OPTICAL RADIOMETRY FOR OCEAN CLIMATE MEASUREMENTS

Edited by

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Foreword

The view of the Earth from space has become an icon of our time. First seen through the spectacular photographs taken by the Apollo astronauts, it showed us the Earth, which had seemed limitless to our ancestors, to be small and fragile, a vulnerable oasis for life in the vast vacuum of space. If no other benefit had ever come from the space age, those pictures alone would have justified the effort to leave the Earth, for they changed our view of the planet forever.

But those photographs, it turned out, were just the beginning of what can be learned by looking down on the Earth from space. Only from the vantage point in orbit above the planet can we really get the whole picture—seeing far enough to give a truly global view, but also with sufficient detail to get down to the local scale. Since the time of the early satellites, the number and sophistication of remote sensing measurements has grown hugely, so that we now have a nearly continuous view of the Earth from space that is highly resolved in area, time, and wavelength. Terabytes of data now flood down from our satellites, documenting the view of Earth from space in unprecedented detail. If only we can make sense of it all, it offers the chance to understand our home planet as never before, allowing us to see how every locality fits into the whole picture. For the oceans in particular, this is a transformative view, because over large areas they are only rarely visited by people or instruments to make in situ observations. Much of our uncertainty over prediction of seasonal and longer term changes originates in this ignorance of the oceans, which are the main storage for heat in the climate system and the site of half the world's biological productivity.

This book describes the latest knowledge and techniques in visible and infrared radiometry from satellites. These regions of the electromagnetic spectrum can be used to give important information about several aspects of the oceans: the infrared observations can be used to measure sea surface temperature, which is a fundamental variable needed for climate and weather prediction studies. Visible measurements characterize ocean color, from which we can derive estimates of chlorophyll and other pigments to enable characterization of the plankton community. The plankton are in turn the base of the ocean food chain and play important roles in the Earth's carbon cycle, both in the rapid changes occurring today as a result of human activities—climate change and ocean acidification—and over the longer term for in maintaining a habitable planet.

As the contributions here illustrate, making sense of the flood of data from satellites is no easy task: it requires meticulous attention to detail. The sensors must be continually calibrated and the data validated, so that long-term records, constructed over time from successive instruments, can be relied on to be free from drift. This is of critical importance for studies of climate change, where any long-term change in temperature must be carefully separated from instrumental effects. To achieve this kind of reliability requires continuous and extended free exchange and cooperation between all those involved—from the designers and engineers who build the sensors, those interpreting the data, and researchers making in situ observations who provide the ground truth. However, there is a rich return on this effort for our civilization as a whole, for from it we can understand our home planet as never before.

Andrew Watson
University of Exeter 27th July 2014

Preface

Climate change science relies on the combined use of models and measurements to advance understanding of climate fluctuations and trends, and ultimately to formulate predictions. Gathering measurements for climate change investigations requires well-characterized observing systems and the implementation of strategies to detect decadal variations that are much smaller than those occurring at daily or interannual scales. This requirement imposes the collection of uninterrupted time series of highly accurate measurements traceable to accepted international standards that collectively constitute the evidence baseline for climate research.

Satellite systems provide a quasi-synoptic global sampling dimension of climate data measured using a variety of instruments operated over the Earth's surface. Like any observing system devoted to the generation of climate-quality data records, space-based instruments supporting climate change investigations need to deliver continuous highly accurate measurements with defined uncertainties. This imposes lifetime calibration and validation processes for each component of the end-to-end observing system and for the derived data products.

During the last few decades, several space missions have been designed to support ocean climate studies through measurement of physical, biological, and chemical variables. Among the various remote sensing technologies, optical sensors operating in the visible, near-infrared, and thermal infrared spectrum are well suited to measure variables such as sea surface temperature and water leaving radiance at timescales varying from hours to days and geographical-scales from tens of meters to kilometers. While the sea surface temperature has relevance for the heat, gas, and momentum coupling between the atmosphere and ocean, reconstruction of patterns associated with dynamical processes such as surface currents, eddies, and upwelling, the water-leaving radiance in the visible spectral region is fundamental for the quantification of optically significant seawater constituents, including phytoplankton biomass, that play a major role in the Earth's carbon cycle.

Optical remote sensing technologies used to generate climate-quality data records share the need for thorough prelaunch characterization and absolute calibration of the satellite radiometer. These activities are then followed by the postlaunch monitoring of the radiometer stability over the mission lifetime, the continuous assessment of data product quality, and finally, successive reanalysis and reprocessing of all data in conjunction with better understanding of error sources. The postlaunch activities largely rely on in situ reference measurements for the development and assessment of the algorithms and methods applied to determine each climate variable, and successively for the continuous validation of derived satellite products. Furthermore, reference measurements are required to homogenize climate data records obtained from multiple or successive satellite instruments. Because of this, advances in remote sensing optical technology demand progress to deliver in situ reference instrumentation, measurement methods, and field strategies. Such progress embraces the design of increasingly precise and stable field optical radiometers, the improvement of laboratory techniques for their characterization and absolute calibration, the assessment of measurement methods and field intercomparison strategies, and finally, advances in the creation and handling of data repositories.

This book, through a number of contributions from various authors, presents the state of the art for optical remote sensing and shows how it can be applied for the generation of marine climate-quality data products. The various chapters are grouped into six thematic parts each introduced by a brief overview. The different parts include: (1) requirements for the generation of climate data records from satellite ocean measurements and the basic radiometry principles addressing terminology, standards, measurement equation, and uncertainties; (2) satellite visible and thermal infrared radiometry embracing instrument design, characterization, and pre- and postlaunch calibration; (3) in situ visible and thermal infrared reference radiometry including overviews on basic principles, technology, and measurement methods required to support satellite missions devoted to climate change investigations; (4) computer model simulations as fundamental tools to support interpretation and analysis of both in situ and satellite radiometric measurements; (5) strategies for in situ reference radiometry to satisfy mission requirements for the generation of climate data records; and finally, (6) methods for the assessment of satellite data products.

The expectation of the editors is that this book will become a working tool, as either a reference text or as background literature for discussions, for students and scientists interested in ocean climate studies and satellite radiometry.

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