Preface to the Second Edition

Never before has there been a tool that in its application spans all the four dimensions of relevance to mankind (position, navigation, timing and the environment). Global Navigation Satellite Systems (GNSS), a satellite microwave (L-band) technique, is such a tool that has widely been used for positioning (both by military and civilians), navigation, timing and is now revolutionizing the art of monitoring our environment in ways never fathomed before. In the first edition of the book, the theory and applications of GNSS to environmental monitoring was presented. Since then, however, so many things have changed both in the GNSS satellite development and applications. For instance, Galileo and Beidou satellites that were not operational during the writing of the first edition of the book are now operational. Furthermore, more long-term GNSS data collected from low earth orbiting satellites such as COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) have become available thereby enabling climate variability studies.

With all GNSS satellites (GPS, Galileo, GLONASS and Beidou) becoming operational, multi-signals are now available that are capable of remotely sensing the Earth's atmosphere and surface providing highly precise, continuous, all-weather and near real-time environmental monitoring data. In this regard, the refracted GNSS signals (i.e. occulted GNSS signals or GNSS-meteorology) are now emerging as sensors of climate variability while the reflected signals (i.e., GNSS-Reflectrometry or GNSS-R) are increasingly finding applications in determining, e.g. soil moisture content, ice and snow thickness, ocean heights and wind speed and direction of ocean surface among others. Furthermore, the increasing recognition and application of GNSS-supported unmanned aircraft vehicles (UAV)/drones in agriculture (e.g. through the determination of water holding capacity of soil) highlights the new challenges facing GNSS. Frank Veroustraete [1] puts it candidly:

> A lot is happening lately on the subject of drone applications in agriculture and precision farming. From the ability to image, recreate and analyze individual leaves on a corn plant from 120 meters height, to getting information on the water-holding capacity of soils to

> variable-rate water applications, agricultural practices are changing due to drones delivering agricultural intelligence for both farmers and agricultural consultants.

In recognition to the developments above, it is necessary that the first edition of the book be updated. This has necessitated the writing of this second edition with a completely new title that captures its increasing applications to remotely sense the environment for changes. To this end, three new chapters have been added; GNSS reflectrometry and applications, GNSS sensing of climate variability and the applications to UAV/drones. In addition, various chapters of the first edition have been updated.

I am grateful to Dr. Richard Fischer, publisher of Inside GNSS/Inside Unmanned Systems for the permission to use Fig. 10 and to Dr. Volker Jenseen and Taylor & Francis Publishers for permission to use Figs. 19.7–19.9. Special thanks to my Ph.D. student Hu Kexiang (Frank), Curtin University, who contributed Chap. 20 and also helped with the preparation of the references as well as the figures in Chaps. 10 and 12.

Perth (Australia) and Recife (Brazil) Joseph Awange
April 2017

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Preface to the First Edition

With ever increasing global population, intense pressure is being exerted on the Earth's resources, leading to severe changes in its land cover (e.g. forests giving way to settlements), diminishing biodiversity and natural habitats, dwindling fresh water supplies and the degradation in the quality of the little that is available, and changing weather and climatic patterns, especially global warming with its associated predicted catastrophes such as rising sea level and increased numbers of extreme weather events. These human-induced and natural impacts on the environment need to be well understood in order to develop informed policies, decisions and remedial measures to mitigate current and future negative impacts for the benefit of human society, and the natural world at large.

Such a situation calls for the continuous monitoring of the environment to acquire data that can be soundly and rigorously analyzed to provide information about the current state of the environment and its changing patterns, and to enable predictions of possible future impacts. Environmental monitoring techniques that may provide such information are under scrutiny from an increasingly environmentally conscious society that demands the efficient delivery of such information at a minimal cost. In addition, it is the nature of environmental changes that they vary both spatially and temporally, thereby putting pressure on traditional methods of data acquisition, some of which are very labour intensive, such as animal tracking for conservation purposes. With these challenges, conventional monitoring techniques, particularly those that record spatial changes, call for more sophisticated approaches that deliver the necessary information at an affordable cost. One direction being followed in the development of such techniques involves *satellite environmental monitoring*, which can act as stand-alone methods, or to complement traditional methods.

One of the most versatile means of using satellites for environmental monitoring involves global navigation satellite systems (GNSS), the general term for the US-based Global Positioning System (GPS), Russian's GLObal NAvigation Satellite System (GLONASS), China's Beidou or Compass and the European Galileo satellite systems. GNSS is a satellite tool with the capability of providing location (spatial) data, remote sensing of the Earth's atmosphere (temperature and pressure) and surface, assisting in precise orbit determination of low earth orbiting environmental satellites, and supporting the tracking of elusive fresh underground and surface waters, among many other uses. Its spatial data are also integrable with other remote sensing, socio-economic and field survey data through geographical information systems (GIS) to provide highly continuous real-time spatio-temporal dataset that are of enormous benefit to the emerging field of *geosensor-network* environmental monitoring discussed in Sect. 17-12.

For example, *GNSS-based radio telemetry* is a modern method for observing animal movements, thereby moving the burden of making observations from the observer (i.e. researcher) to the observed (i.e. animal), and in so doing alleviating the difficulties associated with personal bias, animal reactions to human presence and animal habits that make most of them secretive and unseen [1]. This method provides large, continuous, high-frequency data about animal movement, data which, if complemented by other information dealing with animal behaviour, physiology and the environment itself, contributes significantly to our knowledge of the behaviour and ecological effects of animals, allowing the promotion of quantitative and mechanistic analysis [1]. Another very different example of the use of GNSS for environmental studies is its contribution to weather and climate change monitoring via the new field of *GNSS-meteorology*. Such methods are complimentary to traditional radiosonde techniques, which unfortunately inadequately cover the southern hemisphere and oceanic regions, while water vapor radiometers are adversely affected by clouds. In environmental impact assessment (EIA), strategic environmental assessment (SEA) and sustainability assessment (SA), GNSS methods provide maps, distances and locations that help in decision-making and also in the modelling of the impacts of policies. In epidemiology, GNSS is finding use in the study of the spread of infectious diseases and climate change effects on vector-borne diseases.

It is with this almost overwhelming variety of uses of GNSS for environmental monitoring in mind that this book is written, the purpose being to bring its theory and possible environmental monitoring applications together within one volume. It is hoped that environmentalists will be able to quickly find references to the theory of GNSS, while geodesists and others not specifically working in environmental fields will have numerous examples that could motivate further development of GNSS techniques for the benefit of environmental monitoring. For this reason, the book is divided into two parts. Part I deals with the basics of GNSS, while part II looks at its applications.

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