Chap 1 Introduction

1.1 Why study the physics of the ocean?

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, especially 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 pattern.

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.

1.2 The big picture

As we study the ocean, 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 nonlinear, turbulent flow in complex basins is not well developed. Theories used for

describing the ocean are much simplified approximations to reality.

2. Observations are spare 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 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 (Fig. 1.1). Contributed 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.

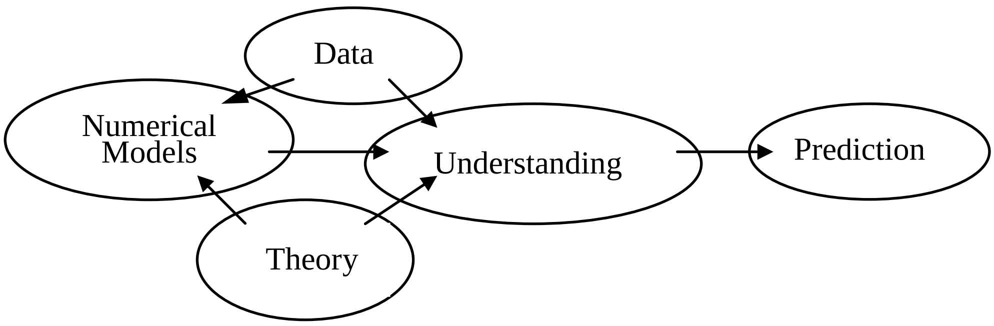

Fig. 1.1 Data, numerical models, and theory are all necessary to understand the ocean. Eventually, an understanding of the ocean-atmosphere-land system will lead to predictions of future states of the system.

1.3 Definitions

Oceanography: Study of the oceans, with an emphasis on their character as an environment. The goal is to obtain a clear and systematic description of the oceans, sufficiently quantitative to permit us to predict their behavior in the future with some certainty.

Geophysics: Study of the physics of the Earth.

Physical Oceanography: Study of physical properties and dynamics of the oceans, and the interaction of the ocean with the atmosphere. The primary interests are, the oceanic heat budget, water mass formation, currents, and coastal dynamics. Physical oceanography is considered by many to be a sub-discipline of geophysics.

Geophysical Fluid Dynamics: Study of dynamics of fluid motion on scales influenced by the rotation of the Earth. Meteorology and oceanography use geophysical fluid dynamics to calculate planetary flow fields.

Hydrography: Preparation of nautical charts, including charts of ocean depths, currents, internal density field of the ocean, and tides.

Descriptive Oceanography: Observations are made of specific features and these are reduced to as simple a statement as possible of the character of the features themselves and of their relations to other features.

Dynamical Oceanography: Use physical laws to the ocean and to endeavor to obtain mathematical relations between the forces acting on the ocean waters and their consequent motions.

1.4 Eras of Oceanographic Exploration

1. **Era of Surface Oceanography: Earliest time to 1873**
   – Characterized by systematic collection of mariners' observation of winds, currents, waves, temperature, and other phenomena observable from the deck of sailing ships.
   – Examples include Halley's charts of the trade winds, Franklin's map of the Gulf Stream, and Matthew Fontaine Maury's *Physical Geography for the Sea*.

2. **Era of Deep-Sea Exploration: 1873–1914**
   – Characterized by wide ranging oceanographic expeditions to survey surface and subsurface conditions near colonial claims.
   – Examples include H.M.S. Challenger, Gazelle and Fram Expeditions.

3. **Era of National Systematic and National Surveys: 1925–1940**
   – Characterized by detailed surveys of colonial areas.
   – Examples include Meteor surveys of Atlantic (Fig. 1.2), and Discovery Expedition.

4. **Era of New Methods: 1947–1956**

– Characterized by long surveys using new instruments.

– Examples include seismic surveys of the Atlantic by Vema leading to Heezen's physiographic diagram of the sea floor.

5. Era of International Cooperation: 1957–1970

– Characterized by multinational surveys of oceans.

– Examples include the Atlantic Polar Front Program, the NORPAC cruises, and the International Geophysical Year cruises.

