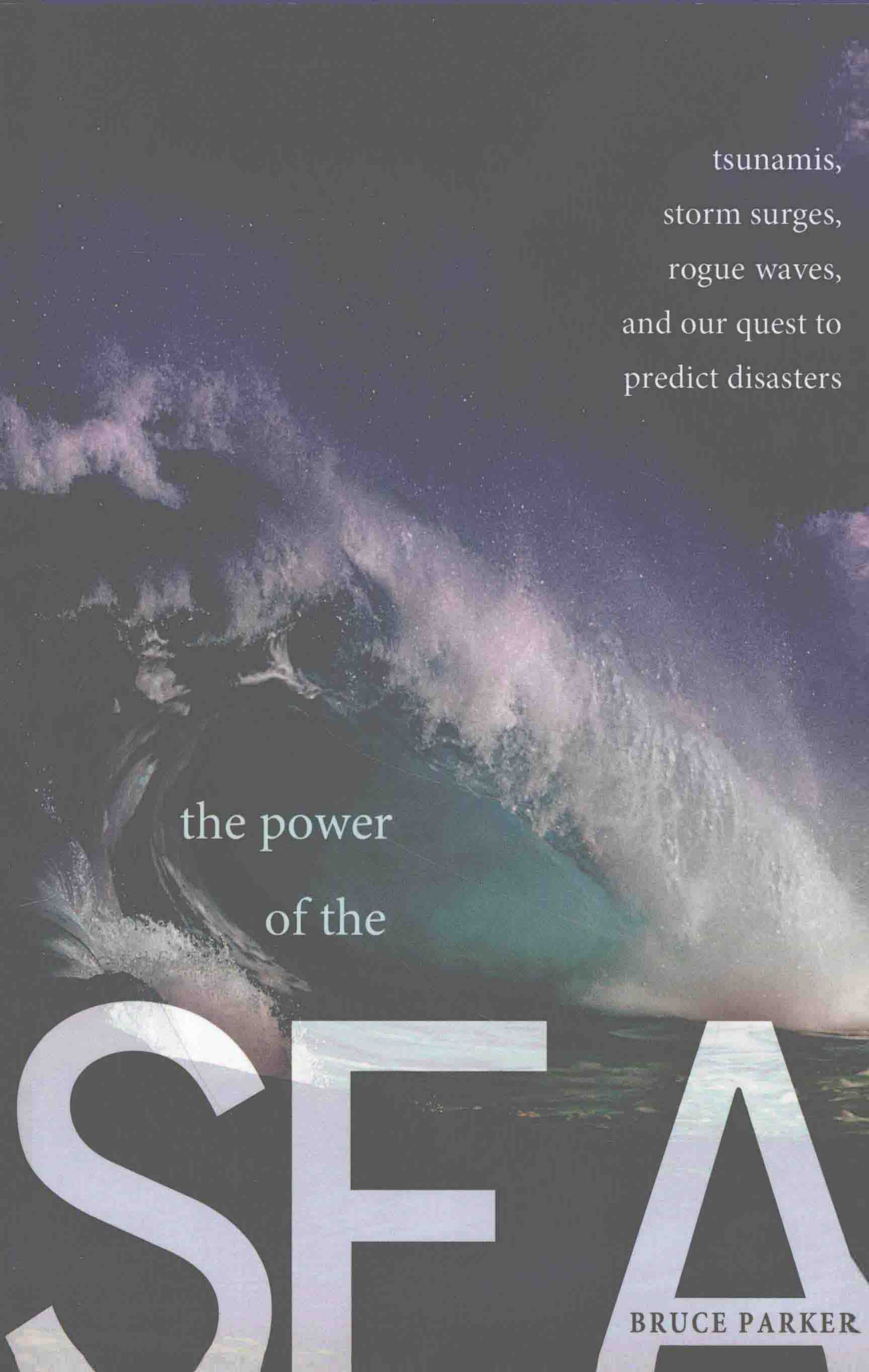

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storm surges,
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and our quest to
predict disasters

the power of the SEA

BRUCE PARKER

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First published in 2010 by
PALGRAVE MACMILLAN®
in the United States—a division of St. Martin's Press LLC,
175 Fifth Avenue, New York, NY 10010.

