# A Holistic Case-Study Approach to Applying Satellite Remote Sensing to Disaster Management

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Edited by

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To the memory of Horst
and
to my wife
and
Marilyn

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Note: Table in italics (1-2) can also be found in the color centerfold.

# FOREWORD

This book provides case and holistic studies on “applying satellite remote sensing to disaster management” by various organizations, institutes, or universities in each country/region. 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 working for disaster management, including rescue/relief/evacuation; not just disclosing them on the Internet.

Satellite remote sensing is one of the primary support tools for disaster management. However, it is not easy for people involved in this field, such as emergency responders, policy makers, administrative officials, researchers, and students, to actually use it. They have been actively seeking good practices and lessons learned, as a practical reference to their activities. It would be a great pleasure for me if this book could contribute to this.

From a methodological point of view, in such applied science research areas as "applying satellite remote sensing to disaster management”, where practical implications are often required for their research results, case studies are useful. It would be also a great pleasure for me if this book could contribute to the active application of a holistic case-study approach to this research area.

This book is published as part of the Cambridge Scholars Publishing Frontiers of Knowledge Series, inviting proposals to guest-edit collections of chapters: Cynthia S. J. Liu, Ming-Chih Cheng, Shih-Chieh Chou, Masahiko Nagai, Nopphawan Tamkuan, and Masami Fukuda contributed chapters. I wish to gratefully acknowledge them. I am also deeply grateful to Cambridge Scholars Publishing (CSP) for giving me the opportunity to write and edit this book, with the support of the whole team at CSP.

Kazuya Kaku<br>Guest Editor, CSP<br>Visiting Researcher, ADRC<br>July 2021

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I am also grateful to Ms. Tomoko Suzuki for her support to create figures in this book.

Finally, I am grateful to JAXA and Asian Disaster Reduction Center (ADRC) for giving me the opportunity to write and edit this book.

# PART I:

# INTRODUCTION

# CHAPTER ONE

# OVERVIEW OF SATELLITE REMOTE SENSING FOR DISASTER MANAGEMENT

KAZUYA KAKU

This chapter gives an overview of satellite remote sensing for disaster management as the basic information on applying satellite remote sensing to disaster management.

## 1.1 Basic principles of satellite remote sensing

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. 1-1: 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.

### 1.1.1 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. 1-1. 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. 1-2 (for derivation of Fig. 1-2(a) and (b), refer to the reference (Kaku, 2019b, appendix A)). 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. 1-2), 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.

Solar radiation, that reached the top of the Earth's atmosphere (see Fig. 1-2(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. 1-2(c) and Section 1.1.2). Similarly, terrestrial radiation that reaches sensors at the space segment through the atmosphere is influenced by the atmosphere.

