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Foreword

Global change and the major environmental issues caused by climate change are challenging the fundamentals of human existence in the twenty-first century. Because it produces changes in the natural environment, climate change has a profound influence on economic and social development. The question of how to achieve sustainable development while dealing with climate change is one of the most important topics that human society currently faces.

China is fully committed to climate change research, including the study of the interactions between human activities and climate change, Earth system models, the assimilation of Earth observation data and its applications, and economic issues related to climate change. Long-term, high-quality observation data and their assimilation into Earth system models help to limit uncertainties in the understanding of climate change. Hence, it is necessary to establish sensitive, reliable, and comprehensive Earth observation systems. These systems should have integrated observation processes that focus on the key parameters of climate change and possess resilient capabilities in terms of data assimilation, data fusion, and application of the data.

Although climate change research in China has made a great deal of progress, it is still extremely important to enhance the involvement of Earth observation technology in climate change research. Earth observation technology has the ability to acquire accurate data about Earth rapidly, and at a large scale, and thus plays a key role in the study of climate change. The Cape Town Declaration, agreed at the Group on Earth Observations Ministerial Summit in 2007, stressed the importance of Earth observation technology for climate change research, recognizing that "nations are facing major environmental, social, and economic challenges as a consequence of global change" and that "sound policy making for addressing the environment and sustainable development must be based on understanding, describing and predicting a complex and interdependent world, and therefore requires terrestrial, oceanic, airborne, and space-based Earth observations, data assimilation techniques, and Earth system modeling."

To enhance global change research, the concept of Moon-based Earth observation has been proposed. Since 2016, Professor Huadong Guo and his team have been undertaking the research project "Moon-based observation research of Earth's macroscopic scientific phenomena," a project of the National Natural Science Foundation of China. This project has achieved fruitful results that address the theoretical and methodological aspects of climate change. This book, which is one of the outcomes of the project, systematically analyzes the present state of climate change research and also the scientific requirements of Earth observation technology. It comprehensively introduces the decades of international and domestic development in Earth observation, and thoroughly addresses the frameworks and technical parameters of satellite systems used for climate change research. More importantly, the book introduces scientific insights into climate change's sensitive variables and also the concept of a climate change satellite. Meanwhile, several new directions for the application of Earth observations in climate change research are proposed.

This book is of both a high academic level and great practical value and describes the role of Earth observation satellites in climate change research. It will serve as an important reference for climate change research and the development of space technology. China is making rapid progress in space technology. However, in the coming years, it will be necessary to develop and launch scientific satellites that are to be used exclusively for climate change research. This book will be valuable to climate change researchers, Earth scientists, Earth observation engineers, government officers, decision makers, teachers, and graduate students. It should also provide significant lessons for the development of the national Earth observation satellite system and the construction of space infrastructure.

Beijing, China
March 2019

Guanhua Xu

Preface

In recent decades, global change has become one of the central issues to be addressed by researchers, innovators, and decision makers around the world. Global change not only brings severe challenges for the survival and development of the nations but also poses fundamental threats to the living conditions and lifestyle of humanity as a whole. As Rajendra K. Pachauri, chair of the IPCC stated, “The effects of climate change are already occurring on all continents and across the oceans. Nobody on this planet is going to be untouched by the impacts of climate change.” Thus, there is no doubt that global change research is essential if the social, economic, ecological, and political dimensions of issues are to be recognized.

Global change involves the systematic and complex variations of Earth’s systems. Along with changes in time, spatial transformations are also evident at multiple scales. Therefore, a variety of theoretical and technological methods are essential in global change research. It is well known that, because of their ability to provide large-scale, accurate, fast, and dynamic monitoring, satellite observations have been widely used in global change studies. Over the past fifty years, Earth observation has developed into a stereoscopic observation system that can conduct dynamic monitoring of the land, the oceans, and the atmosphere at local to regional and to global scales, using sensors operating the whole spectrum from visible to microwave frequencies. Such an integrated monitoring network definitely plays a significant role in detecting and predicting global change phenomena at fine scales.

During the past thirty years, China has concentrated on building up a relatively stable Earth observation system and has launched four series of satellites, including meteorological satellites, resource satellites, environmental satellites, and ocean satellites. However, it is worth noting that although a large number of Earth observation satellites have been launched, most of these are industrial satellites, and scientific satellites account for only a small proportion. Moreover, very few of them are used in global change studies. For this reason, large-scale research on global change is greatly limited by the lack of corresponding scientific satellite programs.

