Preface

TOWARD A SUSTAINABLE EARTH THROUGH REMOTE SENSING

Sustainability and Earth Observation

In recent years, we have witnessed an emerging trend worldwide to pursue green technologies and low-carbon economies and lifestyles. However, the sustainability issue is not new. At the 1992 United Nations Conference on Environment and Development (UNCED) in Rio, UNCED Principle Three characterized sustainable development as "the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations," while Principle Four stated that "in order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be isolated from it." These principles were reaffirmed at the 2002 Johannesburg World Summit on Sustainable Development and have since produced a profound implication for use and stewardship of natural resources, ecology, and environment (Weng and Yang 2003). In practice, sustainable development is a multifaceted concept and has been viewed from many perspectives, depending on one's personal experience, viewpoint, and discipline (Weng and Yang 2003). As we consider sustainable development from an ecological perspective, we must have an appreciation of ecosystem integrity, which implies the existence of the system structure and function, maintenance of system components, interactions among them, and the resultant dynamic of the ecosystem (Campbell and Heck 1997). Shaller (1990) suggested that "sustainable agriculture over the long-term enhances environmental quality and the resource base upon which agriculture depends, provides for basic human food and fiber needs, is economically viable, and enhances the quality of life for farmers and society as a whole." This definition illustrates well three pillars of sustainable development: ecological, economic, and social objectives (Weng and Yang 2003). The ecological objective seeks to preserve the integrity of the ecosystem, while the economic objective attempts to maximize human welfare within the existing capital stock and technologies and use economic units (i.e., money or perceived value) as a measurement standard (Campbell and Heck 1997). The social objective stresses the needs and desires of people and uses standards of well-being and social empowerment. The ecological perspective for sustainable development balances the ecological, economic, and societal values, and falls at the intersection of the spheres that represent the three components (Weng and Yang 2003). Incoordination among the three components will likely result in failure to achieve sustainability (Zonneveld and Forman 1990).

The spatial and temporal scales are key elements in assessing ecological and environmental sustainability, because they module the objectives of what we wish to sustain, over what time scale and in which geographical scope (Weng 2014). With more than one-half of the world population living in cities, the 21st century has become the first "urban century." Cities are human-central ecosystems and are the most complex of all human settlements. While the economic and societal values are stressed, the ecological value is often ignored, and therefore, the ecological perspective of sustainable development asserts the importance of the coordination and balance among the three objectives for sustainability of cities (Weng and Yang 2003). Because of the nature of cities as dynamic, complex settlements and human-central ecosystems, the development of evaluation methods for sustainable cities should reflect these characteristics (Weng and Yang 2003). The US Climate Change Science Program (CCSP 2008) defines one of its five goals to be "understanding the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes." Although vulnerabilities of settlements to impacts of climate change vary regionally, they generally include some or many of the following impact concerns: health, water and infrastructures, severe weather events, energy requirements, urban metabolism, sea level rise, economic competitiveness, opportunities and risks, and social and political structures. CCSP (2008) further recommends that research on climate change effects on human settlements in the United States be given a much higher priority in order to provide better metropolitan-area scale decision-making.

Earth observation technology, in conjunction with in situ data collection, has been used to observe, monitor, measure, and model many of the components that comprise natural and human ecosystems cycles (Weng 2012a). Driven by the societal needs and improvement in sensor technology and image processing techniques, we have witnessed a great increase in research and development, technology transfer, and engineering activities worldwide since the turn of the 21st century. Commercial satellites acquire imagery at spatial resolutions previously only possible to aerial platforms, but these satellites have advantages over aerial imageries including their capacity for synoptic coverage, inherently digital format, short revisit time, and capability to produce stereo image pairs conveniently for high-accuracy 3D mapping thanks to their flexible pointing mechanism (Weng 2012b). Hyperspectral imaging affords the potential for detailed identification of materials and better estimates of their abundance in the Earth's surface, enabling the use of remote sensing data collection to replace data collection that was formerly limited to laboratory testing or expensive field surveys (Weng 2012b). While LiDAR technology provides high-accuracy height and other geometric information for urban structures and vegetation, radar technology has been re-invented since the 1990s mainly because of the increase of spaceborne radar programs (Weng 2012b). These technologies are not isolated at all. In fact, their integrated uses with more established aerial photography and multispectral remote sensing techniques have been the main stream of current remote sensing research and applications (Weng 2012b).

