OLR and SLHF anomalies is closer to the epicenter of earthquake than BT.

And according to the result of over one hundred seismic cases, the variation characteristics of these parameters prior to the earthquakes have been summarized. Approximately, 50 % earthquakes of the magnitude greater than 5.0 appear abnormal variation on these parameters. The variation characteristics of BT, OLR, and SLHF related to earthquake can be seen in the Table 1. It is greatly similar and synchronous for infrared multi-parameter in the process of earthquake preparation, e.g., the anomalies mostly appeared in two weeks prior to earthquakes; the location of seismic anomalies was different for each parameter. BT anomalies usually isolated and have a large area of distribution; OLR and SLHF are near the epicenter and always distribute along the seismogenic fault; the infrared anomalies are more likely to be detected in earthquakes that magnitude greater than 6.0.

LCA (Lithosphere–Coversphere–Atmosphere) coupling model has been proposed by China scientist according to analyzing the variation of multi-parameter(including outgoing longwave radiation, surface latent heat flux, thermal infrared radiation, diurnal temperature range, atmospheric temperature, and skin temperature) before some major earthquakes (Wu et al. 2012a, b). This model can explain the quasi-synchronism and geo-consistency of different parameters in different spheres, which will help us to better understand the mechanism of earthquake infrared anomalies variation.

Table 1 Features of Infrared Multi-parameter variation related to earthquakes

Parameter	Characteristics			Reflect capacity
	Time	Space	Magnitude	
BT	Most in 15 days	Isolated, always not in the epicenter	1–3 (K threshold)	>*M*6.0 for better
OLR	Several days to few months	Near the fault	1.5–3 (STD threshold)	>*M*6.0 for better
SLHF	Most in 2 weeks	Moving toward to the epicenter	>90 W/m^2 (difference from background)	>*M*6.0 for better

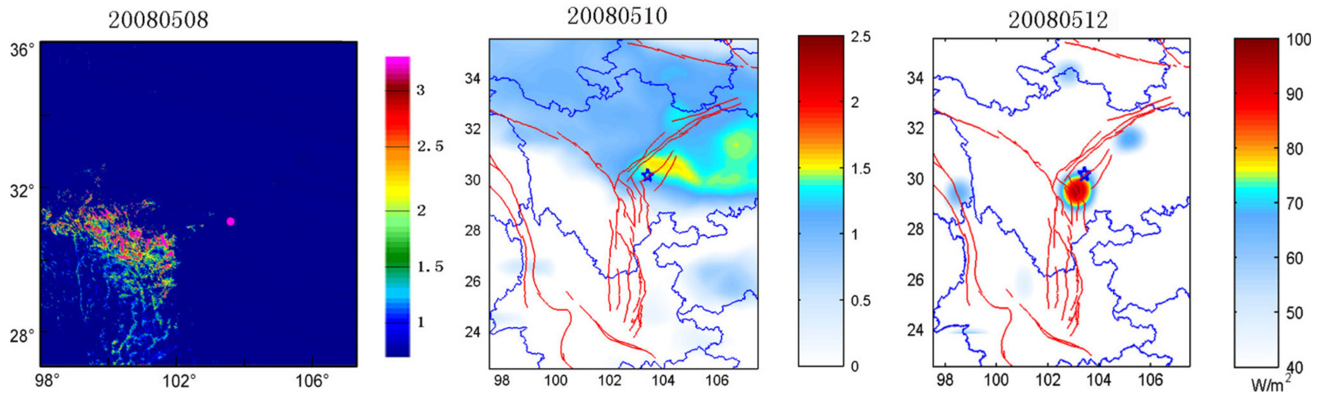

Fig. 3 Multi-parameter variation prior to Wenchuan earthquake (Wen 2011; Jing et al. 2013) (*left* BT, *middle* OLR, *right* SLHF. Epicenter is marked with *star* or *point*, active faults with *red lines*)

4.2 Multi-band infrared variation related to earthquakes

At present, earthquake infrared anomalies research mainly concentrated in two infrared bands, far-infrared (8–12 μm) and longwave infrared (4–50 μm). Outgoing longwave radiation data have been applied in seismologic consideration of China earthquake networks center, and far-infrared data are also the important information for carrying out earthquake prediction in some provincial earthquake bureau.

