# An Introduction to Applying Satellite Remote Sensing to Disaster Management

# An Introduction to Applying Satellite Remote Sensing to Disaster Management

By

Kazuya Kaku

Cambridge Scholars Publishing

An Introduction to Applying Satellite Remote Sensing to Disaster Management

By Kazuya Kaku

This book first published 2019

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Copyright © 2019 by Kazuya Kaku

All rights for this book reserved. No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the copyright owner.

ISBN (10): 1-5275-3741-2
ISBN (13): 978-1-5275-3741-5

To all collaborators in Sentinel Asia and JAXA,
and my wife

# TABLE OF CONTENTS

# LIST OF FIGURES

.

Note: Figures in italics (3-8, 3-12 to -19, 6-13, 7-8, 8-4, 8-7, 9-7, and 12-1) can also be found in the color centerfold.

# List of Tables

Note: Table in italics (7-1) can also be found in the color centerfold.

# PREFACE

In Japan, the Japan Aerospace Exploration Agency (JAXA) has been engaged in disaster management support activities using the Advanced Land Observing Satellite (ALOS), launched in January 2006. I have been involved in this activity of JAXA from this time. At the beginning, I did not know what I should do to apply satellite remote sensing to disaster management. More than 10 years have passed since then; this book summarizes the knowledge and experience during this period and will be a response to my own question.

Satellite remote sensing is one of the primary support tools for disaster management, and the number of people involved in this field will increase in the future; however, it is not easy to approach for a beginner. It would be a great pleasure if this book would be useful for people with similar situations as the author in the year 2006, by providing a brief introduction and overall view of applying satellite remote sensing to disaster management, covering an overview of satellite remote sensing, case studies on areas of disaster management to which satellite remote sensing is applicable, and how to apply satellite remote sensing to disaster management.

It should be noted that “application of satellite remote sensing to disaster management” in this book refers to the employment of satellite-based disaster information/data by users and end-users working for disaster management, including rescue/relief/evacuation; not just disclosing them on the Internet.

Kazuya Kaku

# ACKNOWLEDGEMENTS

I wish to gratefully acknowledge all the members of the Sentinel Asia (SA) Joint Project Team, the JAXA SA team, and the JAXA domestic disaster response support team for their contribution and collaboration in promoting the project, especially:

Dr. A. Alexander Held of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia for his contribution to SA initiation,

Dr. Renato U. Solidum, Jr. of the Department of Science and Technology (DOST) and Dr. Arturo S. Daag of the Philippine Institute of Volcanology and Seismology (PHIVOLCS) in the Philippines for leading the SA success story,

Dr. Lal Samarakoon and Dr. Manzul Kumar Hazarika of the Asian Institute of Technology (AIT) for their contribution to emergency satellite data analysis and the SA mini-project,

Dr. Ming-Chih Cheng and Mr. Bo Chen of the National Applied Research Laboratories (NARLabs) for their contribution to emergency observation using FORMOSAT-2, particularly after the termination of ALOS operation,

Mr. Koji Suzuki, Mr. Atsushi Koresawa, Mr. Kiyoshi Natori, and Ms. Kyoko Kondo, Executive Directors of Asian Disaster Reduction Center (ADRC), for their contribution and collaboration in promoting the project to the disaster management community,

Professor Emeritus Masami Fukuda of Hokkaido University for leading the SA wildfire working group (WG) as the chair. He introduced me to the field of wildfire management and its close relationship to the mitigation of global warming,

Professor Emeritus Toshihisa Honma of Hokkaido University for leading the JST/JICA project on wildfire and carbon management in a peat forest in Indonesia. He introduced me to application of Analytic Hierarchy Process (AHP) to project management,

Dr. Masami Tokuno of the Meteorological Research Institute, Japan Meteorological Agency (at that time) for his instruction about hotspot detection using MTSAT, Dr. Orbita Roswintiarti and Mr. Agus Hidayat of the Indonesian National Institute of Aeronautics and Space (LAPAN) for their contribution to the wildfire WG and disaster response in Indonesia,

Mr. Kwoh Leong Keong and Dr. Liew Soo Chin of the National University of Singapore for their contribution to the wildfire WG,

Professor Hiromichi Fukui of Chubu University for his contribution to Step-1 Web-GIS and leading the SA glacial lake outburst flood (GLOF) WG as the co-chair,

Mr. Basanta Shrestha of the International Center for Integrated Mountain Development (ICIMOD) for leading the GLOF WG as the co-chair,