With these recent advances, techniques of and data sets from remote sensing and Earth observation have become an essential tool for understanding the Earth, monitoring the world's natural resources and environments, managing exposures to natural and man-made risks and disasters, and helping the sustainability and productivity of natural and human ecosystems (Weng 2012b). This book aims at introducing to the current state of remote sensing knowledge needed for sustainable development and management with selected studies. These studies either explore the methods and techniques of remote sensing for application to various aspects of sustainable development or provide important insights into sustainability science from the perspective of remote sensing technology. Therefore, this book would be of great value for students, professors, and researchers in both remote sensing and sustainability science. It can help narrow the gap between the two disciplines. This book may also serve as a textbook for undergraduate and graduate students or as an important supplement for those majoring in sustainability, remote sensing, geography, geosciences, planning, environmental science and engineering, civic engineering, resources science, land use, energy, and geographic information system (GIS). On college campuses, we have recently witnessed an ever-increasing number of classes and programs on sustainability or related subjects. Remote sensing is emerging as an essential geospatial tool in sustainability; this book would meet the need of those classes and programs. In addition, this book may be used as a reference book for sustainability officers, practitioners, and professionals alike in the government, commercial, and industrial sectors. Since its contents cover numerous applications of remote sensing to sustainability, this book, indeed, provides a useful toolbox.

International Cooperation and Collaboration on Earth Observation for a Sustainable Earth

The 2002 World Summit on Sustainable Development in Johannesburg highlighted the urgent need for coordinated observations relating to the state of the Earth. The First Earth Observation Summit in Washington, DC, in 2003 adopted a declaration to establish the ad hoc intergovernmental Group on Earth Observations (ad hoc GEO) to draft a 10-Year Implementation Plan. Since 2003, GEO has been working to strengthen the cooperation and coordination among global observing systems and research programs for integrated global observations. The GEO process has outlined a framework document calling for Global Earth Observation System of Systems (GEOSS) and has defined nine areas of societal benefits (http://www.earthobservations.org/about_geo.shtml), including the following:

- "Reducing loss of life and property from natural and human-induced disasters,
- Understanding environmental factors affecting human health and well-being,
- Improving the management of energy resources,
- Understanding, assessing, predicting, mitigating, and adapting to climate variability and change,
- Improving water resource management through better understanding of the water cycle,
- Improving weather information, forecasting and warning,
- Improving the management and protection of terrestrial, coastal and marine ecosystems,
- Supporting sustainable agriculture and combating desertification, and
- Understanding, monitoring and conserving biodiversity."

On September 25, 2015, the United Nations adopted a set of sustainable development goals (SDGs), each of which has specific targets to be achieved over the next

