

THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

Oceanography

CITATION

Church, J.A. 2015. Review of *Sea-Level Science: Understanding Tides, Surges, Tsunamis and Mean Sea-Level Changes*, by D. Pugh and P. Woodworth. *Oceanography* 28(1):177–178, <http://dx.doi.org/10.5670/oceanog.2015.24>.

DOI

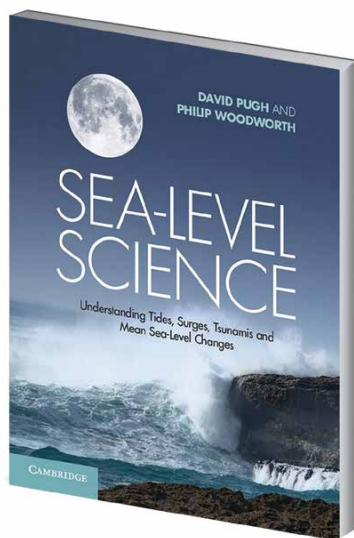
<http://dx.doi.org/10.5670/oceanog.2015.24>

COPYRIGHT

This article has been published in *Oceanography*, Volume 28, Number 1, a quarterly journal of The Oceanography Society. Copyright 2015 by The Oceanography Society. All rights reserved.

USAGE

Permission is granted to copy this article for use in teaching and research. Republication, systematic reproduction, or collective redistribution of any portion of this article by photocopy machine, reposting, or other means is permitted only with the approval of The Oceanography Society. Send all correspondence to: info@tos.org or The Oceanography Society, PO Box 1931, Rockville, MD 20849-1931, USA.



SEA-LEVEL SCIENCE: UNDERSTANDING TIDES, SURGES, TSUNAMIS AND MEAN SEA-LEVEL CHANGES

By David Pugh and Philip Woodworth, Cambridge University Press, Cambridge, UK, 395 pp., ISBN 978-1-107-02819-7, Hardcover \$99 US

Reviewed by John A. Church

The ocean surface provides pathways for shipping and fishing activities and is the reference level marine scientists use when measuring ocean interior properties. Its intersection with land forms coastal environments important for marine ecosystems, coral reefs, coastal fisheries, and many of our recreational activities. We are all familiar with the ocean's surface but, in general, take its existence for granted, pay little attention to its spatial and temporal variability, and are unfamiliar with its importance.

The spatial and temporal variability of the ocean surface ranges from small-scale, high-frequency ripples to energetic wind-driven surface waves, ocean tides, and storm surges, and on to basin- and global-scale low-frequency climate variability and change signals. This variability is of immense economic and environmental importance.

Sea-Level Science: Understanding Tides, Surges, Tsunamis and Mean Sea-Level Changes by David Pugh and Philip Woodworth is a great introduction to a broad interdisciplinary spectrum of sea level variability and change topics. The subjects range from tidal frequencies to the centennial changes related directly to climate change and the emission of anthropogenic greenhouse gases, and include the most important issues facing society today. Though surface waves are mentioned in various chapters of the book, they are not the central focus.

The first six chapters generally follow the course of David Pugh's earlier

book *Tides, Surges and Mean Sea-Level*. The new book brings these topics up to date and provides additional information related to climate change and variability as well as results from modern satellite observing systems and related analysis. The book is well written by two of the leading scientists in these fields, is easy to understand despite the underlying complexity of the science, and is well illustrated with high-quality diagrams and photographs. Each chapter begins with a few lines of poetic introduction and ends with a comprehensive, but not exhaustive, list of references.

The Introduction (Chapter 1) provides a general background and outlines early ideas and observations. This is followed by a brief description of tidal patterns around the world, with some illustrative examples of tidal observations and of meteorological and other nontidal sea level changes, including a brief mention of storm surges and tsunamis and their impacts. Chapter 1 concludes with definitions of common terms and gives the reader a good overview of sea level variability, with a useful discussion of some simple statistics and the spectrum of sea level variability. Chapter 2 introduces historical sea level measuring techniques, from tide poles, to tide gauges, to GPS technology, and provides an important discussion of datum control. It is a very useful introduction to anyone beginning to analyze sea level data or manage a sea level observing network.

Tidal analysis is a seemingly complex field for the newcomer, with historical developments sometimes obscuring the simplicity of the underlying ideas. In Chapters 3 and 4, the reader is led through the concept of the tidal forces and the closely related topic of tidal analysis. The

description of tidal forces begins with the basic ideas of gravitational attraction and then develops the concept of the equilibrium tide of the Earth-Moon-Sun system. This leads to identification of the basic astronomical frequencies and a description of tidal patterns and their interannual to decadal variations. These frequencies lead directly to the harmonic and response methods used for the analysis and prediction of surface height and ocean current observations.