Mr. Kazuhiko Fukami and Mr. Yoichi Iwami of the International Centre for Water Hazard and Risk Management under the auspices of UNESCO (ICHARM) for leading the SA flood WG as the chairs,

Dr. Giriraj Amarnath of the International Water Management Institute (IWMI) for leading the flood WG as the co-chair and his contribution to emergency satellite data analysis,

Dr. Yoshiyuki Kaneda of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) (at that time) and Professor Shunichi Koshimura of Tohoku University (successor) for leading the SA tsunami WG as the chairs,

Dr. Masahiko Nagai of Yamaguchi University for his contribution to emergency satellite data analysis as P-DAN, and

Ms. Tomoko Suzuki for her support to create figures in this book.

I am also deeply grateful to Professor David E. Alexander of University College London (UCL) who is the editor-in-chief of the International Journal of Disaster Risk Reduction (IJDRR), and the editors/reviewers of IJDRR for their reviews, comments, and suggestions for my contributions to IJDRR.

Finally, I am grateful to JAXA for giving me the opportunity to write this book.

A part of wildfire WG activity (refer to Section 7.5) is funded under the Science and Technology Research Partnership for Sustainable Development (SATREPS) scheme, which is jointly coordinated by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA).

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

According to the Natural Disasters Data Book 2016 (ADRC, 2016), Asia has been seriously damaged by natural disasters over the last 30 years, as shown in Fig. 1-1. This is compounded by its high population density (more than half of the world's population). Disasters occurring in Asia comprise 39% of the worldwide total. The region suffers 61% of global fatalities and has 88% of the total victims associated with such disasters. In view of these circumstances, the Asia-Pacific Regional Space Agency Forum (APRSAF) proposed Sentinel Asia (SA) in November 2004, when it was realized that the rapid technological advances in the region could confer life-saving benefits, if satellite imagery and derived information could be delivered more quickly via the Internet to disaster management agencies in affected countries, in the form of easily interpreted disaster-related information. APRSAF itself was established in 1993 in response to a 1992 declaration adopted by the Asia-Pacific International Space Year Conference (APIC) to enhance the development of each country's space program and to exchange views toward future cooperation with respect to space activities in the Asia-Pacific region. It was originally designed to provide opportunities for regional space agencies and associated governmental bodies to exchange technical views, opinions, and information on national space programs and space resources.

The application of satellite remote sensing to disaster management under an international framework began around 2000, when satellite-based Earth observations for rapidly assessing disaster situations globally (namely, response support) were started by the International Charter Space and Major Disasters (hereinafter referred to as "the Charter" or "the International Charter" or "the International Disaster Charter") and the United Nations (UN) (Voigt et al., 2016).

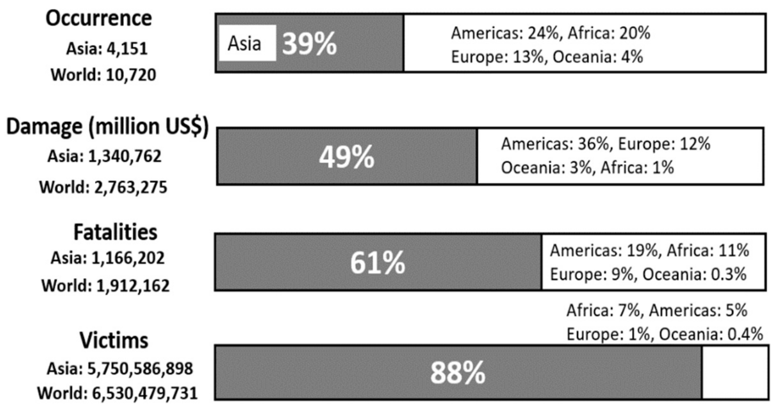


Fig. 1-1. Impacts of natural disasters by region, 1987–2016. Source: ADRC-Natural Disasters Data Book 2016.

The International Charter (Bessis et al., 2004) was initiated by the European Space Agency (ESA), the French Space Agency (CNES), and the Canadian Space Agency (CSA) in 2000 and has provided a mechanism for the rapid tasking of satellites for immediate response after sudden major disasters, such as floods, earthquakes, and tropical storms, under an international collaboration amongst space agencies and space operators. Between 2000 and 2017, 13 other space agencies, including the Japan Aerospace Exploration Agency (JAXA), joined. Free satellite-based information is provided to national disaster management authorities and humanitarian organizations to support the immediate response to major natural or man-made disasters (source: the 17th Annual Report of the International Charter).