Earth observation satellites mainly consist of industrial satellites and scientific satellites. Global change scientific satellites make use of the "resource" of the entire electromagnetic wave to provide abundant observation data for global change factors. Therefore, it is of great scientific and social significance that China is developing industrial satellites and meanwhile also building a global change scientific satellite system to make contributions to global change research in China and the rest of the world.

The project "Moon-based observation research of Earth's macroscopic scientific phenomena" aims to establish a Moon-based Earth observation platform in the future and to develop the theory of Moon-based Earth observation for studying Earth's macroscopic scientific phenomena. By analyzing the interaction between ground features and electromagnetic waves, the project demonstrates the utility of Moon-based Earth observation for long-distance, large-scale observation. Responding to the demand for precision observation of macroscopic-scale targets, the project will explore the models and methods of Moon-based Earth observation. Based on the movement of the Sun, Earth, and Moon, the project will establish theoretical parameter settings and optimizations for Moon-based sensors. Through multidisciplinary crossover studies, the project will propose a scientific framework for the Moon-based Earth observation platform.

This book, therefore, proposes a new series of satellites—global change scientific satellites—as part of China's Earth observation satellite programs. These will not only provide basic datasets relevant to global change research in China but also offer accurate information to be used in international negotiations on global change, provide scientific support for decisions made by the government and, in particular, bring the implementation of a "Beautiful China" a step closer, as well as facilitating advances in international global change research.

The book is divided into three parts that comprise a total of 18 chapters. Part I contains six chapters and can be grouped into four aspects: (1) an overview of the development of Earth observation satellites during the past half century and a discussion on future trends; (2) a presentation of the development of Earth observation satellites in specific countries and regions, including the USA, Europe, Russia, Japan, and Canada; (3) an introduction to China's meteorological, ocean, resource, and environmental satellites, as well as the satellites belonging to the high-resolution Earth observation system, the "BeiDou" navigation satellite system, and the "Shenzhou" spacecraft program; and 4) an illustration of the latest research progress produced by comprehensive projects on global Earth observation and the organizations related to these projects, including the Global Earth Observation System of Systems (GEOSS), the Committee on Earth Observation Satellites (CEOS), and the Global Monitoring for Environment and Security (GMES) initiative.

Part II consists of eight chapters. In this section, we propose a plan for a series of global change scientific satellites, which includes the following six satellites: (1) an atmospheric carbon satellite to objectively acquire real-time data on CO_2 concentrations to meet the demand for global model-based estimations of carbon sources and sinks; (2) an aerosol satellite to retrieve aerosol optical thickness to provide information on spatial patterns of aerosols and haze; (3) a night-light satellite to provide data for comprehensive analysis and rapid assessment of urbanization factors, such as land cover, population density, and economic activity; (4) a forest biomass satellite to enable the acquisition of quantitative, continuous, high-precision forest biomass data at regional and global scales using spaceborne LiDAR systems and SAR to estimate carbon storage; (5) a glacier satellite to record glacial processes closely related to temperature, rainfall, and mass balance to provide evidence of global environmental change in a unique way; and (6) an ocean salinity satellite to provide data on the variables necessary for the study of such oceanic phenomena as ocean circulation and global sea-level change. These six satellites would be of great importance in dealing with major scientific issues and, at the same time, would facilitate the development of China's Earth observation satellites. Finally, an analysis of the techniques and models used in multi-satellite networks is discussed in this part.

Part III introduces Moon-based Earth observation and comprises three chapters. It focuses on Moon-based global change observation, frontiers of Moon-based Earth Observation, and a comparison of global change research related Earth and the other planets. Among these, the topic of Moon-based global change observation is a highlight of the book. Aircrafts and satellites are commonly used as observation platforms, but here we propose the installation of sensors on the Moon, using it as a platform for observing global-scale phenomena. The Moon has many unique advantages as an Earth observation platform. For one, a panoramic view of a whole hemisphere can be acquired. Another is that the lunar surface is in an ultra-high vacuum state. Also, one side of the Moon always faces Earth, and thus, the same area on Earth can be observed from various angles over a long period of time. These factors make it possible to monitor geological and global change phenomena at a large scale. Also, as Earth does not exist in isolation, it is necessary to conduct comparable research on global change on both Earth and other planets.

I would like to take this opportunity to express gratitude to my colleagues who have devoted their time and effort toward the publication of this book. First of all, I am grateful to all the contributing authors. My heartfelt appreciation also goes to all the experts who contributed substantially toward the implementation of the Moon-based Earth observation project. The Foreword written by Professor Guanhua Xu is also greatly appreciated.