In recent years, mid-infrared (3–5 μm) has been exploring the potential applications in order to study multi-band infrared variation related to earthquakes. It has been found that mid-infrared, far-infrared, and long-wave infrared can play a role in seismic infrared radiation anomalies detection. But cloud detection and removing must be carried out before seismic information extraction, because mid-infrared and far-infrared radiations are affected by clouds. So it is difficult to obtain infrared brightness temperature variation in continuous time. And outgoing longwave radiation data reflect the radiation on the top of the clouds and conducive to obtain continuous radiation variation, which have great significance to study short-term and impending earthquake precursor. Besides, microwave radiation seismic anomalies also are found in some earthquakes by China scientist (Liu et al. 2012). So the comprehensive analysis on radiation information derived from different wavebands related to earthquakes is an important developing trend in future.

5 Seismo-ionospheric detection technology

With the development of ionospheric detecting technology and accumulation of numerous earthquake cases, remarkable ionospheric disturbances have been found around some large earthquakes. Seismo-ionospheric signals receive the world attention due to its typical short-term precursory feature, and then satellite electromagnetic detection technology has got rapid development. Although ground-based seismo-electromagnetic precursor detection has continued a few 10 years in China, seismo-ionospheric research started late (Ding et al. 2004; Wu et al. 2005) and witnessed rapid growth especially after the plan of China seismo-electromagnetic satellite (Shen et al. 2011). At present, the main technical tools on space ionosphere detection include ground-based vertical ionosonde/slant ionosonde, the total electron content (TEC) by inversion of global position system (GPS) observation, occultation events, in-situ satellite observation, and so on.

5.1 Research on seismo-ionosphere coupling mechanism

Abroad scientists found that the electromagnetic signals, chemical materials, ground waves produced during the earthquake preparation processes mainly propagate and cause perturbations of electromagnetic field and plasma parameters in ionosphere by three ways: electromagnetic wave propagation, acoustic gravity wave propagation, direct current (DC) electric field coupling (Molchanov et al. 1995; Pulinets et al. 1994; Sorokin et al. 2001). In order to explain the anomalous phenomena in ionosphere related to earthquakes, Chinese expert has also carried out corresponding study on theoretical simulation.

Zhang et al. (2009a) analyzed the behavior of extremely low frequency/super low frequency (ELF/SLF) electromagnetic waves in atmosphere and ionosphere with the variation horizontal distance, altitude, frequency, and depth of electric dipole. Wang et al. (2009) deduced the spherical harmonic expression of electromagnetic field produced underground, aboveground and in ionosphere from underground SLF/ELF horizontal electric dipole by regarding the ground layers and ionosphere as spherical uniform sharp boundary mediums. Zhao et al. (2010) developed the full-wave modeling of transionospheric propagation of very low frequency (VLF) waves which was applied to calculate the electromagnetic field in the stratified ionosphere for ground-based dipole transmitters and compared to observation. The simulation results coincide with the observations, which illustrate the reliability of the propagation model of electromagnetic waves (Shen et al. 2011).

The simulation on traveling ionospheric disturbances was only done by linear transfer function (Sun et al. 2006, 2007b). Lu (2008) built 2D numerical model of acoustic gravity wave propagation under polar coordinates. The results show that responding perturbations in ionosphere occur after the excitation of gravity wave, and the amplitude amplifies with the increase of altitude. Based on compressible inviscid 2D gas, we simulate the nonlinear propagation process of acoustic gravity waves. Figure 4 shows that the wave packet changes significantly during the propagation process, with the related disturbance wave velocity exponentially rising with the increase of height. The wave packet moves to the upper right continuously.