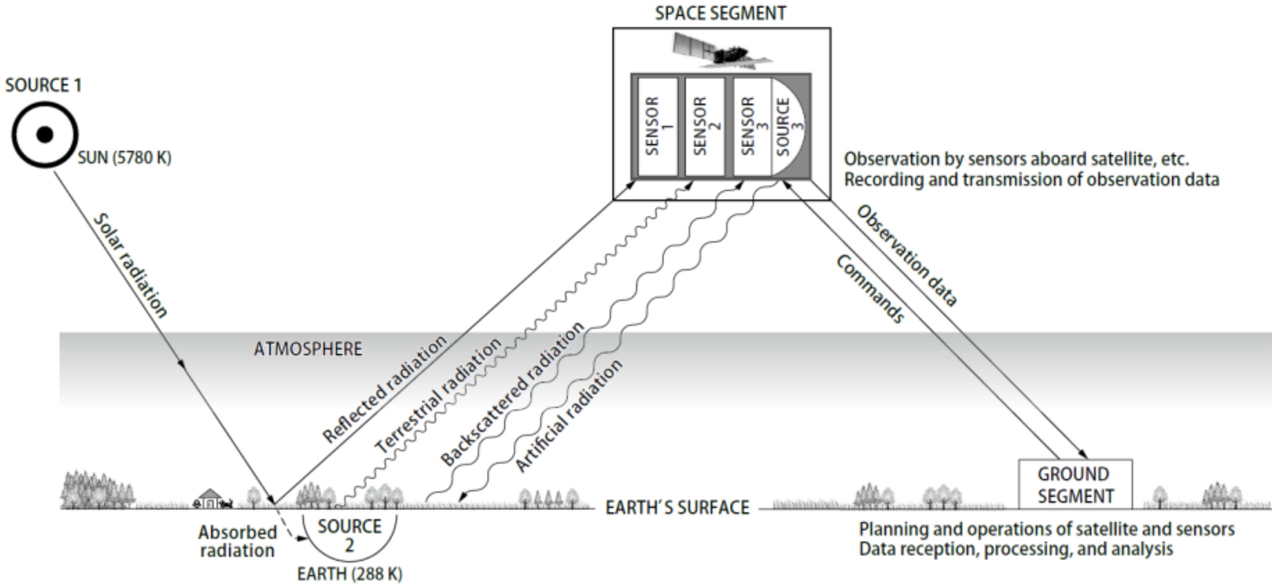


Fig. 1-1. Satellite remote sensing system with five components: sources of radiation, interaction with the atmosphere, interaction with the Earth's surface, space segment, and ground segment (Curran, 1985; with modifications).

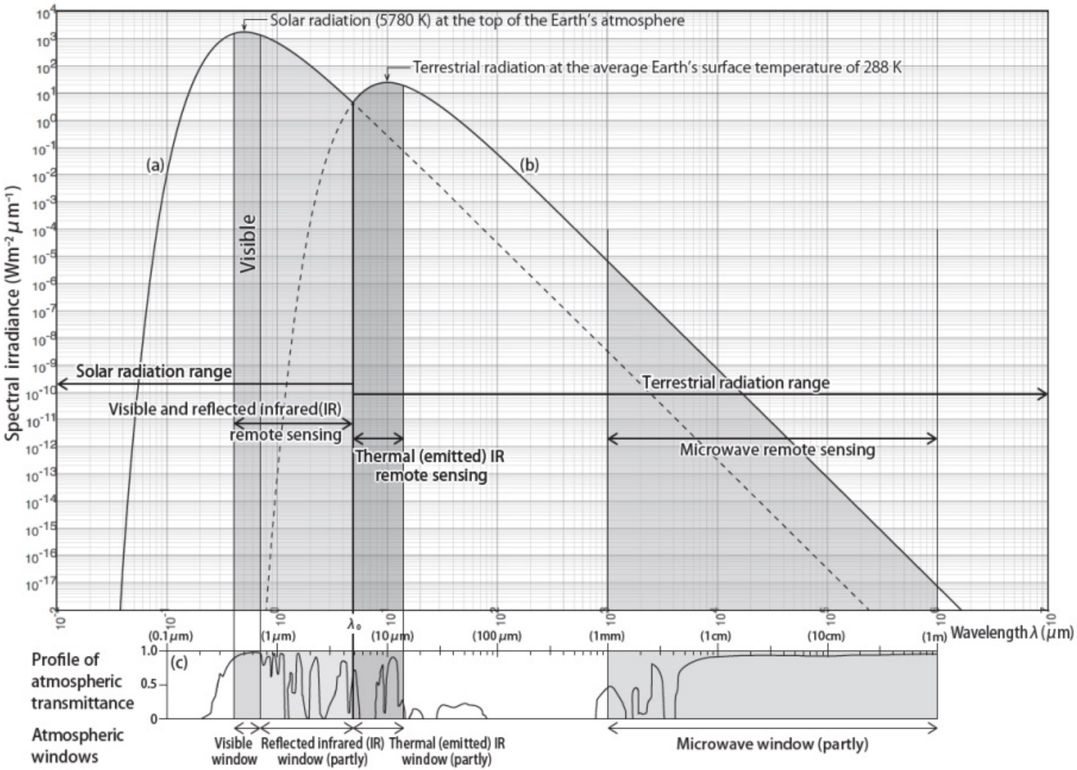


Fig. 1-2. Overview of passive satellite remote sensing with respect to (c) atmospheric windows and segregation of (a) solar radiation and (b) terrestrial radiation. Source of atmospheric transmittance: NASA Earth Observatory. (a), (b): with MAC/Graper v2.

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, as can be seen from Fig. 1-3, 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.

