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Earth observation big data for climate change research

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Abstract

Earth observation technology has provided highly useful information in global climate change research over the past few decades and greatly promoted its development, especially through providing biological, physical, and chemical parameters on a global scale. Earth observation data has the 4V features (volume, variety, veracity, and velocity) of big data that are suitable for climate change research. Moreover, the large amount of data available from scientific satellites plays an important role. This study reviews the advances of climate change studies based on Earth observation big data and provides examples of case studies that utilize Earth observation big data in climate change research, such as synchronous satellite−aerial−ground observation experiments, which provide extremely large and abundant datasets; Earth observational sensitive factors (e.g., glaciers, lakes, vegetation, radiation, and urbanization); and global environmental change information and simulation systems. With the era of global environment change dawning, Earth observation big data will underpin the Future Earth program with a huge volume of various types of data and will play an important role in academia and decisionmaking. Inevitably, Earth observation big data will encounter opportunities and challenges brought about by global climate change.

Keywords: Earth observation big data; Climate change; Information and simulation systems; Sensitive factors; Synchronous satellite-aerial-ground observation experiments

1. Introduction

The Earth observation big data era is on its way. In 2012, the International Data Corporation (IDC) released the 2020 Digital Universe report (Gantz and Reinsel, 2012), which stated that the total amount of data available will double every two years. Increasingly, there is a drive to observe the Earth in multi-scale, comprehensive, and real-time perspectives, and the capability of accessing global Earth observations information has been rapidly enhanced.

Concurrently, with global climate change becoming an international issue, the study of Earth observations related to global environmental change is increasingly linked to national interests and international politics and diplomacy. Global climate change research using big data from Earth observations is urgently needed not only to understand the Earth system's evolution but also to enable the coordinated and sustainable development of humanity within the Earth system, with the added consideration of safeguarding national rights and maintaining diplomatic relations.

1.1. The demand for Earth observation big data for climate change research and its applications

Prior to the development of Earth observation technology, scientists monitored the Earth predominantly through ground-

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based observations. Even though scientists could combine a series of single surface pictures into a global picture, such as the method established by World Weather Watch in 1963, other geophysical and biological phenomena were often not sampled as the coverage and density of networks and the vertical resolution of data was insufficient.

Earth observation technology has been widely applied in climate change research over the past few decades. This has facilitated the development of global climate change research, especially through providing a complete picture of biological, physical, and chemical parameters. The integration of data from Earth observations covering a large area is an improvement over that which can be achieved from data through ground-based measurements. In addition, multi-temporal Earth observation data may reveal large-scale processes and features that are not observable via traditional methods. Consequently, this large quantity of Earth observation data, along with the frequency and coverage of the data, provide scientists with global change images and maps that could not be produced using ground-based technologies.

1.2. The characteristics of Earth observation big data fitting for global climate change research

Global change is a complex system, with large-scale and long-period spatio-temporal characteristics, which must be studied using a variety of theories and methods. Earth observation big data has not only its own 4V features (volume, variety, veracity, and velocity) (Guo et al., 2014a) but also the unique advantages for global climate change research of macro-scale, rapid, and quantitative features. In addition, it has 3H scientific connotations (Guo et al., 2014a), indicating high dimension (The data can reflect and present complex relationships between natural and social phenomena, and external characterizations generally have good correlations and multiple data attributes) (Abarbanel et al., 1993; Guo, 2010); high complexity (The data is incorporated in highly complex data models, and calculations include data processing and analysis, as well as modeling and computing between complex systems and data) (Rocha, 1999; Guo and Zhu, 2013); and high uncertainty (Data errors or incompleteness of data is unavoidable because of the high uncertainty involved in data acquisition, which includes understanding natural processes and conducting scientific experiments such as climate change modeling).

After half a century of development, three-dimensional Earth observation systems have been developed to monitor terrestrial, oceanic, and atmospheric changes. The operating band of satellite data covers the electromagnetic spectrum from visible light and infrared to microwave. Therefore, multi-system observation networks are very effective technical methods for accurately monitoring global change. However, Earth observation big data faces the challenge that a huge amount of data must be collected, characterized, and analyzed, accounting for the multi-source, multi-variable, and multi-scale data with the different spatial and temporal attributes. In addition, Earth observation big data faces the challenges of building and quantitatively analyzing complex geoscience processes and spatio-temporal systems that express socioeconomic processes. Consequently, Earth observation big data research combines many research areas and disciplines.

