全球变化科学卫星

Scientific Satellites for Global Change Research

郭华东 等 著

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内 容 简 介

本书全面论述全球变化空间观测的发展、现状和趋势，提出全球变化敏感因子、全球变化科学卫星的概念和科学内涵。全书共三篇，第一篇概述空间对地观测卫星的发展及主要发达国家和组织的发展现状及趋势；第二篇介绍全球变化系列科学卫星，包括大气碳卫星、气溶胶卫星、夜间灯光卫星、森林生物量卫星、冰川卫星、海洋盐度卫星等的系统概念和技术参数；第三篇提出全球变化空间观测的新方向，包括全球变化多星组网观测、全球变化月基观测系统及行星与地球的全球变化比较等。

本书可供从事空间对地观测、全球环境变化、地球系统科学领域的科学工作者、相关专业的高等院校师生、相关政府部门的管理者和决策者参考。

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序

21 世纪，挑战人类生存底线的一个重大命题是全球变化以及全球变化产生的重大环境问题。全球变化在改变人类赖以生存的自然环境的同时，也正在对经济社会发展产生着深刻的影响。如何应对全球变化、实现可持续发展，是当前人类社会发展面临的重大命题。

我国正在全面部署全球变化的科学计划，从加强人类活动和全球变化的相互影响机制、地球系统模式、地球观测数据同化和应用、全球变化经济学等问题入手开展系统研究。长时间、高质量的观测资料及其与地球系统模式的同化有助于减少对全球变化认识的不确定性，有必要建立高质量、连续、均一、综合的对地观测系统，加强全球变化关键参数和过程的多变量联合观测，强化海量数据的同化、融合技术与集成应用及数据共享机制研究。

我国的全球变化研究已取得了很大的进展，但进一步加强空间对地观测对全球变化研究的作用，无疑是十分重要的。空间对地观测技术的宏观、快速、准确特点使其成为全球变化现象观测的关键手段，在全球变化的观测与分析中起着不可替代的作用。全球综合对地观测计划部长级会议“开普敦宣言”中曾指出，“认识到世界各国正面临全球变化影响所带来的环境、社会和经济的挑战；认识到对地观测技术的重要性，需要发展地基、海基、机载和空基对地观测系统、数据同化技术和进行地球系统模拟”，显见空间对地观测技术对全球变化研究的重要作用。

郭华东教授及其研究团队 2009 年起承担了我国 973 计划“空间观测全球变化敏感因子的机理与方法”项目。这是 973 计划中第一个用空间对地观测技术研究全球变化的项目，在空间观测全球变化理论和方法方面取得了富有成效的成果。作为该成果的一部分，这本专著系统分析了全球变化研究的现状及对卫星观测的科学需求，全面叙述了几十年来国际国内对地观测卫星的发展，论述了全球变化系列科学卫星系统框架与技术参数，提出了全球变化敏感因子和全球变化科学卫星概念及其科学内涵，同时，前瞻性地提出了几个全球变化研究空间观测新方向。

该书是难得的专门研究论述全球变化科学卫星的专著，具有很高的学术水平和实用价值，对我国全球变化研究和空间技术发展具有很好的参考作用。我国已拥有了较高水平的空间对地观测技术，但是全球变化研究所需的空间科学卫星尚为薄弱环节，发展面向全球变化研究的科学卫星具有重要的学术和实用意义。该书的出版将为我国的全球变化研究科研工作者、地球系统科学领域研究者、空间对地观测技术工作者、相关政府部门管理者和决策者以及相关大学教师和研究生等提供有益的参考，同时对国家对地观测体系建设和空间基础设施发展亦有重要的借鉴作用。

徐冠华

2014 年 3 月

Foreword

Global change and the major environmental issues caused by climate change are challenging the fundamentals of human existence in the 21st century. Being producing changes in the natural environment, climate change has a profound influence on economic and social development. 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 and 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 abilities 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 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 the 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; that sound policymaking 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, air-borne, and space-based Earth observations, data assimilation techniques and Earth system modelling".