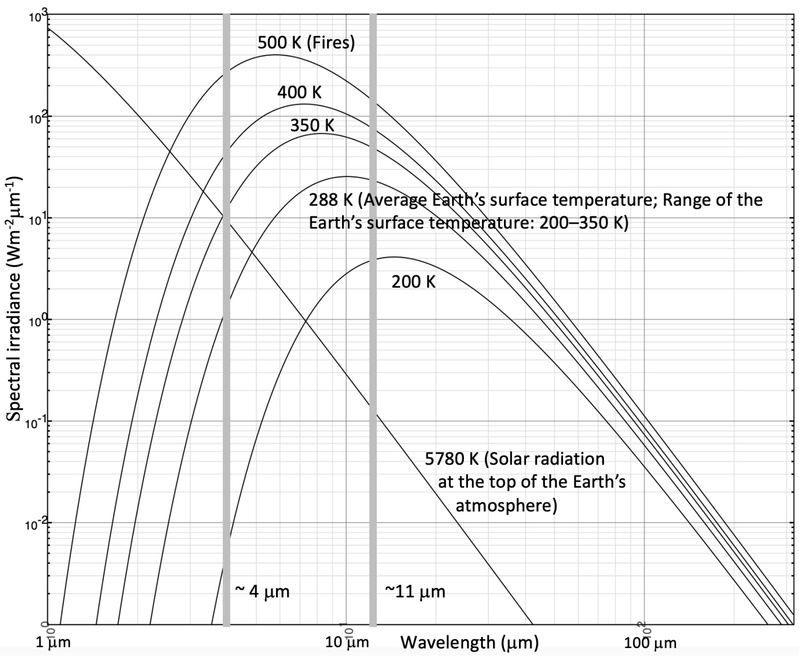


Fig. 1-3. Terrestrial radiances from 200 to 500 K. For the range of the Earth's surface temperature 200–350 K, the intersection point is rounded as ~3–8 μm. (Drawn with MAC/Graper v2.7)

The terrestrial radiation in the microwave band (1 mm–1 m), which is the band with the longest wavelength used for remote sensing, is very low in energy (e.g., see Fig 1-2, the radiant intensity at a wavelength of 1 cm is ~$10^{-11}$ times the peak at 10 μm), which is difficult to observe using satellites, whereas microwaves can penetrate clouds and be used to observe the Earth's surface, regardless of weather conditions.

## 1.1.2 Interaction with the atmosphere

Generally, electromagnetic radiation is absorbed or scattered by atmospheric gases such as water vapor, carbon dioxide, oxygen and ozone, methane, and nitrous oxide, while passing through the atmosphere. However, there are ranges of electromagnetic wavelengths to which the Earth's atmosphere is relatively transparent (little or no absorption or scattering), which are called atmospheric windows.

In remote sensing, wavelengths in the atmospheric windows are used for observation of the Earth's surface, whereas the wavelengths of specific absorption bands can be used to observe the absorbing substance. A profile of the atmospheric windows (atmospheric transmittance) is shown in Fig. 1-2(c). The windows are found in the visible band (0.4–0.7 μm); the partly infrared band (0.7–14 μm), consisting of the reflected infrared band (0.7–3 μm) and thermal (emitted) infrared band (3–14 μm); and the partly radio-wave band (1 mm–30 m). The visible, infrared, and microwave (1 mm–1 m) bands in the radio-wave band are employed for remote sensing.

## 1.1.3 Types of satellite remote sensing

Considering the sources of radiation (see Section 1.1.1) and atmospheric interaction (Section 1.1.2), satellite remote sensing is classified into three types with respect to wavelength regions, as shown in Fig. 1-2: visible and reflected infrared remote sensing, thermal (emitted) infrared remote sensing, and microwave remote sensing.

## 1.1.4 Typical sensors for disaster management

In the space segment, instruments (called sensors) aboard satellites receive reflected solar radiation and emitted terrestrial radiation and emit and receive artificial radiation according to commands from the ground segment (refer to Fig. 1-1).

Typical spaceborne sensors are listed in Table 1-1. Regarding disaster management activities so far, data from the following sensors have been employed:

(1) Optical sensors: passive sensors using solar radiation (visible and reflected infrared)
(2) Synthetic aperture radar (SAR): active sensors using artificial radiation (microwave)
(3) Infrared sensors: passive sensors using terrestrial radiation (thermal (emitted) infrared)
(4) Microwave radiometers: passive sensors using terrestrial radiation (microwave)

