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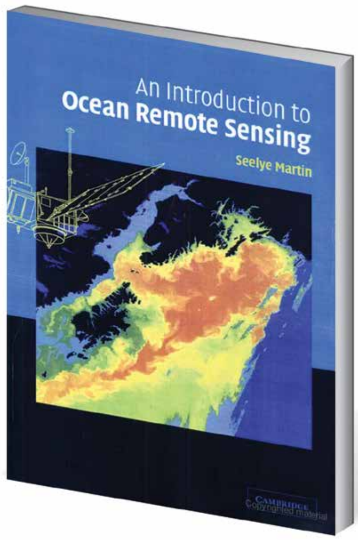


## AN INTRODUCTION TO OCEAN REMOTE SENSING, 2ND ed.

**By Seelye Martin, 2014, Cambridge University Press, 496 pages, ISBN 0-521-80280-6, e-book: $68 US, Hardcover: $85 US**

**Reviewed by Kristina B. Katsaros**

This second edition of *An Introduction to Ocean Remote Sensing* by Seelye Martin has all the fine attributes of the first edition, and also provides an excellent update on the long-term remote sensing of ocean properties from space. It covers several innovative new remote sensing satellites that were launched or began to produce results during the 10 years between the two editions. This review concurs in most details with my review of the first edition published in *Oceanography* a decade ago (http://www.tos.org/oceanography/archive/18-3_katsaros.pdf). Here, I aim to point out both changes and new information provided in the second edition. For instance, the first edition's section on further developments was eliminated for the second edition because most items in the original list of future satellites have come to fruition. There are still developments to come in the near future, but information about them is now sprinkled throughout the text.

This book is a wonderful contribution to the education of oceanographers in the second decade of the twenty-first century. The basics of satellite techniques are now well understood so that more oceanographers can rely on remotely sensed data. Every graduating oceanography student should be well versed in this important data source. It took a while for ocean remote sensing products to be accepted as "real data," but today the spatial and temporal variations exhibited by the many ocean variables that can be measured from space with good fidelity have contributed a whole new way of seeing the global ocean. In conjunction with data from Argo floats, which sample the upper layers down to 2,000 m water depth and are spread over the global ocean by the thousands, the remotely sensed ocean surface data can now readily be connected to deeper layers as well.

*An Introduction to Ocean Remote Sensing* is a classical textbook that begins with fundamentals and basic principles. It covers the whole field, which was difficult to do in the past as some aspects were better developed than others. Meteorologic and some oceanographic data have been available from space for 50 years, counting from the Nimbus I satellite and the early infrared measurements of sea surface temperature (SST) that became available in the mid-1960s. We have used a broad range of the electromagnetic spectrum, from visible and infrared wavelengths to microwaves. Remote-sensing techniques have been used in passive and active modes, the latter mostly from space in the microwave range, and visible light lasers are now in use from aircraft and in new satellite missions. I mention meteorology because satellite oceanography is dependent on developments in satellite meteorology as the ocean is observed through the intervening atmosphere. Observing the ocean with visible and infrared wavelengths requires that the images be "cloud cleared"—that is, cloudy pixels (individual observations) must be removed and signals from the ocean must be corrected for atmospheric transmission and scattering. The author points out that 90% of a signal that reaches a satellite in these wavelength bands comes from the atmosphere, so such signals must be accurately accounted for in order that the 10% emanating from the ocean will be correctly interpreted.

This book gives clean and detailed explanations and definitions of most concepts that are required for informed use of satellite data. Author Martin should be commended for the systematic and thorough manner by which he has structured his book. The first section provides the motivation for remote sensing and study of the ocean for societal interests: commercial, naval operations, fisheries, and recreation are mentioned as well as the ocean's role in extreme weather events and climate variability. He points out that 50% of the global population lives within 50 km of coastlines, regions that are vulnerable to natural hazards such as sea level rise, tsunamis and tropical cyclones, and also the effects of urban run-off and waste and sewage disposal.

The first chapter, Background, covers the basics of typical satellite orbits and sampling possibilities. It discusses imaging techniques and provides an overview of satellite systems from 1978 through 2007. There is a new section in the second edition on "the growth in international programs and observing constellations," a most welcome advance in space science. Martin reports on the Group on Earth Observations (GEO) and its System of Systems (GEOSS), whose goal is to gather all civilian satellite programs into a voluntary coordinated program. I recommend this section for general readership because it discusses several broadly useful programs such as a coordinated SST effort and the "A-train," satellites of several nations that orbit Earth one behind the other on the same afternoon polar orbits to assure continuity of valuable operational and research data.