Since 2009, Professor Guo Huadong and his team have been undertaking the research project "Earth Observation for Global Change Sensitive Variables: Mechanisms and Methodologies", a National Basic Research Program of China (973 Program). Recognized as China's first 973 Program that uses Earth observation technology in climate change research, this project has achieved fruitful results that address the theoretical and methodological aspects of climate change. This book, which is one the outcomes of the project, systematically analyses the present state of climate change research and also the scientific requirements of Earth observation technology. It comprehensively introduces decades of international and domestic development in Earth observation, and thoroughly addresses the framework and technical parameters of satellite systems used for climate change research. More importantly, the book introduces scientific insights into climate change 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 satellites that are to be used exclusively for climate change research. These systems will have high academic and practical significance. This book will be a valuable reference for 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.

Xu Guanhua

March, 2014

前　言

全球变化正在对人类生存与发展形成严峻挑战，威胁着人类的生活方式和生存环境，越来越成为包括我国在内的世界各国关注的重大命题。正像 IPCC 主席 R. Pachauri 所言："气候变化的影响已经在世界各地显现出来，在这颗星球上没有一个人会不受影响"。因此，开展全球变化研究已是国家的重大政治、经济和社会需求，是一个十分重要而迫切的研究命题和使命。

全球变化具有大尺度长周期的时空演变特性，是一个复杂的系统，需要用多种理论和技术开展研究。卫星对地观测技术的宏观、快速、动态、准确探测特点，使其在全球变化研究中具有独特优势。历经半个多世纪的发展，在对地观测领域已经构成了对陆地、海洋、大气等各个层面的立体观测体系，传感器工作波段覆盖了自可见光、红外到微波的全波段范围，多系统的综合组网观测为全球变化现象精细观测提供了有效的手段.

目前，全球已发射对地观测卫星 200 余颗，正在计划和规划至 2030 年的对地观测卫星也有 200 余颗。30 多年来我国已发射了包括气象卫星、资源卫星、环境卫星、海洋卫星在内的一系列业务卫星，初步形成相对稳定的对地观测体系。值得注意的是，虽然人类已发射了大量的对地观测卫星，但主要为行业卫星，科学卫星数量很少，面向全球变化研究的科学卫星更少。全球变化科学卫星规划的缺乏和缺失，使全球变化的宏观研究受到很大制约。

2008 年，笔者主持成功申请到国家 973 计划项目"空间观测全球变化敏感因子的机理与方法"，由大学和中科院研究所 7 个单位组成的研究团队自 2009 年至 2013 年共同开展了 5 年的研究工作。本项目的总体目标是进行陆地、海洋和大气全球变化敏感因子的空间探测新理论、新技术和新方法的多学科综合研究，阐明敏感因子的最优电磁波谱、最优空间分辨率、最优时间分辨率，挖掘遥感监测全球变化敏感因子的电磁波谱资源，建立新的模型方法和探测全球变化现象的前沿技术模式。在此基础上，提出我国全球变化科学卫星方案。可以看出，全球变化科学卫星是本项目的一个重要研究方向。

在对地观测卫星的行业卫星和科学卫星范畴内，我们将科学卫星中面向全球变化研究的称为全球变化科学卫星。全球变化科学卫星充分利用全波段电磁波"资源"，可提供丰富的全球变化因子观测数据。因此，开展全球变化科学卫星的研究具有重要的科学和社会意义，我国在大力发展行业卫星的同时，应开拓对给人类生存带来重要影响的全球变化问题进行研究的科学卫星，构建我国有特色的全球变化科学卫星观测系统。

本书核心思路是在我国对地观测卫星计划中布局新类型卫星——全球变化科学卫星。该类型卫星计划的实施，不仅可为我国全球变化研究提供基础数据，为国际全球变化谈判提供准确信息，为政府宏观决策提供科学支持，而且可为"美丽中国"目标的实现提供先进手段，为国际性全球变化研究作出贡献。