5.2 Data processing techniques of electromagnetic satellite observation

The space ionospheric variation is influenced mainly by solar activity, in which the daily, seasonal, and annual variations are all related to that. Multi-parameters in ionosphere will change intensively in large scale under the effects of severe space weather events like sun coronal mass ejection, magnetic storms, etc. Seismic activity and volcano eruption are just weak factors to affect the ionosphere. Their excitation sources are formed underground or on the surface, and their intensity will damp to some extent when propagating to the ionosphere, so they become the weak signals under strong electromagnetic

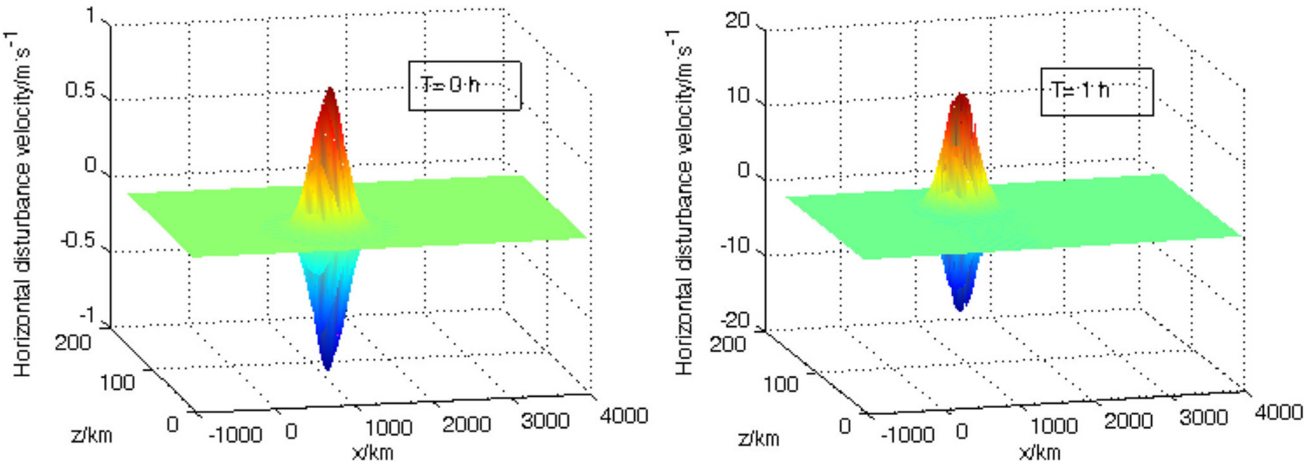

Fig. 4 Horizontal movement of nonlinear gravity wave packet with time (*left* $T = 0$ h, *right* $T = 1$ h)

background in ionosphere. When the ionospheric detecting data by satellite are employed in earthquake research, the distinguishing methods on anomalies are crucial besides deleting out the routine disturbances from instruments.

On the basis of widespread application and continuously validation, some kinds of anomaly extraction techniques have been built, and they play an important role in case studies (Zhang et al. 2009b; Yang et al. 2011). The space electromagnetic observation has four dimensional variation features due to the flying mode of satellite. The key point in anomaly extraction is to construct different extraction techniques in accordance with different observational data, based on clear understanding on background information. So far the widely used methods can be concluded as following, such as Time Series Analysis to construct the long time sequence in a studied region by accumulating the observational data average or median for a certain period of time and space scale (Zhang et al. 2009b); space–time re-sampling methods for the global or regional spatial observation data (Liu et al. 2013); wave vector analysis to get the propagation feature of electromagnetic wave (Yu et al. 2010); and computerized ionospheric tomography(CIT) aiming at the profile data in ionosphere by GPS TEC, occultation, and tri-frequency beacon (Yang et al. 2011).

5.3 Statistical analysis on electromagnetic satellite data and seismo-ionospheric characteristics

Owing to the certain randomness and occasionality in case study, all kinds of observational tools and anomaly analytical techniques need to validate by accumulation of numerous earthquake cases and statistical analysis, to estimate the correlation between detecting technology and earthquakes. The accumulation of large amount of data makes it possible to do the statistical analysis between ionospheric perturbations and earthquakes. In recent years, the seismo-ionospheric statistical analysis has been widely carried out about earthquakes over China and the world.

