Chapter 1

A Voyage of Discovery

The role of the ocean on weather and climate is often discussed in the news. Who has not heard of El Niño and changing weather patterns, the Atlantic hurricane season and storm surges. Yet, what exactly is the role of the ocean? And, why do we care?

1.1 Why study the Physics of the Ocean?

The answer depends on our interests, which devolves from our use of the oceans. Three broad themes are important:

- 1. The oceans are a source of food. Hence we may be interested in processes which influence the sea just as farmers are interested in the weather and climate. The ocean not only has weather such as temperature changes and currents, but the oceanic weather fertilizes the sea. The atmospheric weather seldom fertilizes fields except for the small amount of nitrogen fixed by lightening.
- 2. The oceans are used by man. We build structures on the shore or just offshore; we use the oceans for transport; we obtain oil and gas below the ocean; and we use the oceans for recreation, swimming, boating, fishing, surfing, and diving. Hence we are interested in processes that influence these activities, especially waves, winds, currents, and temperature.
- 3. The oceans influence the atmospheric weather and climate. The oceans influence the distribution of rainfall, droughts, floods, regional climate, and the development of storms, hurricanes, and typhoons. Hence we are interested in air-sea interactions, espcially the fluxes of heat and water across the sea surface, the transport of heat by the oceans, and the influence of the ocean on climate and weather patterns.

These themes influence our selection of topics to study. The topics then determine what we measure, how the measurements are made, and the geographic areas of interest. Some processes are local, such as the breaking of waves on a beach, some are regional, such as the influence of the North Pacific on Alaskan weather, and some are global, such as the influence of the oceans on changing climate and global warming. If indeed, these reasons for the study of the ocean are important, lets begin a voyage of discovery. Any voyage needs a destination. What is ours?

1.2 Goals

At the most basic level, I hope you, the students who are reading this text, will become aware of some of the major conceptual schemes (or theories) that form the foundation of physical oceanography, how they were arrived at, and why they are widely accepted, how oceanographers achieve order out of a random ocean, and the role of experiment in oceanography (to paraphrase Shamos, 1995: p. 89).

More particularly, I expect you will be able to describe physical processes influencing the oceans and coastal regions: the interaction of the ocean with the atmosphere, and the distribution of oceanic winds, currents, heat fluxes, and water masses. The text emphasizes ideas rather than mathematical techniques. We will try to answer such questions as:

- 1. What is the basis of our understanding of physics of the ocean?
 - (a) What are the physical properties of sea water?
 - (b) What are the important thermodynamic and dynamic processes influencing the ocean?
 - (c) What equations describe the processes and how were they derived?
 - (d) What approximations were used in the derivation?
 - (e) Do the equations have useful solutions?
 - (f) How well do the solutions describe the process? That is, what is the experimental basis for the theories?
 - (g) Which processes are poorly understood? Which are well understood?
- 2. What are the sources of information about physical variables?
 - (a) What instruments are used for measuring each variable?
 - (b) What are their accuracy and limitations?
 - (c) What historic data exist?
 - (d) What platforms are used? Satellites, ships, drifters, moorings?
- 3. What processes are important? Some important process we will study include:
 - (a) Heat storage and transport in the oceans.
 - (b) The exchange of heat with the atmosphere and the role of the ocean in climate.
 - (c) Wind and thermal forcing of the surface mixed layer.
 - (d) The wind-driven circulation including the Ekman circulation, Ekman pumping of the deeper circulation, and upwelling.
 - (e) The dynamics of ocean currents, including geostrophic currents and the role of vorticity.

- (f) The formation of water types and masses.
- (g) The thermohaline circulation of the ocean.
- (h) Equatorial dynamics and El Niño.
- (i) The observed circulation of the ocean plus the Gulf of Mexico.
- (j) Numerical models of the circulation.
- (k) Waves in the ocean including surface waves, inertial oscillations, tides, and tsunamis.
- (1) Waves in shallow water, coastal processes, and tide predictions.
- 4. What are the major currents and water masses in the ocean, what governs their distribution, and how does the ocean interact with the atmosphere?

1.3 Organization

Before beginning a voyage, we usually try to learn about the places we will visit. We look at maps and we consult travel guides. In this book, our guide will be the papers and books published by oceanographers. We begin with a brief overview of what is known about the oceans. We then proceed to a description of the ocean basins, for the shape of the seas influences the physical processes in the water. Next, we study the external forces, wind and heat, acting on the ocean, and the ocean's response. As we proceed, I bring in theory and observations as necessary.