To tackle the scientific problems associated with climate change, global climate change research requires not only a wide range of data gained through real-time dynamic monitoring and analysis but also information on the relationships and laws that connect the large quantity of Earth observation big data. This combination leads to the development of new models, increased knowledge and even the implementation of new laws related to global change, which would not be possible with conventional observation methods.

2. Advances in climate change research based on Earth observation big data

2.1. Earth observation satellites and global climate change

Earth observations have changed the way that we understand the Earth. For example, Earth observations can provide the necessary information that verifies and improves our knowledge of the coupling between the El Niño−Southern Oscillation and ocean currents, temperatures, atmospheric processes, the effect of snow on water circulation, the effects of global and regional factors on sea level changes, and a range of other phenomena.

NASA launched the first weather satellite, TIROS 1, in 1960. The images taken by this satellite have revealed astonishing cloud features. By December 2011, a further 514 Earth observation satellites were launched worldwide and 200 more launches are planned by 2030. This huge amount of satellite data now available plays an important role in global climate change research. The functions of these satellites are summarized in Table 1.

2.2. Earth observations data parameters and their capabilities

The United Nations Framework Convention on Climate Change (UNFCCC) provides a total of 34 Essential Climate Variables (ECVs) that require contributions from Earth observations from space (Table 2).

2.2.1. The capacity of Earth observations for atmospheric parameters

Ground systems such as the rain gauge network and ground-based radar are still a major means of observing atmospheric structures. Yet, Earth observation satellites can monitor clouds, water vapor, precipitation, and wind at different spatial and temporal scales. For example, the combination of data from instruments such as Advanced Very High Resolution Radiometers (AVHRR) from the U.S., Moderate Resolution Imaging Spectrometers (MODIS) from the U.S.,

Table 1
Summary of the functions of satellites related to global change research.

Satellite	Function
TIROS series, Nimbus 4 and 7, ERS-1, ERS-2, Envisat	Monitoring global stratospheric ozone depletion (including Antarctica and Arctic)
Nimbus 7, ERS-2, Envisat, Aqua, Aura, MetOp	Detecting tropospheric ozone
Explorer 7, TIROS, Nimbus	Measuring radiation balance
TIROS series, ATS, SMS, MetOp	Producing weather images
Meteorological satellite, including TIROS series, GOES and POES (NOAA), MetOp (Eumetsat), ERS-1, ERS-2, Envisat	Weather forecasting
Radarsat, Landsat, Aura, Terra, Jason, ERS-1, ERS-2, Envisat	Investigating ice flow in Antarctica and Greenland
Topex/Poseidon, ERS-1, ERS-2, Envisat	Detecting mid-scale sea surface topography, and important variables in ocean mixtures
TIORS-N and NOAA series, ERS-1, ERS-2, Envisat	Observations of oceanic contributions to climate change
Landsat, SPOT series	Agricultural land monitoring
LAGEOS, GPS	Confirming high-precision terrestrial reference frames

Sources: NRC (2008).

the Medium Resolution Imaging Spectrometer (MERIS) from the European Space Agency (ESA) and the international A-Train satellite system have provided collective data on clouds, rain, and pollutants that has led to a greater understanding of cloud pollution influences.

2.2.2. The capacity of Earth observations for ocean parameters

At present, Earth observation satellites can provide hundreds of spatial, spectral, radiation, and time-scale data products (Table 3) to monitor water quality, water color (e.g. chlorophyll, suspended solids, and turbidity) and sea surface temperatures. For example, the AVHRR, AATSR, and MODIS sensors provide data on sea surface temperatures (CEOS, 2006).

2.2.3. The capacity of Earth observations for terrestrial parameters

Soil moisture and salinity parameters profoundly affect the global energy and moisture balance. The cryosphere, consisting of lakes, river ice, snow cover, glaciers, ice caps, ice, and frozen ground (including permafrost), is one of the most important parts of the climate system. Thus, soil moisture, salinity, and changes in the cryosphere are very important in monitoring global climate change, managing regional water resources, and investigating water and land ecosystems and global sea levels. For example, the data from polar-orbiting and geostationary satellites (carrying visible/near-infrared sensors), such as the Geostationary Operational Environmental Satellite system (GOES), Landsat, MODIS, MERIS, and AVHRR, can be used to monitor the melt flow from snow cover and glaciers. This provides important information for the management of water resources, such as flood disaster prediction and reservoir operation. Data from the Sea Winds scatterometers on board QuikSCAT satellites can monitor seasonal changes in ice, track giant icebergs, and provide daily maps of ocean ice at 6-km resolution.