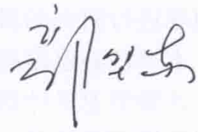
本书共 3 篇 17 章。第一篇 6 章内容分 4 个层次论述：一是介绍半个世纪来国际对地

观测卫星的发展历程，讨论未来对地观测卫星的发展趋势；二是分别介绍主要对地观测技术先进国家与地区，包括美国、欧洲、苏联/俄罗斯、日本、加拿大等的对地观测卫星发展；三是介绍我国对地观测卫星，包括气象卫星、海洋卫星、资源卫星、环境减灾卫星、高分辨率对地观测专项卫星、神舟飞船对地观测计划、北斗卫星导航系统等；四是介绍以全球综合对地观测系统(GEOSS)、国际卫星对地观测委员会(CEOS)和欧洲全球环境和安全监测计划(GMES)为代表的综合性全球对地观测计划和组织研究进展。

第二篇是本书的重点，由 7 章组成。本篇提出发展包括以下 6 类卫星在内的我国全球变化科学卫星系列，重点为：①大气碳卫星。利用碳卫星实时捕捉大气二氧化碳浓度，以适应全球模型模拟计算碳源与碳汇的要求。②气溶胶卫星。观测大气气溶胶空间分布，反演气溶胶光学厚度及其发生范围与趋势，同时可为雾霾监测作贡献。③夜间灯光卫星。用以土地覆盖、人口估算、经济活动等城市化关键要素的快速评估分析与空间综合研究。④森林生物量卫星。利用星载激光雷达和合成孔径雷达系统，定量获取区域至全球尺度高精度森林生物量，进而估算碳储量。⑤冰川卫星。记录冰川过程，此过程与气温、降水与物质平衡密切相关，用以反馈全球环境变化。⑥海洋盐度卫星。观测环流、全球海平面变化等海洋现象中必不可少的环境变量。这 6 类卫星对解决全球环境变化重大科学问题至关重要，同时为促进我国的对地观测卫星发展意义显著。

第三篇由 3 章组成，提出全球变化空间观测新方向；重点论述多星组网观测、全球变化月基观测和行星与地球全球变化比较研究；提出的全球变化月基观测是本书的一大亮点，在人们习惯于把飞机、卫星等作为对地观测平台时，我们提出将月球作为人类新的对地观测平台的设想。月球作为对地观测平台具有独特优点：月表处于超高真空状态，有一面总是朝向地球，可以对地球上的同一地区进行长时段、可变视角的快速观测，可同时观测到地球半球的全景。这些优势可使观测宏观地球科学及全球变化现象，乃至可能发现尚未预料到的地球科学现象。考虑到地球不是独立存在的行星，本篇提出将地球与其他行星进行全球变化对比研究。本篇还对多星组网观测技术与模式作了系统分析。

本书付梓出版之际，笔者衷心感谢为本书作出贡献的所有人员：首先感谢本书所有合著者，特别是自始至终参与组织、撰写工作的傅文学博士，并感谢为本书做了工作的吴文瑾、丁翼星、任永政、张道卫、周建民、朱岚巍和 Claudia Kuenzer 博士；其次感谢来自中国科学院遥感与数字地球研究所、青藏高原研究所、大气物理研究所、上海技术物理研究所，以及北京航空航天大学、武汉大学、中国海洋大学的 973 项目组为本书作出贡献的专家；最后要特别感谢科技部的立项支持，以及 973 专家顾问组周光召、孙鸿烈院士的支持和以徐冠华院士为代表的项目专家组的指导与支持。



2014 年 3 月

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 any nation but also poses fundamental threats to the living conditions and life-style of humanity as a whole. As Rajendra K. Pachauri, chairman 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 the 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 dynamical 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 scales, or even over the whole globe, using sensors covering 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.