Where this book is distributed in the UK, Europe, and the rest of the world, this is by Palgrave Macmillan, a division of Macmillan Publishers Limited, registered in England, company number 785998, of Houndmills, Basingstoke, Hampshire RG21 6XS.

Palgrave Macmillan is the global academic imprint of the above companies and has companies and representatives throughout the world.

ISBN: 978-0-230-61637-0

Library of Congress Cataloging-in-Publication Data

Parker, Bruce B.
The power of the sea : tsunamis, storm surges, rogue waves, and our quest to predict disasters / Bruce Parker.
p. cm.—(MacSci)
Includes index.
ISBN 978-0-230-61637-0
1. Ocean. 2. Ocean and civilization. 3. Ocean—Environmental aspects. I. Title.

GC28.P37 2010
551.46—dc22 2010013626

A catalogue record of the book is available from the British Library.

Design by Newgen Imaging Systems (P) Ltd., Chennai, India.

First edition: November 2010

10 9 8 7 6 5 4 3 2 1

Printed in the United States of America.

Praise for *The Power of the Sea*

"Anyone who appreciates the fact that the sea remains something we cannot control will love this book from Bruce Parker. You will come away with a better understanding of why the sea will leave us in awe till the end of time."

—Jim Cantore, The Weather Channel

"From the ancient tides to ingenious ways of predicting tsunamis and weighing the impact of climate change today, Bruce Parker's *The Power of the Sea* is an engaging and essential history of science. It's also a terrific account of survival on our wild blue planet."

—David Helvarg, author of *Saved by the Sea: A Love Story with Fish*

"Bruce Parker is not only a brilliant scientist but a natural storyteller as well. *The Power of the Sea* presents the destructive nature of ocean waves in human terms. For me, the power of *The Power of the Sea* lies in the compelling personal stories that make the book immensely readable. From Napoleon's near death encounter with a raging Red Sea tide, to the vital importance of predicting tide and swell before the D-Day landings, to the individual acts of heroism during the tragic 2004 Indian Ocean tsunami, to the epic storm surges that continue to flood Bangladesh and Myanmar today, Parker never loses sight of the uneasy alliance between man and sea. All who play or live near the sea should read this book. Be warned, you may never look at the ocean the same way again."

—John Kretschmer, author of *At the Mercy of the Sea* and columnist for *Sailing* magazine

"In a changing world driven by the sea, it is important for everyone to understand how it works. Bruce Parker has blended history and science into a book that clearly and often dramatically explains how and why the sea will affect their lives—now and in the future. This is a must-read for anyone who has ever been awed by the ocean."

—Dan Basta, Director, NOAA Office of National Marine Sanctuaries

"Rarely does a book written by a practicing scientist grab you like this one. Intelligent, accurate, and accessible, *The Power of the Sea* reads like a *Believe It or Not* of aquatic destruction. The largest wave in history? What did the tides have to do with the Normandy invasion? What should we have done about Katrina? For the answers to these and other questions you never thought to ask, read Bruce Parker's wonderful book."

—Richard Ellis, author of *The Empty Ocean* and *Tuna: Love, Death, and Mercury*

"A vivid portrayal of sea disasters and the important role that the ocean has played in so many historic events. An illuminating scientific look at how we have learned to predict such disasters and what still needs to be done to safeguard us from future global calamities."

—Curtis Ebbesmeyer, author of *Flotsametrics and the Floating World*

"The Power of the Sea is the best book I have ever read about tsunamis, storm surges, or rogue waves. It dramatically demonstrates the need to better understand the awesome power of the sea if we are to save lives and property."

—Jerry Schubel, President, Aquarium of the Pacific

"Whether you love history, science, or just want to know how the world shapes our lives, this is both an informative and enjoyable read."

—Margaret Davidson, Director, NOAA Coastal Services Center

"This richly researched, eloquent volume gives the reader a front-row seat where the action plays out. Dr. Parker's thorough knowledge of the subject is abundantly evident and his comfortable and informative style makes this a must-read for anyone interested in the environment. The power of the sea is palpable in Dr. Parker's treatment of a fascinating diversity of historically significant events."

—Richard Spinrad, Director, NOAA's Office of Oceanic and Atmospheric Research and former Technical Director to the Oceanographer of the Navy

"An appealing overview of sea movements. Former National Ocean Service Chief Scientist Bruce Parker...mixes hair-raising descriptions of disasters with efforts to understand them, followed by advances, mostly since 1800, in predicting sea movements, a complex process that today involves satellites, supercomputers, and worldwide warning networks. Focusing on water alone—leaving marine life to Rachel Carson and others—the author provides a lucid, original contribution to popular-science writing."