In addition, many satellites can obtain data on elevation measurements, geopotential heights, and terrain. For example, P-band Synthetic Aperture Radar (SAR) has the ability to penetrate cloud cover and the vegetation canopy and is therefore useful in tropical and northern forest research at high altitudes. Improved SAR such as the Advance Synthetic Aperture Radar (ASAR) and Phased Array L-band SAR (PALSAR) are available for agriculture, forestry, land cover classification, hydrology, and cartography.

Table 2
Essential Climate Variables (ECVs) that are feasible for global implementation and have a high impact on UNFCCC requirements.

Domain		Essential climate variables
Atmospheric	Surface	Air temperature, wind speed and direction, water vapor, pressure, precipitation, surface radiation budget
	Upper-air	Temperature, wind speed and direction, water vapor, cloud properties, Earth radiation budget (including solar irradiance)
	Composition	Carbon dioxide, methane, and other long-lived greenhouse gases; ozone and aerosols, supported by their precursors
Oceanic	Surface	Sea surface temperature, sea surface salinity, sea level, sea state, sea ice, surface current, ocean color (for biological activity), carbon dioxide partial pressure, ocean acidity
	Sub-surface	Temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers, phytoplankton, marine biodiversity, and habitat properties
Terrestrial	River discharge, water use, ground water, lakes, snow cover, glaciers and ice caps, ice sheets, permafrost, albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (fPAR), leaf area index (LAI), above-ground biomass, soil carbon, fire disturbance, soil moisture, terrestrial biodiversity, and habitat properties	

Sources: CEOS (2006, 2007).

Table 3
Remotely sensed oceanographic parameters, their observational category and representative sensors.

Parameter	Observational category	Satellite/Sensor
Bio-optical	Visible to near-infrared	ENVISAT/MERIS, AQUA/MODIS, OrbView-2/SeaWiFS
Bathymetry	Visible to near-infrared	Landsat, SPOT, IKONOS
Sea surface temperature	Thermal infrared microwave radiometers	POES/AVHRR, GOES/Imager DMSP/SSM/I, TRMM/TMI
Sea surface roughness, wind velocities, waves and tides	Microwave scatterometers and altimeters synthetic aperture radar	ERS-1 & -2/AMI QuikSCAT RADARSAT-1
Sea surface height and wind speeds	Altimeters	Topex/Poseidon, Jason-1
Sea ice	Visible to near-infrared microwave radiometers, scatterometers and altimeters synthetic aperture radar	POES/AVHRR DMSP/SSM/I ERS-1 & -2/AMI RADARSAT-1
Surface currents, fronts, and circulation	Visible to near-infrared, thermal infrared microwave scatterometers and altimeters	POES/AVHRR, GOES/Imager Topex/Posiedon, Jason-1
Surface objects—ships, wakes, and flotsam	Synthetic aperture radar	RADARSAT-1, ENVISAT/ASAR

Source: Brown et al. (2005).

2.3. Scientific global change program based on Earth observation big data in China

With the rapid expansion of Earth observation big data, on July 9, 2010, China launched a major national scientific research project on global change research. This consisted of initial 19 major projects that would take advantage of in the progress of Earth observation. On May 14, 2012, the Ministry of Science and Technology of the People's Republic of China announced the National Science and Technology Major Project on Global Change in their 12th Five-Year Plan. The main aims of this project are to develop knowledge of global change, climate changes process and mechanisms, the impacts of human activities on global change, and climate change effects and adaption, through comprehensive observation, data integration, and Earth system models.

On September 17, 2014, the Ministry of Science and Technology of the People's Republic of China held a strategic seminar on global change research regarding the major scientific research project of the 13th Five-Year Plan. Due to the current limitations of global climate change research and its progress, the meeting proposed that efforts should be focused on research methods and global issues and priority given to a range of specific scientific issues.

Prior to this, the National Basic Research Program of China (973 Program) launched the Earth Observation for Sensitive Variables of Global Change: Mechanisms and Methodologies, on January 1, 2009. This was the first research project on Earth observation techniques for global change research in China. The project highlighted sensitive variables in terrestrial, oceanic and atmospheric systems, based on Earth observation big data from multi-platform and multi-band sensors, through