JAXA has begun engaging in disaster management support activities using the Advanced Land Observing Satellite (ALOS), launched in January 2006. JAXA has been striving to highlight the role of Earth observation satellites in disaster management, within Japan and in the international activities of SA and the International Charter. JAXA worked to establish the SA framework and determine the implementation plan as an SA secretariat.

## 1.2 JAXA's approach

Space technology is a new tool in the field of disaster management in Japan. JAXA began supporting disaster management efforts using ALOS series (refer to Section 4.3) beginning in 2006 (Kaku et al., 2018). Concerning disasters within Japan, under an agreement with the Cabinet Office (in charge of disaster prevention), when a disaster occurs, JAXA conducts emergency observations by ALOS-2 and others and provides observation images and disaster information to users of disaster-related ministries and agencies; for preparedness, JAXA provides the necessary satellite images for their Geographic Information System (GIS) and disaster prevention drills. Furthermore, to expand employment of satellite data and imagery for disaster management to end-users, JAXA also has agreements with specific municipal users and promotes demonstration incorporating satellite-based disaster information to regional disaster prevention. Working groups (WGs) for each type of disaster are organized in collaboration with disaster-related research institutions and universities and proceed with the goal of creating a mechanism whereby disaster-related organizations can employ satellite images. The volcano WG (secretariat: Japan Meteorological Agency (JMA)) and the earthquake WG (secretariat: Geospatial Information Authority of Japan (GSI)), organized as a working group on satellite image analysis under the umbrella of the Coordinating Committee for Prediction of Volcanic Eruptions and the Coordinating Committee for Earthquake Prediction, respectively, promote the employment of satellite data in monitoring active volcanoes, as well as grasping the situation after volcanic eruption and earthquake.

Disaster management support using the ALOS series is conducted not only within Japan but also for overseas disasters through the international collaboration framework of SA and the International Charter. The international collaboration framework makes it possible to receive support from overseas space agencies when domestic disasters occur.

In November 2016, JAXA concluded a bilateral agreement on disaster response collaboration with the Italian Space Agency (ASI), whereby ALOS-2 and COSMO-SkyMed (CSK) can be used for disaster response in both countries. JAXA's approach to disaster management support is summarized in Fig. 1-2.