Beijing, China
March 2019

Huadong Guo

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Acronyms

AATSR	Advanced Along-Track Scanning Radiometer
ADEOS	Advanced Earth Observing Satellite
AIRS	Atmospheric infrared sounder
ALOS	Advanced Land Observing Satellite
AMSR-E	Advanced Microwave Scanning Radiometer—Earth Observing System
AMSU	Advanced microwave sounding unit
AOT	Aerosol optical thickness
APS	Aerosol Polarimetry Sensor
Argo	Array for Real-Time Geostrophic Oceanography
ASAR	Advanced synthetic aperture radar
ASCAT	Advanced scatterometer
ASI	Agenzia Spaziale Italiana
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very-High-Resolution Radiometer
AVNIR	Advanced Visible and Near-Infrared Radiometer
BRDF	Bidirectional reflectance distribution function
CAI	Cloud and aerosol imager
CAST	China Academy of Space Technology
CBERS	China–Brazil Earth Resources Satellite
CCD	Charge-coupled device
CCRS	Canada Centre for Remote Sensing
CCSP	Climate Change Science Program
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth’s Radiant Energy System
CH4	Methane
CHP	Canopy height profile
CLIVAR	Climate Variability and Predictability Program
CMA	China Meteorological Administration

CNES	Center National d'Études Spatiales
CPR	Cloud profiling radar
CPS	Charged particle spectrometer
CSA	Canadian Space Agency
CZCS	Coastal zone color scanner
DDA	Delay Doppler Radar Altimeter
DEM	Digital elevation model
DIAL	Differential Absorption Light Detection and Ranging
DInSAR	Differential interferometry synthetic aperture radar
DIVERSITAS	An International Program of Biodiversity Science
DLR	The German Aerospace Center
DMC	Disaster Monitoring Constellation
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DORIS	Doppler Orbitography by Radiopositioning Integrated on Satellite
DU	Dobson unit
ECVs	Essential climate variables
EEA	European Environment Agency
ENSO	El Niño and Southern Oscillation
EO	Earth observation
EOP	Earth observation program
EOS	Earth observation system
EPPS	Energetic Particle and Plasma Spectrometer
ERIM	Environmental Research Institute of Michigan
ERS	Europe remote sensing satellite
ESA	European Space Agency
ESE	Earth Science Enterprise
ESSP	Earth System Science Partnership
ETM+	Enhanced Thematic Mapper
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization
FTIs	Fast-track initiatives
FTS	Fourier-transform spectrometers
GAMES	Gravity and Magnetic Earth Surveyor
GAW	Global Atmosphere Watch
GCOM	Global Change Observation Mission
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GCSVs	Global change sensitive variables
GDP	Gross domestic product
GEC	Global environmental change
GECAFS	Global Environmental Change and Food System
GECHH	Global Environmental Change and Human Health
GECHS	Global Environmental Change and Human Security

GEO	Group on Earth Observations
GEOGLAM	GEO Global Agricultural Monitoring Initiative
GEOSS	Global Earth Observation System of Systems
GFZ	German Research Centre for Geosciences
GIS	Geographic information system
GLAS	Geoscience Laser Altimeter System
GLOBEC	Global Ocean Ecosystem Dynamics
GLONASS	Global navigation satellite system
GLP	Global Land Project
GMES	Global Monitoring for Environment and Security
GOCE	Gravity Field and Steady-State Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellites
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOOS	Global Ocean Observing System
GOSAT	Greenhouse Gases Observing Satellite
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRAS	Global Navigation Satellite System Receiver for Atmospheric Sounding
GRNS	Gamma-ray and neutron spectrometer
GRS	Gamma-ray spectrometer
GSD	Ground sample distance
GTOS	Global Terrestrial Observing System
GWSP	Global Water System Program
HDP	Human Dimensions Program
HEX	High-energy X-ray spectrometer
HIRDLS	High-resolution dynamics limb sounder
HIRS	High-resolution infrared radiation sounder
HRSC	High-resolution stereo camera
HRV	High-resolution visible range instrument
HySI	Hyperspectral imager
IASI	Infrared atmospheric sounding interferometer
ICSU	International Council of Scientific Unions
IEA	International Energy Agency
IEOS	Integrated Earth Observing System
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Program
IHDP	International Human Dimensions Program on Global Environmental Change
IIM	Interferometric imaging spectrometer
iLEAPS	Integrated Land Ecosystem–Atmosphere Processes Study
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
INPE	Instituto Nacional de Pesquisas Espaciais
InSAR	Interferometric synthetic aperture radar

IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IRAS	Infrared Atmospheric Sounder
IRS	Indian remote sensing satellite
IRTM	Infrared radiometers for thermal mapping
ISA	Impervious surface area
ISDR	International Strategy for Disaster Reduction
ISRO	The Indian Space Research Organization
ISS	International Space Station
ISSC	The International Social Science Council
IUBS	International Union of Biological Sciences
JAXA	Japan Aerospace Exploration Agency
JERS	Japanese Earth Resources Satellite
JPL	Jet Propulsion Laboratory
LAI	Leaf area index
LALT	Laser altimeter
LARS	Laboratory for Applications of Remote Sensing
LEO	Low Earth orbit
LiDAR	Light detection and ranging
LLRI	Lunar laser-ranging instrument
LMAG	Lunar Magnetometer
LOICZ	Land–Ocean Interactions in the Coastal Zone
LOLA	Lunar Orbiter Laser Altimeter
LRO	Lunar Reconnaissance Orbiter
LRS	Lunar Radar Sounder
LUCC	Land-use and land-cover change
LWIR	Longwave infrared
MAG/ER	Magnetometer and electron reflectometer
MEO	Medium Earth orbit
MERIS	Medium resolution imaging spectrometer
MFMR	Multi-frequency microwave radiometer
MHS	Microwave humidity sounder
MI	Multi-band imager
MIMR	Multi-frequency Image Microwave Radiometer
MIP	Moon impact probe
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MIRAS	Microwave Imaging Radiometer with Aperture Synthesis
MODIS	Moderate-resolution imaging spectroradiometer
MSMR	Multi-frequency scanning microwave sadiometer
MSS	Multispectral scanner
MTG	Meteosat Third Generation
MVISR	Multichannel Visible Infrared Scan Radiometer
MWR	Microwave radiometer
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration

NDVI	Normalized difference vegetation index
NEAR-GOOS	North-East Asian Regional–Global Ocean Observing System
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRC	United States National Research Council
NS	Neutron spectrometer
OCO	Orbiting Carbon Observatory
OLI	Operational Land Imager
OMI	Ozone monitoring instrument
PACE	Plasma analyzer
PAGES	Past Global Changes
PALSAR	Phased Array-Type L-band Synthetic Aperture Radar
POES	Polar-orbiting environmental satellite
PolInSAR	Polarimetric Interferometric Synthetic Aperture Radar
PRF	Pulse repetition frequency
PRISM	Panchromatic Remote Sensing Instrument for Stereo Mapping
RA	Radar altimeter
ROSCOSMOS	The Russian Federal Space Agency
RSAT	Relay Satellite Transponder
SAR	Synthetic aperture radar
SARSAT	Search and Rescue Satellite Aided Tracking System
SBUV	Solar Backscatter Ultraviolet Instrument
SCAR	Scientific Committee on Antarctic Research
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCOPE	Scientific Committee on Problems of the Environment
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SEM	Space Environment Monitor
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SIAR	Solar irradiance absolute radiometer
SIRAL	SAR/interferometric radar altimeter
SLFMR	Scanning low-frequency microwave radiometer
SMOS	Soil Moisture Ocean Salinity
SOLAS	Surface Ocean–Lower Atmosphere Study
SOOS	Southern Ocean Observing System
SP	Spectral profiler
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave/Imager
SSS	Sea surface salinity
SST	Sea surface temperature
SWIR	Shortwave infrared
TC	Terrain camera
TCCON	Total Carbon Column Observing Network
TIR	Thermal infrared

TIRS	Thermal infrared sensor
TM	Thematic mapper
TMC	Terrain mapping camera
TOGA	Tropical Ocean Global Atmosphere program
TRMM	Tropical Rainfall Measuring Mission
UHI	Urban heat island
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USGCRP	United States Global Change Research Program
USGEO	United States Group on Earth Observations
USGS	United States Geological Survey
UTCSR	University of Texas Center for Space Research
VI	Vegetation indices
VISSR	Visible and infrared spin-scan radiometer
VNIR	Visible and near-infrared
WCRP	World Climate Research Program
WFC	Wide Field Camera
WMO	World Meteorological Organization
WRS	Worldwide Reference System
XRS	X-ray spectrometer

List of Figures