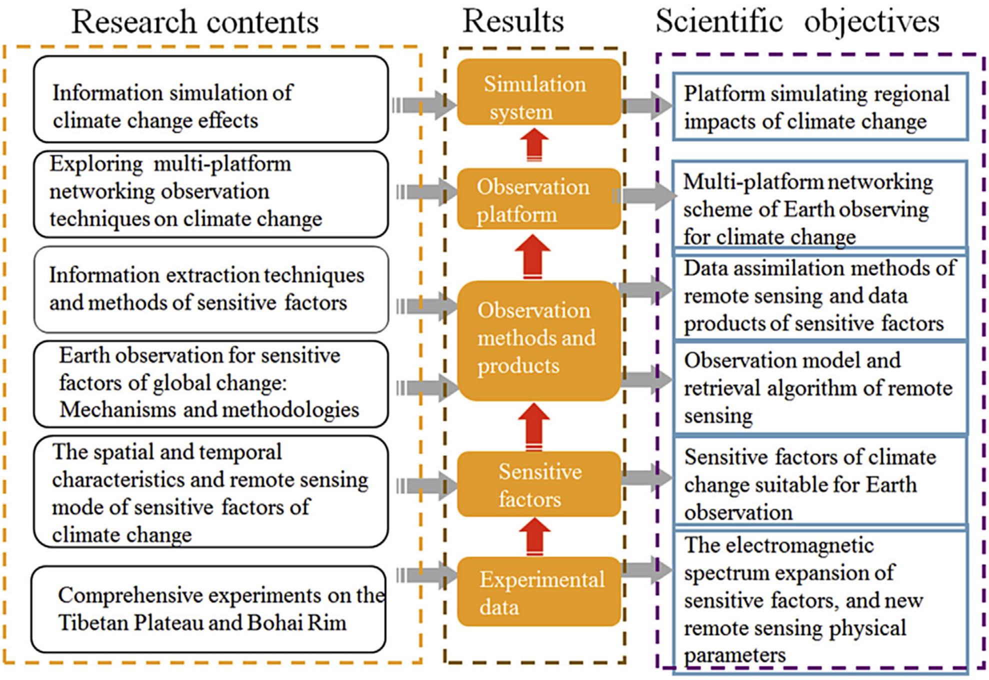

Fig. 1. Research scheme for the Earth observation for sensitive variables of global change: mechanisms and methodologies project.

focusing on new theories, technologies, and methods in these fields. Subsequently, remote sensing theories and methodologies relating the complex variables of these systems were established. The research scheme of the project is shown in Fig. 1.

3. Climate change studies with Earth observation big data

Increasingly, climate change is becoming a major global issue with a significant impact on humanity. Research on climate change requires large amounts of both new and historic data for analysis and modeling.

3.1. Synchronous satellite-aerial-ground observation experiments

A number of Earth observation platforms are used to collectively enable real-time observation and dynamic monitoring of the Earth's land, atmosphere, and oceans, and provide macro-scale, accurate, comprehensive, continuous, and diverse information on Earth's surface. This multi-source Earth observation data has altered the methods by which the Earth system data and perceptions are obtained. It also plays a fundamental role in the support of scientific innovation. Effective use of multi-platform observation data with multi-sensors can avoid issues relating to information extraction and inversions that arise with the use of a single sensor. Multi-source Earth observations also provide long-term and stable spatial data for scientific research, compensating for uneven spatio-temporal observations and playing a fundamental supporting role in global change research.

The Earth is a large, complex system, and research on climate change involves the atmosphere, oceans, and land. Thus, a wide range of scientific data is required to detect sensitive factors related to climate change. Through synchronous satellite−aerial−ground observation experiments (Fig. 2), researchers have acquired large amounts of data, including multi-platform, multi-band, and multi-scale data. Based on these data, researchers have explored new theories, technologies, and methods for climate change studies, developed assimilation models using multi-source heterogeneous spatial data, precisely and rapidly acquired the characteristics of sensitive factors for climate change and developed simulation platforms for regional climate change studies. Other scientific data obtained can include fundamental geographic information data, ground-based and in-situ observation data, and data derived from Earth system and data assimilation models. This Earth observation data combined with auxiliary data has the typical 4V characteristics of big data.

3.2. Earth observation sensitive factors for climate change studies

The spatial properties of sensitive factors for global change enable the usage of Earth observation technology. The spatio-temporal characteristics of the sensitive factors for climate change have experienced significant change in recent decades. These changes are predominantly due to human activity and climate change on regional and global scales. Through a variety of methods such as multi-satellite, multi-sensor, and long-term time series remote sensing data, it has been possible to derive climate sensitivity factors and aid in the study of the