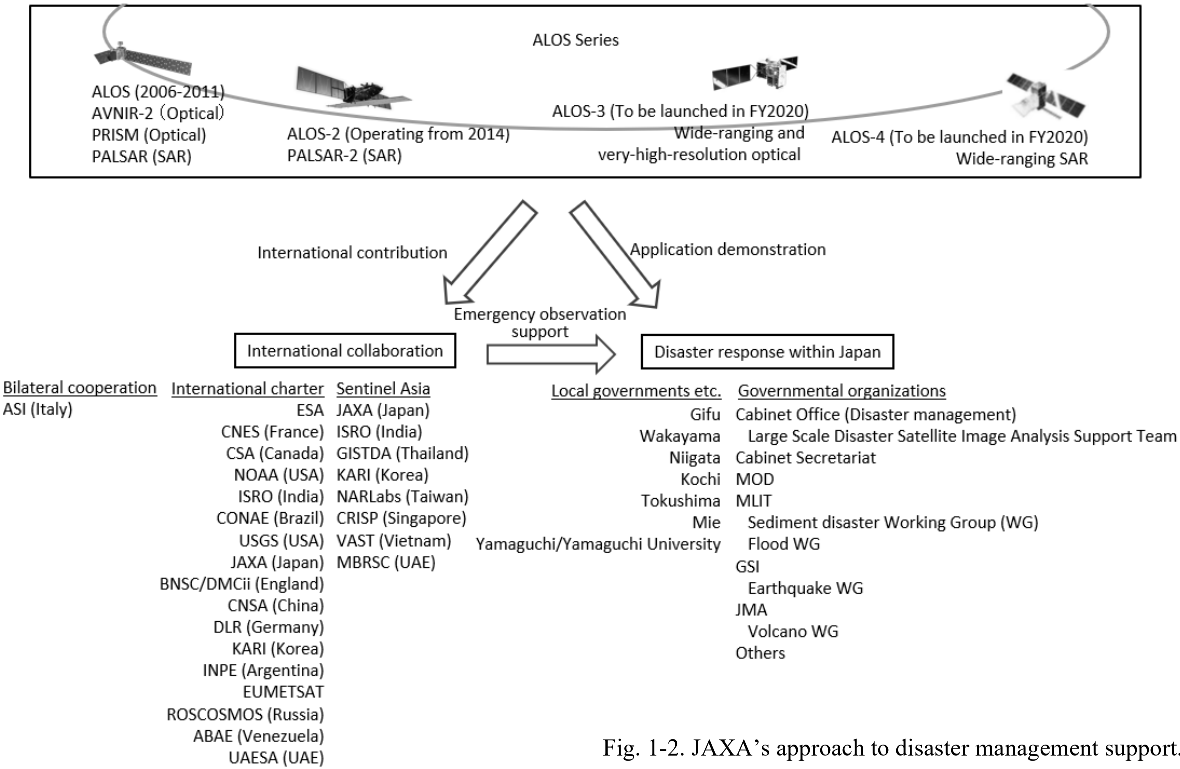


Fig. 1-2. JAXA's approach to disaster management support.

## 1.3 Scope of this book

This book has three themes:

(1) Overview of satellite remote sensing for disaster management (Part I): Satellite remote sensing is comprehensively outlined from the viewpoint of applications to disaster management in Chapters 2 to 5.
(2) Case studies on areas of disaster management to which satellite remote sensing is applicable (Part II): Sections 5.3 and 5.4 for overview; Chapters 6 to 9.
(3) Holistic study on how to apply satellite remote sensing to disaster management (Part III): Section 5.5 for overview; Chapters 10 to 12.

This book provides an overview of satellite remote sensing, detailing how it works and for what fields of disaster management it can be used. This book is unique in the sense that it is based on 13 years of empirical study through international collaboration projects and case studies conducted by JAXA since 2006, taking human factors (users) into account. This book will particularly appeal to practitioners (such as disaster responders, policy makers, and administrative officials) and researchers in the field of disaster management who are interested in applying satellite remote sensing to disaster management, as well as researchers in the satellite-remote-sensing field (such as space agencies, universities, and research institutes) who are interested in or working for applications of satellite remote sensing to disaster management. Of course, people (including students) from other fields who are interested in satellite remote sensing and disaster management are also readers.

I tried to write the text using illustrations and satellite images, without mathematical formulas; three appendices provide mathematical explanations on solar and terrestrial radiations, pulse compression, and wildfire detection algorithms.

# PART I:

# OVERVIEW OF SATELLITE REMOTE SENSING FOR DISASTER MANAGEMENT

Part I (Chapters 2 to 5) provides an overview of satellite remote sensing from the viewpoint of its application to disaster management by describing an entire satellite remote sensing system.

# CHAPTER TWO

# BASIC PRINCIPLES OF SATELLITE REMOTE SENSING

## 2.1 Satellite remote sensing system

Remote sensing is a technology for remotely studying the properties of objects using electromagnetic radiation, without touching the objects directly. Satellite remote sensing covers wide-ranging areas, operates continually during all hours and in all types of weather, and is used to survey Earth's surface and atmosphere to study global environmental problems, monitor disasters, explore resources, and so on.

A satellite remote sensing system (Curran, 1985) consists of five components, as shown in Fig. 2-1: sources of radiation (the Sun, the Earth, and an artificial radiation source), interaction with the atmosphere, interaction with the Earth's surface, space segment (sensors and satellites), and ground segment. It should be noted that human factors (such as system operators and system users working in disaster management and response) in the ground segment as well as technical factors are important when applying satellite remote sensing to disaster management.

## 2.2 Sources of radiation

Everything that is hotter than 0 K emits electromagnetic radiation. The largest source of electromagnetic radiation is the Sun (solar radiation), and the Earth's surface reflects and absorbs the solar radiation, as shown in Fig. 2-1. Furthermore, absorbed solar radiation raises the Earth's temperature and is radiated back to space as thermal radiation according to its temperature (terrestrial radiation). This mechanism keeps absorbed solar radiation and emitted terrestrial radiation in balance macroscopically. Remote sensing measures the reflected solar radiation and emitted terrestrial radiation. In addition, remote sensing employs an artificial source of electromagnetic radiation; that is, the satellite itself emits electromagnetic radiation and receives the retuned electromagnetic radiation from the Earth's surface. The former (which uses natural radiation) is called passive remote sensing; the latter (an artificial radiation source) is known as active remote sensing.