6. Era of Large Experiments: 1970–1978

– Characterized by multiship studies of oceanic processes.

– Examples include MODE, POLYMODE, and NORPAX, and the JASIN experiment; plus the International Decade of Ocean Exploration.

7. **Era of Satellites: 1978–1995**

– Characterized by global surveys of oceanic processes from space.

– Examples include Seasat, NOAA 6-10, NIMBUS-7, Geosat, Topex/ Poseidon, and ERS-1 & 2.

8. Era of Global Synthesis: 1995–

– Characterized by global determination of oceanic processes using ship and space data in numerical models.

– Examples include the World Ocean Circulation Experiment (WOCE) and Topex/Poseidon, SeaWiFs and Joint Global Ocean Flux Study (JGOFS).

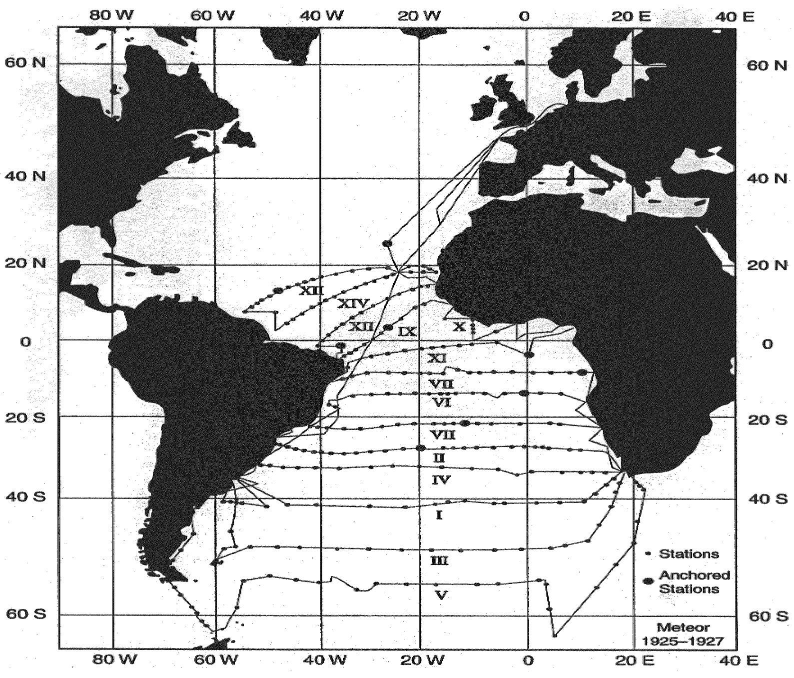

Fig. 1.2 Example of a survey from the era of national systematic surveys. Track of the R/V *Meteor* during the German Meteor Expedition (Wust, 1964).

1.5 Milestones in the Understanding of the Ocean

1685 Edmond Halley investigated the oceanic wind systems and currents.

1735 George Hadley published his theory for the trade winds based on conservation of angular momentum.

1751 Henri Ellis made the first deep soundings of temperature in tropics, finding cold water below a warm surface layer, indicating the water came from the polar regions.