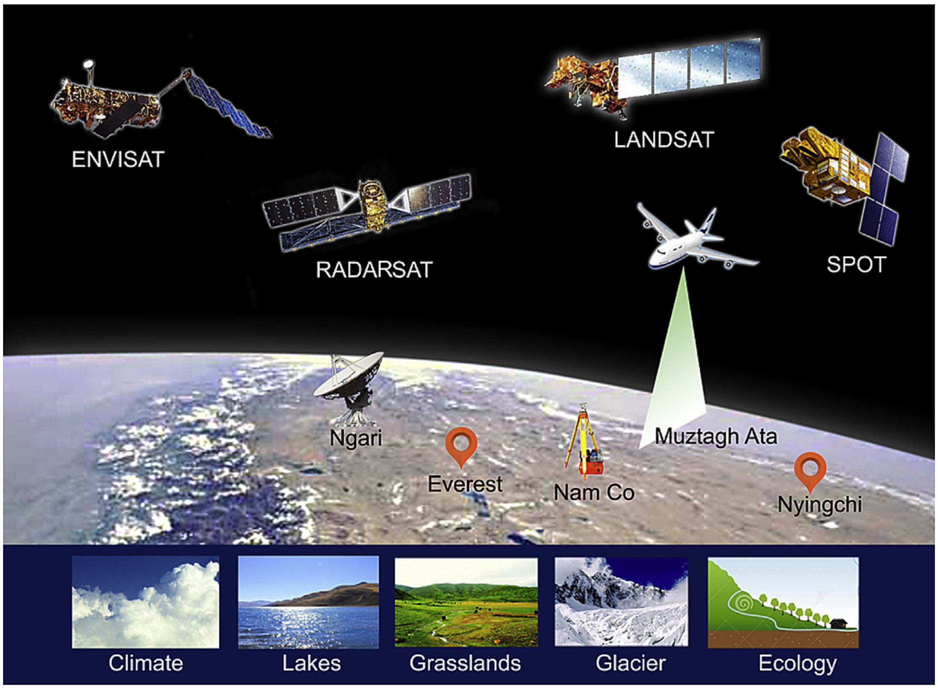

Fig. 2. The synchronous satellite-aerial-ground observation experiments on the Qinghai-Tibetan Plateau.

spatial variability of terrestrial ecosystems (e.g. glaciers, lakes, and vegetation), and in the understanding how they respond to global climate change.

3.2.1. Glaciers

Glaciers provide unique records and feedback that influences global climate change and is closely related to temperature, precipitation, and the material balance. The glaciers on the Tibetan Plateau have retreated considerably since the 1970's and this rate of retreat has accelerated in recent years. In general, the retreat rate for glaciers covering less than 1 km^2 is faster than that for the larger glaciers, yet significant spatial differences do exist. For example, glacial retreat was observed to be fastest in the Himalayas and slow in the central plateau (Yao et al., 2003). It has been suggested that the retreat of the Himalayan glaciers is much more serious than expected (Ma et al., 2010). Consequently, with the rapid melting of glaciers, lakes supplied by the glacier melt water, such as Nam Co Lake (the highest lake in the central Tibetan Plateau), have expanded between 1976 and 2009 (Zhang et al., 2011).

Based on Interferometric Synthetic Aperture Radar (InSAR) data and elevation data from the Geoscience Laser Altimeter System instrument aboard the Ice, Cloud, and land Elevation satellite (ICESat/GLAS14), along with digital elevation model (DEM) data, a method for extracting glacier thickness has been developed. As a result of calculations using ICESat elevation data and the Shuttle Radar Topography Mission digital elevation model (SRTM DEM), a reduction in the rate of the thickness of the Naimona'nyi glacier of 0.63 m per year (water equivalent) between 2000 and 2009 was observed (Zong et al., 2013). This lies between the material balance (0.56 m per year (water equivalent)) and the glacier thickness reduction (0.65 m per year (water equivalent)) measured by GPS (Li et al., 2012). In general, glacial shrinkage decreases toward the interior plateau from the Himalayas, and the minimum degree of shrinkage is in the Pamir mountain range (Yao et al., 2012).

3.2.2. Lakes

Large fluctuations of lake surface area in a short time have a significant influence on water cycles and the local ecological environments. Studies have been conducted on lake areas, together with water level monitoring in different regions of the Tibetan Plateau using Landsat and ICESat data. Since 2003 large spatial variation in lake area on the Tibetan Plateau has been observed, with a shrinkage of lakes in southern Tibet and an expansion trend seen for the lakes in the Qiangtang region (Liao et al., 2013). In the Qaidam Basin, the Qinghai Lake showed an expansion trend and the annual rate of change of water volume in spring was greater than that in autumn. The Gyaring Lake in the eastern Tibetan Plateau also showed an expansion trend mirroring that of the Qinghai Lake (Liao et al., 2013). Glacial melt is the dominant driver for the recent lake expansions on the Tibetan Plateau. By investigating detailed changes in the surface area and levels of lakes across the Tibetan Plateau from Landsat/ICESat data, Li et al. (2014) found a spatial pattern in the lake changes from 1970 to 2010 (especially after 2000). They observed a southwest–northeast transition from shrinking, to stable, to rapidly expanding lakes, which suggests a limited influence of glacial melt on lake dynamics. The plateau-wide pattern of lake area changes is related to precipitation variations and is consistent with the pattern of permafrost degradation induced by rising temperatures (Li et al., 2014).