15 years (United Nations Development Programme 2015). These goals represent the United Nation's responses to numerous societal challenges and the efforts to build a sustainable Earth. Through large-scale, repetitive acquisition of the Earth surface image data, remote sensing can provide essential information and knowledge to supplement statistical analyses in the assessment of indicators toward the attainment of the SDGs. Because Earth observation offers an indispensable tool to measure and monitor the progress toward SDGs, in the recently developed "GEO Strategic Plan 2016–2025: Implementing GEOSS," GEO is determined to develop a concerted direction with the SDGs (Group on Earth Observations 2015). The GEO Global Urban Observation and Information Initiative (GI-17) has set the following goals for the period 2012–2015: (1) improving the coordination of urban observations, monitoring, forecasting, and assessment initiatives worldwide; (2) supporting the development of a global urban observation and analysis system; (3) producing up-to-date information on the status and development of the urban system—from a local to a global scale; (4) filling existing gaps in the integration of global urban observation with data that characterize urban ecosystems, environment, air quality and carbon emission, indicators of population density, environmental quality, quality of life, and the patterns of human environmental and infectious diseases; and (5) developing innovative techniques in support of effective and sustainable urban development. These goals will be implemented by developing and expanding selected activities and programs that the GEO Global Urban Observation (SB-04) task team has been working (Weng et al. 2014). This book intends to contribute to the GEO's Strategic Plan by addressing and exemplifying a number of societal benefit areas of remote sensing data sets, methods, and techniques for sustainable development.

Synopsis of the Book

This book consists of four sections. Section I deals with remote sensing for sustainable cities; Section II discusses remote sensing techniques and methods for forest resources; Section III presents remote sensing studies for sustainable environmental systems, with topics ranging from air, water, to land; and Section IV includes various contributions in remote sensing of sustainable energy systems.

Section I includes five chapters dealing with theories and methods as well as practical applications of sustainable development for cities using remote sensing. Chapter 1 provides key concepts and principles for assessing sustainability of cities. It then discusses the typical parameters derivable from remotely sensing imagery that can be used to define indicators for sustainable cities. Chapter 2 introduces a selection of applications and data products that provide support for day-to-day decision-making activities in urban and regional planning. Chapters 3 through 5 present various studies in which remotely sensed data, methods, and techniques are used for studying cities or urban clusters. In Chapter 3, Zhang and Weng monitor urban growth process in the Pearl River Delta, Guangdong Province, China, by using time series Landsat imagery from 1987 to 2014. This chapter demonstrates the effectiveness of time series data mining for assessing urban growth pattern over a long period and the usefulness of generated data set and information for exploring the relationship between urban growth and environmental sustainability. In Chapter 4, the damage of subsidence on urban structures in the St. Louis Metropolitan area, Missouri, USA, is explored by using Synthetic Aperture Radar images in the period from 1992 to 2011. Their results show hot spots of ongoing and potential land collapses in the region, which are valuable not only to individual homeowners but also to city planners, insurance companies, and regional policymakers charged with assessing risks of abandoned coal mines. In the last chapter in the section, Chapter 5, Xiao and Weng examine urban growth in the North Carolina urban crescent from the Research Triangle Park (Raleigh–Durham–Chapel Hill) to Greensboro, USA, and Guiyang City to Anshun City in Guizhou Province, China, from the 1980s to the 2010s, when accelerated industrialization and urbanization occurred. They compare and contrast the spatial patterns, paths, and driving forces of urbanization in the two regions and countries of different socioeconomic development stages.

Section II focuses on remote sensing methods and techniques for sustainable natural resources. In Chapter 6, Tong et al. present a few case studies on the application of remote sensing in grassland management for a mixed-grass prairie ecosystem in North America; on the basis of the case studies, they further discuss challenges and opportunities for remote sensing in grassland management. Chapter 7 assesses the relationship between species extinction and biodiversity loss using the example of palila (*Loxioides bailleui*), an endangered bird species on the island of Hawaii. To understand its population trend, tree species in its habitat were identified analyzed with high spatial resolution satellite imagery at both pixel and object levels. Chapter 8 takes this direction further along biodiversity and conservation by examining how evolved remote sensing techniques can be employed to investigate forest damages by diseases and insects. The last chapter in Section II, Chapter 9, focuses on water resources. Matsushita and his colleagues first survey major satellite sensors for water quality studies, followed by a discussion of representative algorithms for water area delineation, atmospheric correction, and water quality parameter estimation. This chapter ends with a proposed framework for water quality assessment using remote sensing.