Until now satellite-based Earth observation systems have been in a phase of expansion-more than 200 satellites have been launched and this number is expected to double by 2030. During the past 30 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, a large-scale research on global change is greatly limited by the lack of corresponding scientific satellites programs.

In 2009, I began to charge of the project "Earth Observation for Sensitive Variable of Global Change: Mechanisms and Methodologies", which was part of the 973 National Basic Research Program of China and which was carried out jointly by seven institutes from 2009 to 2013. This project was designed to conduct multidisciplinary comprehensive research and provide theoretical and scientific foundations for spaceborne observations of global change phenomena over the land, the oceans and the atmosphere. Specific tasks included: ①to indicate the optimal spectral band, spatial resolution and temporal resolution for better monitoring of these sensitive variables; ②to collect and set up a database of the spectra of geographic elements with greater sensitivity to global change and use the "resource" of electromagnetic waves to acquire key global change variables; ③to provide novel methods, establish reliable models and offer edge-cutting technologies for the monitoring of global change phenomena. As a result, this 973 project explored the concept of global change scientific satellites for global change monitoring from space and proposed a plan for a series of global change scientific satellites to establish a scientific observation system in China.

The Earth observation satellites would 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 in the rest of the world.

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 sections that comprise a total of seventeen chapters. Section 1 contains six chapters and can be considered to consist of four aspects: ①an overview of the development of Earth observation satellites during the past half century and a discussion on future trends; ②a presentation of the development of Earth observation satellites in some countries and region, including the United States, Europe, USSR/Russia, Japan and Canada; ③an introduction to China's Earth observation satellites, including meteorological satellites, ocean satellites, resource satellites and environmental satellites, as well as the satellites belonging to the high resolution Earth observation system and also the "Shenzhou" spacecraft program and the "BeiDou" satellite navigation system; ④an illustration of the latest research progress produced by the 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 Satellite (CEOS) as well as the Global Monitoring for Environment and Security (GMES) initiative.

Section 2 is the core of the book, consisting of seven chapters. In this section, we propose a plan for a series of global change scientific satellites, which includes the following six satellites: ①an atmospheric carbon satellite that could objectively acquire real-time data on CO_2 concentrations to meet the demand for global model-based estimations of carbon sources and sinks; ②an aerosol satellite that would retrieve aerosol optical thickness, provide information on spatial patterns of aerosols, and also make great contributions to the monitoring of haze; ③a night-light satellite that could provide data used for comprehensive analysis and rapid assessment of urbanization factors, such as land cover, population density and economic activity; ④a forest biomass satellite that would enable the acquisition of quantitative, continuous, high-precision forest biomass data at regional and global scales using spaceborne LiDAR system and SAR, and provide further estimates of the amount of carbon storage; ⑤a glacier satellite that would record the glacier processes closely related to temperature, rainfall and mass balance, and provide evidence of global environmental change in a unique way; ⑥an ocean salinity satellite that would 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.

Section 3 introduces new trends in global change monitoring from space and comprises three chapters. It focuses on multi-satellite networks, Moon-based global change observation and a comparison of global change research relating to the outer planets and the Earth. Among these, the topic of Moon-based global change observation is a highlight of the book. Aircraft and satellites are commonly used as observation platforms, however, here we propose the setting up of sensors on the Moon and using it as a platform for observing global-scale phenomena. The Moon has many unique advantages as an Earth observation platform: the Lunar surface is in an ultrahigh vacuum state and one side of the Moon always faces the Earth, therefore, the same area on the Earth can be observed from various angles over a long period of time. In addition, a panoramic view of a whole hemisphere can be acquired. These factors make it possible to monitor geological and global change phenomena at a large scale. Also, as the Earth does not exist in isolation, it is necessary to conduct comparable research on global change on both the Earth and the outer planets. Finally, an analysis of the techniques and models used in multi-satellite networks are discussed in this section.

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