3.2.3. Vegetation

The plant phenological period is closely related to climate change and phenological changes influence the carbon balance of terrestrial ecosystems by effecting ecosystem productivity. The alpine vegetation in the Tibetan Plateau is extremely sensitive to global change. Zhang et al. (2013) and Wang et al. (2015) used MODIS to analyze the response and driving factors of space observations of plant greenness and phenology (Fig. 3). Zhang et al. (2013) found that the normalized difference vegetation index (NDVI) showed a gradual increasing trend in the plateau during the growing seasons from 2000 to 2009. On the western Tibetan Plateau, the continuous precipitation decline resulted in a delay in the alpine grassland phenology; whereas in the eastern part of the plateau, the precipitation continued to increase, resulting in an advance in the grassland phenology (Wang et al., 2015). In addition, Liu et al. (2014) found that the spring phenology of the grasslands on the Tibetan Plateau exhibited a stronger response to changes in temperature at higher elevations than at lower elevations.

The remote sensing and monitoring of C_3 and C_4 grass species and their response to climate change are mainly focused on the high-precision extraction of plant functional types and on the transformation response of the grassland type to global climate change and human factors. In the U.S. Great Plains, vegetation with different functional types usually shows similar temporal trends in NDVI but different phenological characteristics (Wang et al., 2013). The onset of the growing season for C_3 grasses is earlier than for that for C_4 grasses, and the growing season of C_3 grasses is longer. However, under mild weather conditions, C_3/C_4 shortgrasses have similar onsets of season dates and growing season lengths compared with C_3/C_4 tallgrasses (Wang et al., 2013). In northern China, a study by Guan et al. (2012) showed that temperate grassland was mainly occupied by C_3 species, yet C_4 species made an important contribution to the grassland biomass.

The fraction of photosynthetically active radiation (fPAR) is an important physiological parameter that reflects the growth of vegetation and is one of the key parameters for terrestrial ecosystem models and for reflecting global climate change (Fig. 4). Peng et al. (2012) found that the spatial variation of global fPAR was affected by not only the vegetation types but also the changes in seasonal cycles. Temperature, precipitation and extreme drought have different effects on fPAR. Climate change, deforestation, reforestation, and other human activities also have a significant impact on fPAR in regions such as Southeast Asia and the Three-North Shelter Forest area in China.

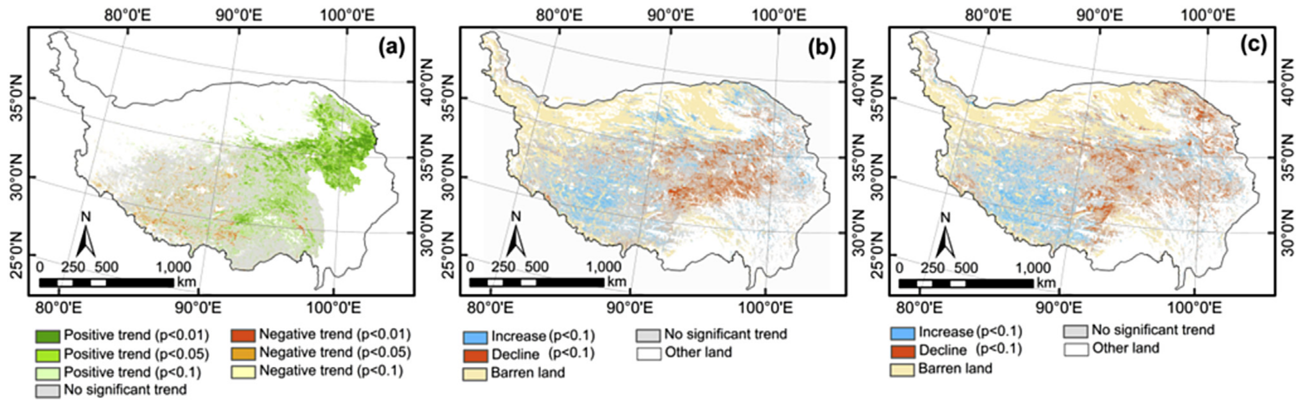

Fig. 3. Trends in (a) the growing season NDVI, (b) the start of the season, and (c) the end of the season during 2000–2009 on the Tibetan Plateau (Zhang et al., 2013; Wang et al., 2015).