—*Kirkus Reviews*

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INTRODUCTION

When the Sea Turns against Us

Escaping the Sea's Fury through Prediction

When the sea turns its enormous power against us, our best defense is to get out of its way. But to do that we must first be able to *predict* when and where the sea will strike.

If we could have predicted that on December 26, 2004, a tsunami would strike the coasts of the Indian Ocean, 300,000 lives would not have been lost in twelve nations. Even a thirty-minute warning could have saved people from the hundred-foot wall of water that bulldozed entire towns out of existence on the northwest coast of Sumatra. The sudden loss of life on such a terrible scale is difficult to fully comprehend, yet it has happened many times over the centuries. In 1970 a tropical cyclone in the Bay of Bengal generated a storm surge, twenty feet high and a hundred miles wide, that flooded the coast of Bangladesh and drowned more than 300,000 people. As recently as 2008 more than 140,000 were killed by an eighteen-foot storm surge that violently washed over the coast of Burma.[1] If the people had been warned, they could have escaped inland and thousands of lives would have been saved. On the high seas, ninety-foot rogue waves have capsized passenger liners and broken oil tankers in half. Not only were those terrifying waves not predicted, but they were not even believed to be real by most scientists—until recently rogue wave reports were dismissed as exaggerated sea stories. If the seventy-foot rogue wave that struck the *Norwegian Dawn* off Virginia in April 2005 could have been predicted, that luxury liner would have taken a different route and escaped the damage that forced her into port. Even the tide, the most predictable of all ocean phenomena (because of its well-understood generation by the gravitational effects of the moon and sun), can still bring death when tide predictions are ignored—when, for example, a boat gets caught in a violently swirling tidal whirlpool or when a thirty-foot tide comes rushing back over fishermen who stayed too long on mudflats harvesting oysters at low tide.

The power of the sea is even more immense on a global scale, forcing weather patterns around the world and changing our climate. The climatic fluctuation of an El Niño that begins with the warming of the waters off Peru causes heavy rains and floods in some regions of the world and droughts in others. At the end of the nineteenth century two large El Niños caused catastrophic droughts in Asia that led to millions dying in India and China from the resulting famine and disease. More recently the strong 1998 El Niño had major impacts around the world, including torrential rains and mudslides in California, where homes sliding into the sea became front-page news. Our primary defense against the harmful global effects of an El Niño is to be able to predict it and prepare for it before its effects begin to be noticed.

The sea also plays a critical role in long-term climate change—in determining whether our planet will move into an ice age or into a period of extreme warming. During an ice age, mile-thick ice sheets cover huge portions of land and sea level drops hundreds of feet. During a warm period, ice sheets melt and a rising sea level floods coastal lands around the world. Any defense we might have against climate change begins with accurate prediction. If we can predict exactly how future climate will be altered in different parts of the world, then we can prepare for that future. Or perhaps we can even change that future—if indeed, as so many believe, it is our own actions that have been pushing Earth's climate in a dangerous direction. Whether the cause of the recent enhanced global warming is increased carbon dioxide from our use of fossil fuels, or centuries of global deforestation, or the Earth's chaotic response to particular astronomical cycles, or all three, the sea plays a critical role in the climatic changes that are occurring.

It has not been an easy endeavor to develop reliable methods to predict the violent motions of the sea, and throughout history humankind has sought to understand the forces that cause the sea to move. This book is about the scientific journey from our earliest strange ideas about the sea to modern marine prediction using computer models fed with gigabytes of real-time oceanographic data collected from satellites and thousands of land- and sea-based instruments. It relates stories of scientific discoveries interwoven with stories of unpredicted natural disasters. Over the centuries, while scientists and mariners have been trying to learn how to predict the motions of the sea, the sea has killed millions, destroyed untold billions of dollars in property, and changed history. This book includes stories of historical events whose outcomes were determined by the sea's power. The leading characters in these tales include some of the most famous names from history—including Napoleon, Moses, Alexander the Great, Julius Caesar, Columbus, and the U.S.