By the time we reach chapter 7, we will need to understand the equations describing dynamical response of the oceans. So we consider the equations of motion, the influence of Earth's rotation, and viscosity. This leads to a study of wind-driven ocean currents, the geostrophic approximation, and the usefulness of conservation of vorticity.

Toward the end, we consider some particular examples: the deep circulation, the equatorial ocean and El Niño, and the circulation of particular areas of the oceans. Next we look at the role of numerical models in describing the ocean. At the end, we study coastal processes, waves, tides, wave and tidal forecasting, tsunamis, and storm surges.

1.4 The Big Picture

As we study the ocean, I hope you will notice that we use theory, observations, and numerical models to describe ocean dynamics. *Neither is sufficient by itself.*

- 1. Ocean processes are nonlinear and turbulent, and the theory of non-linear, turbulent flow in complex basins is not well developed. Theories used for describing the ocean are much simplified approximations to reality.
- 2. Observations are sparse in time and space. They provide a rough description of the time-averaged flow, but many processes in many regions are poorly observed.
- 3. Numerical models include much-more-realistic theoretical ideas, they can help interpolate oceanic observations in time and space, and they are used to forecast climate change, currents, and waves. Nonetheless, the numerical equations are approximations to the continuous analytic equations

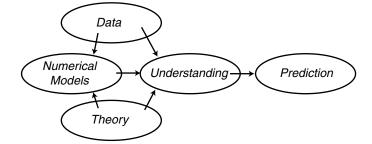


Figure 1.1 Data, numerical models, and theory are all necessary to understand the ocean. Eventually, an understanding of the ocean-atmosphere-land system will lead to predictions of future states of the system.

that describe fluid flow, they contain no information about flow between grid points, and they cannot yet be used to describe fully the turbulent flow seen in the ocean.

By combining theory and observations in numerical models we avoid some of the difficulties associated with each approach used separately (figure 1.1). Contiued refinements of the combined approach are leading to ever-more-precise descriptions of the ocean. The ultimate goal is to know the ocean well enough to predict the future changes in the environment, including climate change or the response of fisheries to overfishing.

The combination of theory, observations, and computer models is relatively new. Three decades of exponential growth in computing power has made available desktop computers capable of simulating important physical processes and oceanic dynamics.

All of us who are involved in the sciences know that the computer has become an essential tool for research ... scientific computation has reached the point where it is on a par with laboratory experiment and mathematical theory as a tool for reserve in science and engineering—Langer (1999).

The combination of theory, observations, and computer models also implies an new way of doing oceanography. In the past, an oceanographer would devise a theory, collect data to test the theory, and publish the results. Now, the tasks have become so specialized that few can do it all. Few excel in theory, collecting data, and numerical simulations. Instead, the work is done more and more by teams of scientists and engineers.

1.5 Further Reading

If you know little about the ocean and oceanography, I suggest you begin by reading MacLeish's book, especially his Chapter 4 on "Reading the Ocean." In my opinion, it is the best overall, non-technical, description of how oceanographers came to understand the ocean.

You may also benefit from reading pertinent chapters from any introductory oceanographic textbook. Those by Gross, Pinet, or Thurman are especially useful. The three texts produced by the Open University provide a slightly more advanced treatment.

- **Gross,** M. Grant and Elizabeth Gross (1996) *Oceanography*—A View of Earth 7th Edition. Upper Saddle River, New Jersey: Prentice Hall.
- MacLeish, William (1989) The Gulf Stream: Encounters With the Blue God. Boston: Houghton Mifflin Company.
- Pinet, Paul R. (1992) Oceanography—An Introduction to the Planet. Saint Paul: West Publishing Company.
- Open University (1989) Ocean Circulation. Oxford: Pergamon Press.
- **Open University** (1989) Seawater: Its Composition, Properties and Behaviour. Oxford: Pergamon Press.
- **Open University** (1989) Waves, Tides and Shallow-Water Processes. Oxford: Pergamon Press.
- **Thurman**, Harold V. (1994) *Introductory Oceanography*. Columbus: Charles E. Merrill Publishing Company.