3.2.4. Radiation

(1) Impacts of aerosols on cloud cover and the regional radiation forcing effect

On the basis of satellite remote sensing data from aerosol-cloud-radiation and trace gases combined with meteorological observations, Xia (2010, 2012) analyzed long-term trends in sunshine duration (SSD) and surface solar radiation and focused on the possible impacts of clouds on solar radiation in China over the last 50 years. The results indicated that the SSD and total cloud cover (TCC) showed a significant decreasing trend; however, with low-level cloud cover (LCC), a slight increasing trend was observed (Xia, 2010). It was further highlighted that short-term variability of SSD is mainly determined by the amount of cloud cover, but the long-term change in TCC cannot account for the decreasing trend in SSD. Regarding the impacts of aerosols on clouds, Xia (2012) found that the data is inconsistent with the expectation that larger decreasing trends in cloud cover should be observed in regions with higher aerosol loading; therefore, the aerosol effect on decreasing cloud cover in China does not appear to be supported by the results of their study.

(2) Spatio-temporal characteristics of land surface solar radiation in China

The land surface solar radiation in China, and its temporal trends, were calculated and the results demonstrate that previous studies had overestimated the downward trend in land surface solar radiation in China (Tang et al., 2011). However, the aerosol abundance from human activities was still negligible on the Tibetan Plateau, and the decrease in solar radiation over the plateau was larger in magnitude than for the rest of China after the 1970s. Further research revealed that solar radiation on the Tibetan Plateau had continually decreased over the preceding 30 years owing to the increasing water vapor and deep convective clouds. These increases were found to be connected to the warming climate and the enhanced effective convection energy of the Tibetan Plateau (Tang et al., 2011).

3.2.5. Urbanization and warming effects

The change in land use driven by human activities is considered to be an important process due to the effect it has on the land surface air temperature. Based on remote sensing data, meteorological station data, and a regional climate model, He and Jia (2012) and He et al. (2013) simulated and examined the impacts of land use changes and vegetation cover on land surface air temperatures over three urban areas in eastern China. The results indicated that rapid land use change has caused a significant regional warming effect in the densely populated area of eastern China during the last few decades (He et al., 2013). The increase in the land surface air temperature in the rural–urban continuum was shown to be larger than that in the city center and outer suburban districts.

A numerical simulation of the regional climate coupled with the urban canopy model shows that high levels of

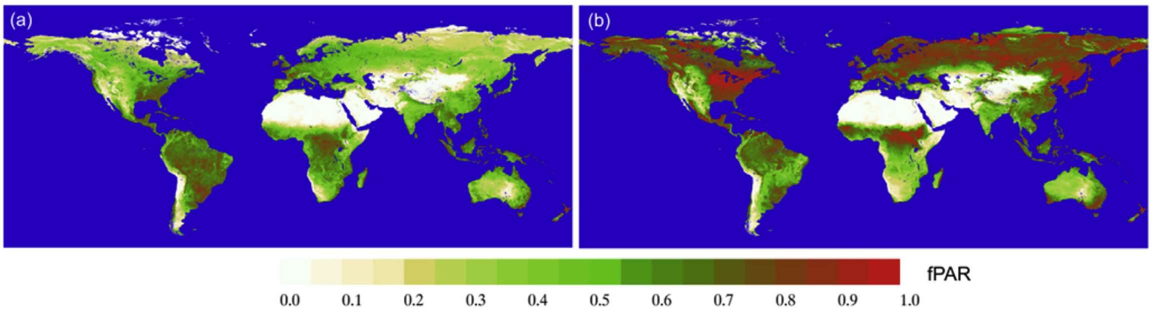

Fig. 4. Spatial patterns of global fPAR,. (a) annual averaged fPAR in 2006, and (b) averaged fPAR in the latter half of August in 2006.

urbanization results in significant regional warming (Wang et al., 2012; Feng et al., 2014). These results indicate that land use changes due to urbanization result in an observable warming effect, especially in summer, whereas anthropogenic heat release in winter also results in a significant warming effect.

3.3. Global environmental change information and simulation systems

Global environmental change information and simulation systems have provided key technologies that allow for efficient visualization of multi-dimensional data and geo-temporal process modeling, enabling the interpretation and simulation of the sensitivity factors for climate change and dynamic simulations of global change processes. These have then been successfully applied to simulate sea level rises, and glacier−lake changes on the Tibetan Plateau, along with earthquake disasters.