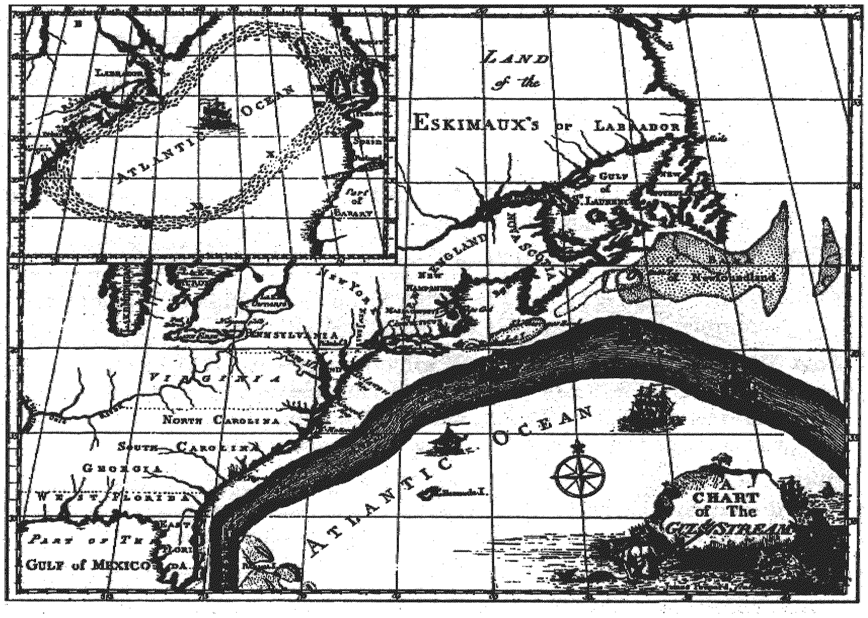

Fig. 1.3 The Fraklin-Folger map of the Gulf Stream published in 1769.

1770 Benjamin Franklin, as postmaster, collected information about ships sailing between New England and England, and made the first map of the Gulf Stream (Fig. 1.3).

1775 Laplace published his theory of tides.

1800 Count Rumford proposed a meridional circulation sinking near the poles and rising near the Equator.

1847 Matthew Fontain Maury published his first chart of winds and currents based on ship logs.

1885 *Physical Geography of the Sea* published by Maury.

1872-1876 ***Challenger*** Expedition began the first systematic study of the biology, chemistry, and physics of the oceans of the world.

1881 Samuel Langley invented the bolometer for measuring radient heat.

1885 Pillsbury made direct measurements of currents in the Florida Current using current meters deployed from a ship moored in the stream.

1910-1913 Vilhelm Bjerknes published ***Dynamic Meteorology and Hydrography*** which laid the foundation of geophysical fluid dynamics.

1912 Founding of the Marine Biological Laboratory of the University of California which became the Scripps Institution of Oceanography.

1930 Founding of the Woods Hole Oceanographic Institution.

1942 Publication of ***The Oceans*** by Sverdrup, Johnson, and Fleming, the first comprehensive survey of oceanographic knowledge.

Post WW2 Founding of oceanography departments at state universities, including Oregon State, Texas A&M University, University of Miami, and University of Rhode Island, and the founding of national ocean laboratories such as the various Institutes of Oceanographic Sciences.

1947-1950 Sverdrup, Stommel, and Munk published their theories of the wind-driven circulation of the ocean.

1949 Start of California Cooperative Fisheries Investigation of the California Current.

1952 Cromwell and Montgomery rediscover the Equatorial Undercurrent in the Pacific.

1955 Bruce Hamon and Neil Brown developed the CTD for measuring conductivity and temperature as a function of depth in the ocean.

196x Sippcan Corporation invented the Expendable BathyThermography XBT.

1969 Kirk Bryan and Michael Cox developed the first numerical model of the oceanic circulation.

1978 NASA launched the first oceanographic satellite, Seasat.

1979-1981 Terry Joyce, Rob Pinkel, Lloyd Regier, F. Rowe and J.W. Young developed techniques leading to the acoustic-doppler current profiler for measuring ocean-surface currents from moving ships.

1992 Russ Davis and Doug Webb invented the autonomous drifter that continuously measures currents at depths to 2 km.

1992 NASA and CNES developed and launched Topex/Poseidon, a satellite that maps ocean surface currents, waves, and tides every ten days.