What remote sensing methods and techniques can do for the sustainability of environmental systems and how they do it are addressed in Section III. In Chapter 10, Hu explores the use of satellite remote sensing data to expand ground network of PM2.5 observation by using aerosol optical depth (AOD). Various AOD products and methods that are widely used in PM2.5 concentration estimation were assessed. This discussion was followed by a case study in the Atlanta metropolitan area, Georgia, USA, to estimate ground-level PM2.5 concentration from MODIS AOD. Chapter 11 continues the discussion on public health but from the perspective of heat hazards. Jiang and Weng develop methods to analyze daily and hourly variations of land surface temperature (LST), which were derived from remotely sensed thermal infrared image data, and discuss the impact of evapotranspiration on LST over a variety of urban surfaces. Both Chapters 12 and 13 study ecosystems in semi-arid and arid regions but with distinct approaches of remote sensing. The former investigates the tendency of desertification along the Mediterranean to arid transition zones in central Israel, and the latter assesses soil moisture condition in the Umer Kot region of Pakistan. In Chapter 12, Shoshany develops three indicators using remote sensing data, that is, Green Vegetation Cover, life-forms' subpixel compositions, and spatial recovery versus erosion potential, and by assessing these indicators, he suggests that no significant shift occurred in the transition zone between 1996 and 2011, but that there was high vulnerability to future degradation. Soil moisture holds the key to drought and agricultural monitoring in semiarid and arid regions. Chapter 13 investigates the potential of near-infrared and red reflectance space (i.e., the RSSMM method) and temperature vegetation dryness index (TVDI) for the assessment of soil moisture. Results of the remote sensing methods were compared with in situ soil moisture measurements at different land surface depths of 0–15, 15–30, and 30–45 cm. RSSMM was found satisfactory in determining soil moisture, but TVDI provided a more reliable estimate of moisture condition.

The last section of the book, Section IV, examines the issues of energy use and sustainable energy sources using remote sensing technology. The development of renewable energies is one of the key challenges in the 21st century. In this context, it is of central importance to focus on the review of surface potentials, the determination of suitable sites, the consideration of user interests, and the detection of trends and impacts on the landscape. To meet these requirements and tasks, timely, spatial, and thematic high-quality geospatial data are indispensable. In Chapter 14, Esch et al. exemplify applications of remote sensing and related technologies and geoinformation products for land management in Germany, which is geared toward the development of potentials of renewable energies. Chapter 15 assesses the capability of DMSP-OLS nighttime light imagery for analyzing the decadal trends of energy consumption (EC) in China, from 2000 to 2012. Here, Xie and Weng demonstrate a moderate to rapid growth of EC for coastal and capital cities, but a slow growth for the majority of central, northeastern, and western cities. They further find the total and urban EC at the prefectural level to be regionally clustered, which may have an implication in future Chinese energy policy and the spatial distribution of EC. The last two chapters examine renewable energy sources. While Chapter 16 focuses on wind energy, Chapter 17 evaluates solar energy potential. Wind speed and wind flow are strongly influenced by land surface properties. Three different remote sensing–based parameters can help characterize wind resources: (a) land cover and land use, (b) digital elevation models, and (c) phenological information. In Chapter 16, Esch et al. discuss how Earth Observation (EO) data can be used to support wind resource modeling, especially the possibilities brought about by the Copernicus Sentinel satellites. They conclude that by using EO-based information on the surface (e.g., roughness) and in situ wind measurements, realistic wind fields for sufficiently large areas can be derived by considering shadowing effects and wind shear as well. Chapter 17 provides two case studies to demonstrate the applicability of remote sensing techniques on sustainable energy development in Indianapolis, Indiana, USA. The first case study demonstrates a method to estimate the solar energy potential of building roofs, and the second case study examines the correlation between energy use and building morphological attributes such as ground area, total floor area, height, surface area, compactness, aspect ratio, and orientation.

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The reviewers of the chapters for this book are listed below in alphabetical order:

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