Marines on Tarawa in World War II. And those who sought ways to predict the sea's movements include some of the most famous names in science—Aristotle, Newton, Laplace, Kelvin, Galileo, Leonardo da Vinci, Benjamin Franklin.

From early humans' first dealings with the sea, whether living by its shores or sailing on its surface, they became all too aware of the sea's fickleness—it was a source of food and the path to exploration, trade, and prosperity, but it also had the power to end life and destroy property at any time without any warning. To live with the sea, people needed to be able to predict when it would rise up against them. But how did one go about predicting what the sea would do? It began with those who lived by the sea recognizing a connection between the movement of the moon and the rise and fall of the ocean's surface. They also realized that the tidal range changed throughout the month with the changing phases of the moon. Early humans learned to predict the tide long before they understood what caused it. Ship captains could thus avoid running their ships aground when they returned to port because they knew when it would be low tide, and Chinese junks could avoid being smashed by a tidal bore barreling up the Qiantang River because they knew when it would come. Mariners also noticed that large waves occurred when the winds blew, so they kept their ships in port when the winds became too strong. But sometimes large waves crashed over their ships even when there was no wind, greatly discouraging those who hoped to predict large waves based on the local wind. When mariners ventured out onto the vast surface of the ocean, they found that at particular locations its waters moved rapidly, pulling their ships along with it. They learned to use these ocean currents to explore a whole new world. Whenever possible, people tried making predictions based on correlations they noticed between episodes of natural destruction and changes in the world that preceded them. And occasionally, when one of those predictions came true, lives were saved.

Prediction is the very essence of science. We do not believe scientific theories unless they can predict specific phenomena. But from a more practical point of view, we use science, and the prediction capability it gives us, to have some control over our lives and to protect us from the environment around us. To accurately predict the sea's actions we had to first learn how the sea works—why it moves like it does in so many varied and complex ways, what drives those movements, and where its power comes from. We learned that ultimately the power of the sea comes from three sources—the sun, the moon, and the Earth. Although the sea stores some of the energy it receives, thus keeping our planet's environment stable and protecting its living creatures from extremes that would kill them, the sea also transmits energy, sometimes concentrating it and amplifying it and at times causing incredible destruction.

Each of the sea's destructive phenomena that we will talk about in this book can be traced back to one of these three energy sources.[2] Storm surges and wind waves originate from the energy of the sun. The winds that generate these surges and waves are produced by the uneven distribution of heat from the equator to the poles, that heat having been derived from sunlight hitting the Earth. In extreme cases winds push a huge volume of water onto the coast in the form of a large storm surge, as when Hurricane Katrina flooded New Orleans. High winds also generate large waves, such as those that threatened the success of the Allied amphibious landing at Normandy in World War II. The tides derive their power from the moon and (to a lesser degree) from the sun through their gravitational effects on the oceans. Twice a day the tides move water into and out of all the bays and estuaries of the world, and what is merely a foot or two of vertical movement in the open ocean is amplified to produce tidal ranges as great as fifty feet in the Bay of Fundy, on Canada's southeast coast. Tsunamis derive their power from energy inside the Earth, the heat from the Earth's formation along with some additional heat from radioactive decay. That heat produces very slow convection in the Earth's mantle, which moves huge crustal plates, their collisions resulting in underwater earthquakes and volcanic eruptions. Both can generate tsunamis, which are very long waves until they reach the shallow water near a coast, at which point they rise up to overwhelm everything in their path, as happened after the great earthquake near Lisbon in 1755 and after the volcanic eruption of Krakatoa in 1883.

That the sea greatly affects the entire world should not come as much of a surprise. The sea covers 70 percent of the Earth's surface. It contains approximately 97 percent of the Earth's water, that amount varying somewhat as sea level drops during glacial periods (when water from the sea goes into snow that accumulates as mile-high glaciers over vast areas of land) and rises during warmer interglacial periods (when water that had been locked up as ice on the land returns to the sea). The sea is the greatest solar collector on Earth and stores heat four thousand times more efficiently than the atmosphere. The sea also stores five hundred times as much carbon as the atmosphere, and it absorbs up to half the carbon dioxide produced by burning fossil fuels. In addition to direct warming by the sun, the oceans of the world receive solar energy from the winds, gravitational energy from the moon, and tectonic energy from the Earth. How these sources of energy produce the movements of the sea is described by the branch of ocean physics known as *hydrodynamics,* which provides the basis for all our prediction techniques. Over the years scientists formulated theories to explain how the sea moves, and they derived mathematical representations of these theories. They also invented instruments to measure the ocean—its temperature, its salinity, the changing height of its surface, the speed and direction of its flows, and the oscillating motion of its waves. In this book we will see an evolution from our earliest attempts at making oceanographic measurements to today's worldwide effort to install and integrate a vast global network of oceanographic sensors—on buoys, on ships, on islands, along coasts, and on satellites, all connected in real time to supercomputers that run prediction models. Ultimately, the size and scope of this task demanded international cooperation and the implementation of the Global Ocean Observing System (GOOS).