Xu et al. (2012) analyzed the critical frequency of F2 layer (foF2) related to 14 large earthquakes in China mainland, and they found that ionospheric anomalies occurred before 85.7 % earthquakes, mostly at 11:00–17:00 LT in 7 days before the earthquakes. Le et al. (2011) performed statistical analysis on global 736 $M \geq 6.0$ earthquakes during 2002–2010 by GPS TEC. Their results demonstrate that GPS TEC varied more intensively before the earthquake with bigger magnitude, shallower focus, and closer time. Yao et al. (2012) studied the global earthquakes with $M \geq 7.0$ in 2010, and they found that GPS TEC anomalies occurred 0–2 days before the earthquakes, concentrating at 12:00–20:00. Zhu et al. (2010) did statistical research on TEC around 50 earthquakes with $M_s \geq 7.0$ since 2007, which demonstrated that obvious ionospheric perturbations occurred before 94 % cases. Positive and negative anomalies all have been detected, and negative anomalies always occurred 1 week before earthquakes, while positive ones had no evident function relation with the occurrence time. Zhang et al. (2012) analyzed the ionospheric perturbations in static electric field data observed by detection of electro-magnetic emissions transmitted from earthquake regions (DEMETER) satellite around global earthquakes larger than 7.0 during 2005–2010. Their results revealed that interplate earthquakes can excite the ionospheric disturbances more easily. The power spectrum of electric field increased to 1–2 orders of magnitude, and the anomalies gradually concentrated to the epicenter when the earthquake approached. He et al. (2011) studied DEMETER data around 7000 $M \geq 5.0$ earthquakes taking place in 2006–2009. Their paper exhibited that the electron density was enhanced both over southern and northern hemisphere, but anomaly center was located at north to the epicenter over northern hemisphere and at south over southern hemisphere. The disturbances were

Table 2 Features of electromagnetic variations related to earthquakes in ionosphere

Parameter	Characteristics			Correspondent ratio to $M_s \geq 7.0$ earthquakes (%)
	Time	Space	Amplitude	
In-situ electric field	3 days	Δlat $\leq 10°$	Enhancement by 1–2 order of magnitude	46
In-situ plasma parameters	A week	$\leq$2,000 km	20–100 %	32
foF2	A week	$\leq$1,000 km	Beyond quartile	85.7
GPS TEC	A week-2 days	$\leq$2,000 km	Beyond quartile	60–94

more intensive around oceanic earthquakes than inland cases. The anomalous amplitude became larger with the increase of earthquake magnitude, but being less with deeper focal depth. Table 2 summarized the anomaly characteristics in space, time, and magnitude about different electromagnetic parameters, which illustrate that ionospheric electromagnetic anomalies have significant imminent feature relative to the earthquake, but distribute in relative larger scales in ionosphere.

Until now most researches illustrate positive relationship between ionospheric disturbances and seismic activities, especially the temporal relationship. However, the studies in China lay particular stress on seismic events and focus less on research of nonseismic time segments and the occurring probability of similar signals in other regions. Full spatial scanning to same kinds of anomalies as those related to earthquakes needs further development in future studies.

6 Trends and prospects on RS application in earthquake science

In past years, the whole world had been continuously attacked by a few giant earthquakes even with magnitude larger than 9, and population, economy, and society suffer huge losses. Stimulated by these unexpectedly great disasters, scientists enhanced the introspection and summary on earthquake monitoring and forecasting ways, and on the other hand, they paid more attention on the multi-sphere interaction with the rapid development of space technology. By using the advantages as all-time, high-dynamic, and global observation in satellite remote sensing technology to develop, the space-based earthquake observational system has become a major trend of technological development in earthquake monitoring and prediction.

(1) More emphasis on the construction of the space segment of China earthquake stereoscope observation system

The first Chinese seismo-electromagnetic monitoring satellite is viewed as a test satellite with clear application prospect in monitoring and forecasting field, equipped with the capability of in-situ observation on plasma parameters and ionospheric structural tomography. At the moment, the first electromagnetic satellite has entered into the engineering development phase and is due to be launched around the end of 2015 and operation for 5 years together with existing ground-based observational network.