The next four chapters cover ocean surface phenomena, electromagnetic radiation and atmospheric properties, and radiative transfer. Chapter 2 discusses ocean surface winds and waves, currents, sea surface height, and sea ice. (Sea surface temperature and ocean color are reserved for later chapters.) Chapter 3 deals with basic electromagnetic theory, fundamentals of visible and infrared radiation, optics, scattering theory, transmission, and signal absorption in atmosphere and ocean. The author talks about an "ideal instrument," the simple telescope, but does not here or anywhere in the book discuss detectors of radiation. Perhaps this is a wise choice. Instead, he concentrates on the basic physics of electromagnetic transmission and on how images are obtained. Chapter 4 covers knowledge about the atmosphere, water vapor, clouds, aerosols, and ozone. Extinction of radiation by atmospheric gases and various scattering mechanisms are derived, and application of this knowledge to remote sensing of the sea is emphasized. Chapter 5 provides details of reflection and scattering from the ocean surface, transmission through the air-water interface, and absorption and scattering in seawater.

Chapter 6 is devoted to ocean color and the interpretation of images. The author spends some time on the empirical and semi-analytic algorithms used to interpret chlorophyll-*a* data from satellite images and discusses chlorophyll's reflectance and fluorescence properties. He discusses in particular the Sea-viewing Wide Field-of-view Sensor (SeaWifs) and the Moderate Resolution Imaging Spectro-radiometer (MODIS) instruments on two satellites, Terra and Aqua, and the Medium Resolution Imaging Spectrometer (MERIS), launched by the European Space Agency and operational from 2002 to 2012). Japanese, Indian, and Korean satellite services have launched other color instruments. In this chapter, several sections are devoted to atmospheric corrections and the role of atmospheric aerosols in modifying ocean color observations. An advanced instrument called Pre-Aerosol, Clouds and ocean Ecosystem (PACE) is planned for a future NASA mission to compensate for the loss of color sensors because only one MODIS instrument is currently viable.

Chapter 7 is devoted to infrared observations of SST. This field, one of the most developed in oceanographic remote sensing, provides data that are used widely. The subject still remains open for research due to the complicated air-sea interaction processes that modify the temperature gradient just below the sea surface. The author covers these details in a succinct and clear manner and discusses the two most well known sensors: the now classic Advanced Very High Resolution Radiometer (AVHRR), carried by NOAA satellites, whose data are used for numerous applications in real time globally, and MODIS, carried on Aqua and Terra. The discussion also includes the European Along-Track Scanning Radiometer (ATSR). Sections of this chapter focus on two important applications of remotely sensed SST, El Niño/La Niña observations (especially for the year 1998) and global SST mapping. Because of the importance of SST and a profusion of formats and protocols, several workshops were held to form the GODAE (Global Ocean Data Assimilation Experiment) High Resolution SST project (GHRSST). The second edition covers this development and includes references. A separate section on Products and Archiving provides an overview of the many available products, as well as their error sources and intercomparisons among them, and information about a special high-resolution product available for detailed studies of eddies and ocean fronts.

Chapter 8 deals with fundamentals of microwave passive instrumentation, such as antennas and scanning patterns and describes some of the well-known instruments, such as the Special Sensor Microwave/Imager (SSM/I), which has had continuous presence in space since 1987 on US Defense Meteorological Satellites. The chapter also describes the TRMM (Tropical Rainfall Measuring Mission) Microwave Imager (TMI) and its important complementary new rain radar. The SSM/I has been followed by Advanced Microwave Scanning Radiometers (AMSR) on several satellites.

Chapter 9 focuses on passive microwave observations of the atmosphere and ocean surface. It includes information on all the relevant issues, such as error sources due to solar reflection and radio interference. The text describes the effects of sea foam, azimuthal variation in emission from a wind-roughened sea surface, and variations due to polarization. The chapter discusses passive microwave measurements of temperature and salinity, the latter developed since the first edition was published.

Chapter 10 turns to a discussion of radars, beginning with the fundamentals of the radar equation, various signal generation processes, and Doppler binning of the retrieved backscattered signal. Chapter 11 describes the use of radar "scatterometers" to measure sea surface winds. This idea was first tested by Seasat in 1978 and has since become well established. A US/Japanese collaboration has launched several scatterometers and the Europeans have launched four: on European Remote Sensing (ERS) satellites 1 and 2 in 1991 and 1995 and the ASCAT (Advanced Scatterometer) on the satellites Météorologiques Opérationnel (MetOp) A and B. India and China are also launching scatterometers. European instruments employ C-band and US-built instruments employ Ku-band, thereby allowing acquisition of knowledge about how the choice of wavelength affects interaction with sea surface wave fields. This chapter also discusses polar ice studies employing scatterometers.