The excitation of long ocean waves (wavelengths of thousands of kilometers in the deep ocean) by tidal forces is responsible for the transfer of tidal energy around Earth and results in observed tidal patterns being very different from the equilibrium tide. Chapter 5 focuses on the nature of these waves, how they interact to result in observed tidal patterns, and the idea of ocean resonance. A number of examples are very informative. The impact of changes in the atmosphere related to the cycles of solar radiative forcing and the response of the solid Earth to gravitational forces are also discussed. There is a brief but incomplete section on internal tides. Although this concept is picked up again in Chapter 6, the incompleteness of this section is perhaps surprising and a little disappointing, given the importance of internal tides to global ocean circulation. The last section of this chapter discusses long-term changes in tides and their relationship to local bathymetric changes. Chapter 6 deals with the generation of shallow water tides from nonlinear interaction, their impacts on tidal currents (both the high-frequency components and also the important low-frequency residual currents), and tidal asymmetries. The interesting phenomenon of tidal bores is also

Upcoming Oceanography Special Issues

Vol 28 | No 2 | Jun 2015

**Emerging Themes in Ocean
Acidification Science**

Vol 28 | No 3 | Sep 2015

**Russian American Long-Term Census
of the Pacific Arctic**

Vol 28 | No 4 | Dec 2015

**A New Look at the Low-Latitude
Western Pacific**

Vol 29 | No 1 | Mar 2016

**Graduate Education in
the Ocean Sciences**

Upcoming Events

**7th Symposium on
Gas Transfer at Water Surfaces**
May 18–21, 2015, Seattle, WA, USA
<http://www.gtws7.org>

**Second International
Ocean Colour Science Meeting**
June 16–18, 2015, San Francisco, CA, USA
<http://iocs.ioccg.org>

OCEANS '15 MTS/IEEE
October 19–22, 2015, Washington, DC, USA
<http://www.oceans15mtsieee.washington.org>

2016 Ocean Sciences Meeting
February 21–26, 2016, New Orleans, LA, USA
<http://meetings.agu.org/meetings/os16>

introduced with some regional examples. Chapter 6 concludes the consideration of tides with a brief description of the global tidal energy budget.

Extreme high sea levels from storm surges (Chapter 7) and tsunamis (Chapter 8) have wreaked havoc in many regions of the world. The generation of storm surges by atmospheric pressure and winds, the phenomena of wave setup and runup, and changes in the statistics of extreme sea levels and other meteorological effects on sea levels are all considered. Chapter 8 is a fascinating discussion of the generation of tsunamis by movements of the ocean floor, their propagation around the world and into coastal regions, and the options for establishing observing and warning systems.

Satellites have revolutionized our approach to and understanding of sea level and its spatial variation. Chapter 9 begins with a comprehensive and insightful introduction to the international terrestrial reference frame (an essential underpinning of the satellite altimetry revolution), measurements of Earth's gravitation field from space, and hence the determination of the geoid (the equipotential surface of a stationary ocean) and the mean sea surface.

Chapter 10 deals with the critically important issue of changes in sea level with time. It considers long-period tides, the seasonal cycle, ocean mesoscale variability, changes in atmospheric pressure, patterns of interannual variability related to climate modes and long-term changes in sea level over ice-age cycles, and lastly the increasing rate of rise resulting from the burning of fossil fuels. For the latter, paleo, tide-gauge, and satellite observations are all considered. The current understanding of the reasons for that change (ocean thermal expansion and loss of mass from glaciers and ice sheets) and projections for the twenty-first century are briefly discussed.

No book on sea level would be complete without a discussion of movement of the *solid* Earth. Chapter 11 introduces the techniques for measuring vertical

land motion and provides a brief discussion of the major factors leading to this motion. This consideration includes tectonic factors associated with Earth's moving lithosphere (crust and upper mantle), changes in the surface loading of Earth by the changing distribution of ice and water from both past (glacial isostatic adjustment) and present-day (elastic response) changes, and the processes of sediment compaction and movement by waves and ocean currents.

The final two chapters discuss applications of our knowledge of sea level variability and change. Chapter 12 considers the issues of managing the coastal region, coastal defenses and associated economic issues, flood warning systems, and power generation. Finally, Chapter 13 considers the impacts of sea level variability and change on coastal ecosystems and on humans; the authors note that sea level exerted control on past human migrations, as recorded in myths and traditions. This chapter also discusses the implications for changes in sea level during the twenty-first century. However, the potentially dramatic effects of the longer-term evolution of sea level that could result from significant loss of ice sheet mass receive little attention.

Despite the minor omissions, *Sea-Level Science* is an excellent book that offers comprehensive coverage of a broad spectrum of elements of sea level science important to today's (and tomorrow's) society. No one working in the area of sea level science or its applications, including policymakers, government officials, coastal engineers and planners, researchers, and students, should be without access to a copy. The book will be particularly useful to new entrants to the field as it constitutes an easy and broad introduction to what can be a bewildering and diverse field of observations and theory. ☐

REVIEWER. John A. Church (john.church@csiro.au) is a CSIRO Fellow, Centre for Australian Weather and Climate Research and CSIRO Ocean and Atmosphere Flagship, Hobart, Australia.