To cope with the overall planning of national civil space remote sensing system, on the basis of developing electromagnetic monitoring test satellite, the satellite-based earthquake monitoring system will be constructed gradually by satellite detecting information, which including following 3 sub-systems: (1) earthquake deformation observation system and application research combined In-SAR, satellite gravity and GNSS with the goal of medium- and long-term earthquake monitoring and forecasting; (2) infrared observation and technical system and application research with the goal of medium- and short-term earthquake monitoring and forecasting; (3) satellite-based electromagnetic observation and technical system and application system with the goal of short-term and imminent earthquake monitoring.

(2) Much attention on geophysical remote sensing detection and inversion techniques

For a long time, space technology and remote sensing community have paid close attention on imaging remote sensing technologies, keeping improve the corresponding spatial, temporal, and spectral resolution. So far the imaging remote information has played significant roles in territorial resources surveys, natural disasters prevention and reduction, ecological environment monitoring, and many other fields, evolving several superior application fields such as geological remote sensing, disaster remote sensing, and so on.

The development of remote sensing technology also spurred the occurrence of earth system science. However, it has been the hotspot in scientific community that how to implement the detection and observation on the whole earth system based on advanced detecting technologies. Essentially, electromagnetic field and gravitational field, as the natural media connecting the multi layers of the earth, have good transport link in each sphere of the earth's system, and representation capability of their correlations, consequently becoming the important tools in detecting the interaction among multi spheres in the earth system by remote sensing technologies.

Taking this opportunity, geophysical remote sensing detection and inversion technique research focused on electromagnetic field and gravity field have been paid more and more attention by international academia. The development of electromagnetic satellite and gravitational satellite is becoming new hotspots in current international remote sensing technology field. Since 2000, several space power countries like America, Russia, European Union (EU), etc. have developed some specialized electromagnetic and gravitational satellites such as DEMETER, gravity field and steady-state ocean circulation explorer (GOCE), gravity recovery and climate experiment (GRACE), and so on, while the electromagnetic satellite constellation SWARM is going to be launched. Based on these specialized satellites' observing information, some researches have come to academic hotspots, for example, the earth ionosphere and atmosphere tomography combined with extended application of GNSS, the earth interior structure detection and inversion techniques based on satellite observation, statistical analysis of global earthquakes, and earthquake science research upon the results of geophysical remote sensing detection.

(3) Imminent major scientific projects by international cooperation

So far, China Earthquake-related Satellite Plan has undergone 10 years progress. From systematically learning the advanced foreign experiences, we effectively push forward all the researches, which powerfully guarantee the implement of China Earthquake Satellite Plan. As extensive international cooperation and communication has been built by taking part in bilateral and multilateral academic communication activities. With the development of the first electromagnetic satellite plan in China, the International Academy of Astronautics (IAA) organized two workgroups of International Global Monitoring Aerospace System (IGMASS) and School for Global Education and Innovation (SGEI) facing giant natural disaster monitoring and early warning, to push through coordinated application of global resources. ESA (European Space Agency) collaborated with Russian space agency, and they proposed their earthquake prediction research project PRE-EARTHQUAKES, in which they planned to develop and offer to the international scientific community an integration platform (PEG) where independent observations and new data analysis methodologies devoted to the research on/of earthquake precursors can be collected and cross-validated.

Acknowledgments This paper is the common achievements of implementing team in satellite plan of China Earthquake Administration (CEA). Besides the authors named in the paper, many persons have been involved in this work, including experts from Institute of Geology, Institute of Crustal Dynamics, Institute of Seismology, Institute of Geophysics, China Earthquake Network Center, Lanzhou Institute of Seismology, and all the colleagues of Lab. of Earthquake Observation from Space in Institute of Earthquake Science, CEA. It is supported by the International Science and Technology Cooperation Program of China (2010DFB20190), the Key Project of Earthquake Science (201008007).

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