3.3.1. Sea level simulations for coastal regions

Based on the information simulation platform of global environmental changes, researchers use geographic data, Earth observation data, ground measurement data, scientific model data, land use data, and socioeconomic data to simulate the influence of sea level rise on river deltas around the world. Based on analyses of DEM characteristics for coastal areas under various sea level rise scenarios, the effects on population and socioeconomic losses are evaluated quantitatively using Geographical Information Systems (GIS) and hydrodynamic methods (Du et al., 2015). A comparative analysis of the influence of a global sea level rise on typical river deltas shows that although China's flooded delta areas are smaller than those of the Mekong River and the Mississippi River, the affected population in the Yangtze River Delta and the Bohai area is far greater than for other river delta areas around the world.

3.3.2. Glacier−lake change simulations over the Tibetan Plateau

On the basis of high-resolution terrain data, multi-platform remote sensing data, meteorological data, and hydrological material (such as lake water depth data), the information simulation platform constructed a three-dimensional virtual environment for the Tibetan Plateau. The platform extracted information on changes in lake and glacial areas and analyzed these changes in response to climate change. On the basis of a water balance model, GIS technology, statistical analysis, and a climate model, the system produced a simulation of the changes in glaciers and lakes for the Tibetan Plateau.

3.3.3. Disaster assessments for disaster relief, quick response, and government decision-making

Disaster relief and response requires a fast, accurate, and comprehensive overview of the damaged and affected areas. An emergency monitoring system has been constructed based on active and passive remote sensing data to improve rapid response and disaster relief cooperative capability. Based on image processing techniques for both optical and radar remote sensing data, including SAR, InSAR, and polarimetric synthetic aperture radar (PolSAR) data, earthquake disaster information can be extracted rapidly (Guo et al., 2011). A visual three-dimensional simulation and assessment system of earthquake regions has been developed using highly efficient three-dimensional spatial information visualization technology. A number of collapse, landslide, mud-rock flow and other geological disaster assessment models are integrated in the system so that it can be used for disaster monitoring, relief, rescue, and government decision-making. Based on basic geographic information such as population, transport infrastructure, administration, and land use, as well as early warning information of the earthquake's intensity, it was possible to rapidly evaluate the disaster-affected population, housing collapses, casualties, and property losses for the Wenchuan and Yushu earthquakes. Remote sensing data and the assessment system were able to provide valuable information for the reconstruction of Beichuan county in China, following an earthquake, in addition to the important role they played in the emergency and disaster relief of the Wenchuan, Yushu, and Yayan earthquakes in China.

4. Conclusions

In 2012, the United Nations Global Pulse published a white paper, Big Data for Development: Opportunities & Challenges, which not only described the opportunities, challenges, and applications that big data had brought about but also noted the value of big data in academia and decision-making. The Future Earth ten-year scientific program (2014−2023) is a response to the challenge that global climate change will bring to states and societies. It is designed to strengthen communication and cooperation between the natural and social sciences, providing globally sustainable development with the necessary theoretical knowledge, research tools, and methods; it will also enhance the global capacity for sustainable development. The development of Future Earth cannot be separated from the huge volume and various types of available data, and it is therefore critical that methods are developed to use such data to meet the challenges brought about by global climate change.

With the advent of the era of global change, Earth observation technologies are developing a systematic observation of the Earth system. Satellite observations have provided a wealth of data on global change research. However, there are still some drawbacks, such as the lack of guarantees for the continuity of the data, the data uncertainty, the fact that the network of multi-source remote sensing data has not been optimized, that the data assimilation process lacks data validation, and that Earth observation information has not yet met the needs of model parameters (IPCC, 2007; FAO, 2011).

These factors will mean that the sensors cannot be fully utilized and will restrict the use of the data for many applications. In addition, they will also restrict the monitoring and assessment capabilities for climate change study.

Our space observation technology has made great progresses in recent years. China is a country very seriously affected by global changes, so global change research is necessary for political, economic, and societal development in China. It has launched a series of satellites, but there is no plan to further develop scientific satellites for global change research (Guo et al., 2014b), which restricts the development of global change research and applications. Therefore, we should regard solutions to the global change issues faced by humanity as the most important scientific goals, and build specific global change scientific satellite observing systems. We must further strengthen the integrated management of our Future Earth observation development, to improve top-level design capability and performance, and to further promote the sharing of resources and observational data to reduce duplication and improve service efficiency for Earth observation data. To improve the use of Earth observation big data in global change research, we should further strengthen the management of data resources and accelerate the construction of the global change Earth observation data-sharing platform for the realization of effective sharing of data resources.

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