Another important accomplishment of microwave radars is the development of the altimeter, a nadir-viewing radar that measures the height of the ocean relative to the geoid. Chapter 12 begins by discussing the fundamentals of Earth's shape, the various orbits selected for sampling by altimeters to account for tides and other temporal variations of sea height, and how to avoid aliasing. Again, several important instruments are discussed, notably the French-American TOPography Experiment (TOPEX) and later JASON missions 1, 2, and 3, as well as calibrations and corrections. The chapter also covers the effects of surface waves on return signals (from which wave height within the footprint can be determined) and discusses both the effects of swell and the so-called "sea state bias" caused by the asymmetry of crests (narrow and peaked) and valleys (open and wide) of ocean swell. Applications in terms of large-scale geostrophic flow, seasonal variations in sea surface height, and Rossby wave propagation are also discussed. Figure 12.23 (page 397) demonstrates that the additional 10 years of data collected between the two editions of the book provide twice the length of sea surface height time series, which show continuous sea level rise ($3.2 \pm 0.4$ mm $yr^{-1}$) from 1993 to 2013, with only one major negative deviation that is suggested to have been caused by extreme rainfall on land during the 2010–2011 El Niño/La Niña event.

Chapter 13 discusses imaging radars, side-looking radars (SLRs), and synthetic aperture radars (SARs). Again, the author clearly and simply describes the operation and resolution of SARs. He goes on to present amazing observations by Canadian RADARSAT SARs 1 and 2 of internal waves, surface slicks, and sea ice. The new edition lists the many modes of sampling these SARs provide as well as those of the European Environmental Satellite (ENVISAT) ASAR (Advanced SAR) launched in 2002 and operational until 2012 and earlier SAR instruments. This chapter is an excellent survey of most of the uses of SAR, but naturally cannot cover all possibilities. In general, Martin should be commended for his restraint in providing the facts and including the most important applications of each instrument without drowning the reader in detail. He includes examples of observations of oil spills, internal waves, and several cases of fascinating sea ice structures from the Antarctic and the Arctic regions.

Chapter 14 in the second edition is devoted to other recent advancements, some of which were mentioned as future possibilities in the first edition of the book. They include three gravity and two salinity missions. The three gravity missions are: The Challenging Mini Satellite Payload (Champ) launched in 2000, the US-German Gravity Recovery and Climate Experiment (GRACE) mission launched in 2002, and the European Gravity field steady state Ocean Circulations Explorer (GOCE). The gravity field is recovered in the GRACE mission by keeping track of the altitude and travel speed of two identical bodies as they travel along the same path and traverse features on Earth that affect gravity. The precision is amazing, but ground resolution is of order 1,000 m to 500 km. The two salinity missions are: SMOS (Soil Moisture and Ocean Salinity, a 2009 European launch) and Aquarius (United States and Argentina, launched in 2011). These satellite systems provide truly new types of measurements that use L–band microwave radiometry. The sea surface salinities (SSSs) obtained have a surface resolution of 150 km, with data provided in monthly averages. In spite of the limited resolution, the data already reveal expected patterns of low SSS in the tropical rain belts and higher SSS where evaporation is strong in the subtropical gyres (e.g., see special issue section of this issue of *Oceanography*). The data also display new features and temporal variabilities.

Chapter 14 also presents two NASA laser altimeter missions, Ice, Cloud and Land Elevation satellite (ICESat-1, operational from 2003 to 2009) and the follow-on ICESat-2 scheduled for launch in 2017. Sensors on ICESat-2 should achieve higher ground resolution. Because clouds hamper the lasers, this new set of satellites benefits from data collected by a dual-beam radar altimeter aboard the European Space Agency's CRYOSat-2, launched in 2010 (the first version was lost on launch). These three missions complement each other and provide information to permit estimates of ice sheet thicknesses on land around the globe. CRYOSat-2 also supports studies of sea ice.

This second edition of *An Introduction to Ocean Remote Sensing* has been prepared meticulously. The judicious restraint exercised in its presentation and the inclusion of excellent illustrations make it eminently practical for students and for teachers of university courses. The book should also provide an almost encyclopedic resource for any practicing oceanographer, and perhaps even for policymakers and their staffs. It serves a very different niche than conference and more specialized books, where the state of the art is presented without the fundamentals.

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