The wavelengths at which solar radiation and terrestrial radiation are employed can be shown to be almost completely distinct for remote sensing, as shown in Fig. 2-2. Although there is much more solar radiation than terrestrial radiation, because the Earth is very far from the Sun, the segregation of the solar radiation and the terrestrial radiation results at the top of the Earth's atmosphere in satellite remote sensing. For wavelengths that are shorter than an intersection point at $\lambda_0$ (see Fig. 2-2), solar radiation is dominant, which is called the solar radiation (or "shortwave radiation") range. For wavelengths that are longer than the intersection point, terrestrial radiation is dominant, which is called the terrestrial radiation (or "longwave radiation") range. For derivation of Figs. 2-2(a) and (b), refer to Appendix A.

Solar radiation, that reached the top of the Earth's atmosphere (see Fig. 2-2(a)), reaches the Earth's surface through the atmosphere and is reflected by the Earth's surface and finally reaches sensors at the space segment through the atmosphere. In this process, solar radiation is influenced by the atmosphere that has unique spectral features of transmittance (see Fig. 2-2(c) and Section 2.3). Similarly, terrestrial radiation that reaches sensors at the space segment through the atmosphere is influenced by the atmosphere.

The intersection point ($\lambda_0$), which is the boundary point between the solar and terrestrial radiation ranges, varies depending on the Earth's surface temperature. Given that the range of the Earth's surface temperature is 200–350 K (Kondo, 2000), the intersection point is rounded as a wavelength interval of ~3–8 μm, where the dominance of solar or terrestrial radiation is not uniquely defined and special handling is required. It should be noted that only terrestrial radiation can be detected without the influence of solar radiation at night, regardless of wavelength. For example, an infrared wavelength of ~4 μm, which is suitable for monitoring volcanoes and wildfires, belongs to the mixing range (~3–8 μm), for which only night-time data are employed.

In conclusion, the solar radiation range and the terrestrial radiation range are separated at the intersection point, although the intersection point is not fixed and is at a wavelength range of ~3–8 μm.

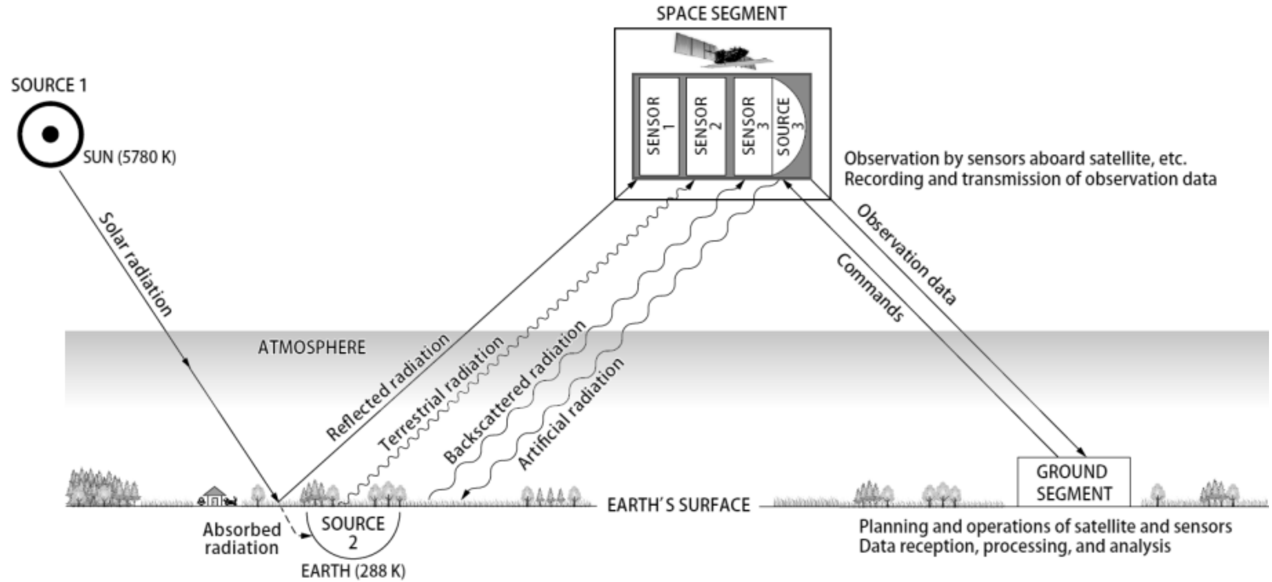


Fig. 2-1. Satellite remote sensing system with five components: sources of radiation, interaction with the atmosphere, interaction with the Earth's surface, space segment, and ground segment (Curran, 1985; with modifications).