**Table 1-1. Three types of satellite remote sensing and typical sensors.**

<table>
<tr><th colspan="2">Types of remote sensing (RS)</th><th colspan="2">Visible and reflected infrared RS</th><th colspan="2">Thermal infrared RS</th><th>Microwave RS</th></tr>
<tr><td colspan="2">Atmospheric windows</td><td>Visible 0.4–0.7 μm</td><td>Reflected infrared 0.7–3 μm (partly)</td><td colspan="2">Thermal (emitted) infrared 3–14 μm (partly)</td><td>Microwave 1 mm–1 m (partly)</td></tr>
<tr><td rowspan="2">Source of electro-magnetic radiation</td><td>Passive</td><td colspan="2">Solar radiation</td><td colspan="2">Terrestrial radiation</td><td>Terrestrial radiation</td></tr>
<tr><td>Active</td><td colspan="2">Artificial radiation</td><td colspan="2">not applicable (NA)</td><td>Artificial radiation</td></tr>
<tr><td rowspan="2">Typical sensors</td><td>Passive</td><td colspan="2">Optical sensors</td><td colspan="2">Infrared sensors</td><td>Microwave radiometers</td></tr>
<tr><td>Active</td><td colspan="2">LiDAR (Light Detection and Ranging)</td><td>NA</td><td colspan="2">Radar (Radio Detection and Ranging)<br>- Synthetic Aperture Radar (SAR)<br>- Precipitation Radar (PR)<br>- Radar Scatterometer<br>- Radar Altimeter</td></tr>
</table>

## 1.2 Optical sensors

Optical sensors work in the wavelength region of visible and reflected infrared light, and they receive the solar radiation reflected by the Earth's surface and clouds. Imagery from optical sensors is similar to photographs taken by digital cameras in an airplane (see Fig. 1-4(a)). An optical sensor cannot work without sunlight. In addition, an optical sensor cannot observe the Earth's surface through clouds; in the case of meteorological satellites, optical sensors are also used to observe the clouds themselves.

### 1.2.1 Spatial resolution and swath width

The spatial resolution of a sensor, which shows what part of an object a sensor can identify, is defined by the size of the surface area corresponding to an individual pixel of a sensor, where a pixel is a single detector element of a sensor. By zooming in on a satellite image displayed on a screen, a square mosaic appears (e.g., see Fig. 1-14), which shows the pixels of the image. The spatial resolution of a sensor is determined by the instantaneous field of view (IFOV) of the sensor and the distance from the object. A sensor at a low altitude has a higher spatial resolution than the same one at a higher altitude.

The belt-shaped area on the Earth's surface imaged by a sensor as the satellite moves is referred to as the swath. The spatial resolution and swath width of a sensor are set for each satellite based on its mission requirements and data handling capacity. Generally, if the spatial resolution is higher, the swath width is obliged to be smaller, as exemplified in Fig. 1-4. Note that, in Fig. 1-4, "very high resolution" means a spatial resolution of less than or equal to 1 m; "high resolution," greater than 1 m and less than or equal to 10 m; "very wide range," a swath of more than 100 km; "wide-range," greater than 50 km and less than or equal to 100 km. (In the classifications above, the best values for resolution and related swath width for each satellite are based on information found on the Internet.) A WorldView-2 image (Fig. 1-4(a)) recorded on March 12 immediately after the Great East Japan Earthquake (Kaku et al., 2015), which occurred on March 11, 2011, covering the Oshika Peninsula in Miyagi Prefecture, showing local conditions around Onagawa (copyright: DigitalGlobe, DLR, and Map produced by ZKI). A FORMOSAT-2 image (Fig. 1-4(b)) observed on March 12, shows Watari and surrounding areas. ALOS/AVNIR-2 images (Fig. 1-4(c)) show area from Sendai Airport (in the north) to Soma (in the south); the image on the right was recorded after the tsunami on March 14, 2011; the image on the left was recorded before the tsunami on February 27, 2011.

A higher spatial resolution or wider swath requires more pixels, which causes the data volume to become larger and makes data transmission and handling more difficult. From the viewpoint of disaster monitoring, immediately after an extensive catastrophe, users mostly request satellite observation to assess the general situation in damaged areas, for which wide-ranging surveillance is most suitable (see Fig. 1-4(b) and (c), in the case of the 2011 Great East Japan Earthquake). Users also request satellite observation to evaluate roads, key facilities, and other infrastructure in greater detail to confirm their availability and ensure routes for evacuation, rescue, and support, for which very-high-resolution observation is necessary (see Fig. 1-4(a), in the case of the 2011 Great East Japan Earthquake).

Fig. 1-4. A classification of optical Earth observation satellites, with respect to spatial resolution and swath width, which supported the response to the 2011 Great East Japan Earthquake.
Mark (X) indicates ALOS-3 to be launched in or after 2021 by JAXA.