Ocean measurements slowly began to show how really complex the sea's motions were. Time and time again scientists had to modify their theories when those theories failed to explain observations made with their instruments. With the exception of tides and ocean currents, scientists would for centuries have very little success in predicting how the sea moved under average conditions, much less during devastating events. The theories eventually formulated to match these measurements would show that the motion of the sea is erratic and chaotic, the regularity of the tide being the only exception. The mathematical equations derived to describe the sea's motions were so complex that they could not be fully solved until computers were invented in the twentieth century. And only then could such computer models be fed with massive amounts of real-time marine observations, these data coming from instruments whose technology was developed only late in that century. As we will see, GOOS is now beginning to provide the real-time data needed by an international array of sophisticated hydrodynamic computer models to make the marine predictions we need. Although this has led to many successes, significant problems still remain in predicting tsunamis and rogue waves and critical aspects of El Niño and climate change.

The sea is a single large, complex geophysical system, but we learned about it in pieces, each new acquired bit of knowledge motivated by our instinct for survival as we searched for ways to predict when and how a particular marine phenomenon would assail us. But these marine phenomena are all interconnected, and they are best studied using an integrated observing system such as GOOS and its U.S. component, the Integrated Ocean Observing System. When fully implemented, GOOS and the ocean models that it supports will be the culmination of centuries of marine scientific research and will finally provide the marine predictions needed around the world. Today more than half the world's population lives near the sea, but even those who live far from its shores are affected by the sea—by the millions of products that come to their country on enormous container ships, by the fish they eat, by the weather that originates over the sea, by the changing climate that is controlled by the sea. Being able to predict what the sea will do, tomorrow or a hundred years from now, affects every person on the planet.

Humankind's earliest success at marine prediction was the ability to roughly predict the tide by watching the moon. And although the tide's astronomical forcing, namely, the periodically varying effects of the moon and sun, makes it unique among oceanographic phenomena, that early success would lay a foundation for all later oceanographic observations and predictions. In centuries past, the consequences of being surprised by the tide could be extremely serious, as a very famous French general once found out, as we will see in the next chapter.

CHAPTER 1

The Earliest Predictions for the Sea

The Tide

On July 25, 1798, Napoleon Bonaparte entered Cairo as the master of all Egypt after defeating the Egyptian Mamluks in the Battle of the Pyramids.[1] Such victories are not always long lasting, however, and Napoleon realized that another battle was imminent, this time against the British and the Turks. While he prepared for that battle, Napoleon immersed himself in the local culture, exploring his newly conquered territory and establishing an institute of arts and sciences at Cairo, staffing it with the 167 scientists and artists he had brought with him from France.[2] In December Napoleon visited Suez to examine the remnants of a canal built many centuries earlier by Egyptian Pharaohs to connect the Nile River with the Red Sea, back when sea level had been higher. He also inspected the site of a planned new canal that was to connect the Mediterranean Sea to the Red Sea. On the morning of December 28 Napoleon intended to take a small band of soldiers to visit the Wells of Moses, on the other side of the Gulf of Suez at the northern end of the Red Sea. The Gulf of Suez extended about three miles farther north of the port of Suez in 1798 than it does today. The point where Napoleon expected to cross the Gulf of Suez was about one mile wide and always dry, or at least fordable, at low tide. Caravans from Tor and Mount Sinai regularly crossed at this spot.

Predicting the time of low tide at that location on the morning of December 28 would have been no problem for Napoleon's scientists. By 1798 tide prediction had finally become a scientific endeavor.[3] But even before then the French, the English, and other peoples living by the sea had developed their own approximate methods for predicting the twice-daily rise and fall of the sea. Tidal ranges were large along all the coasts of France except the