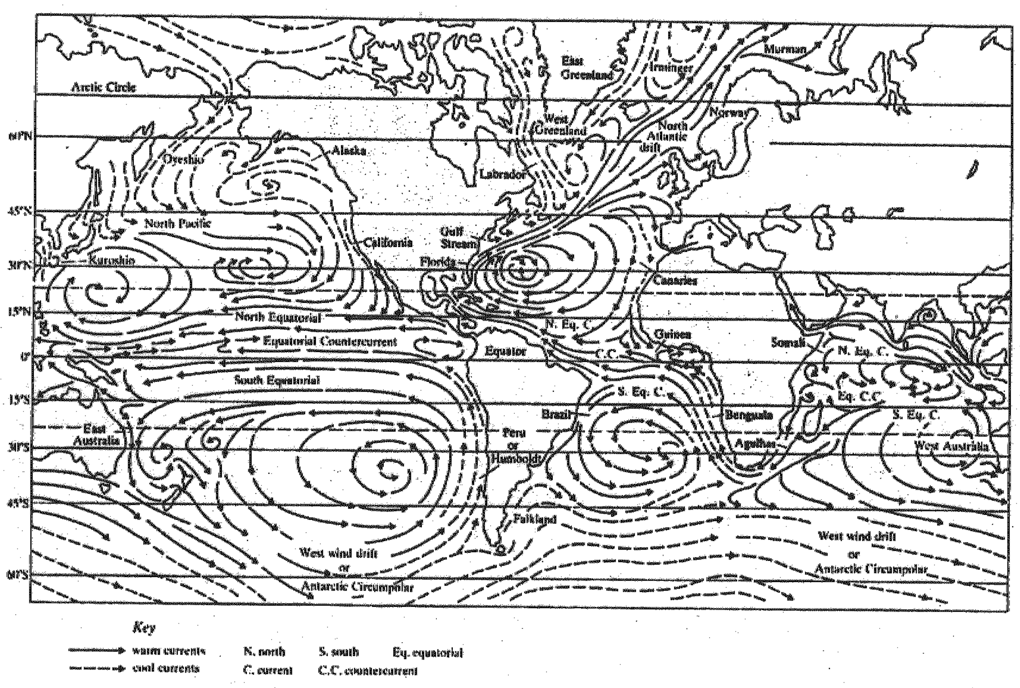

Fig. 1.4 The time-averaged, surface circulation of the ocean deduced from nearly a century of oceanographic expeditions (Tolmazin, 1985).

Data collected from the centuries of oceanic expeditions have been used to describe the ocean. Fig. 1.4 shows an example from that time, the surface circulation of the ocean.

1.7 Evolution of some Theoretical Ideas

19th Century – Development of analytic hydrodynamics with friction. Bjerkness develops geostrophic method widely used in meteorology and oceanography (1898).

1925-40 – Development of theories for turbulence based on aerodynamics and mixing-length ideas. Work of Prandtl and von Karmen.

1940-1970 – Refinement of theories for turbulence based on statistical correlations and the idea of isotropic homogeneous turbulence. Books by Batchelor (1967), Hinze (1975), and others.

1970 – Numerical investigations of turbulent geophysical fluid dynamics based on high-speed digital computers.

1985 – Mechanics of chaotic processes. The application to hydrodynamics is just beginning. Most motion in the atmosphere and ocean may be inherently unpredictable.

1.8 Design of Oceanographic Experiments

Observations are essential for oceanography, yet observations are expensive because ship time and satellites are expensive. As a result, oceanographic experiments must be carefully planned.

1. What is the purpose of the observations? Do you wish to test hypotheses or describe processes?
2. What accuracy is required of the observations?
3. What temporal and spatial resolution is required? What is the duration of measurements?

1.9 Important Concepts

1. The ocean is not well known. What we know is based on data collected from only a little more than a century of oceanographic expeditions supplemented with satellite data collected since 1978.
2. The basic description of the ocean is sufficient for describing the time-averaged mean circulation of the ocean, and recent work is beginning to describe the variability.
3. Observations are essential for understanding the ocean. Few processes have been predicted from theory before they were observed.
4. Oceanographers rely more and more on large data sets produced by others. The sets have errors and limitations in which you must understand before using them.
5. The planning of experiments is at least as important as conducting the experiment.
6. Sampling errors arise when the observations, the samples, are not representative of the process being studied. Sampling errors are the largest source of error in oceanography.

1.10 Bathymetric Features

Continents have a mean elevation of 840 m and oceans have a mean depth of 3,730 m (Fig. 1.5).

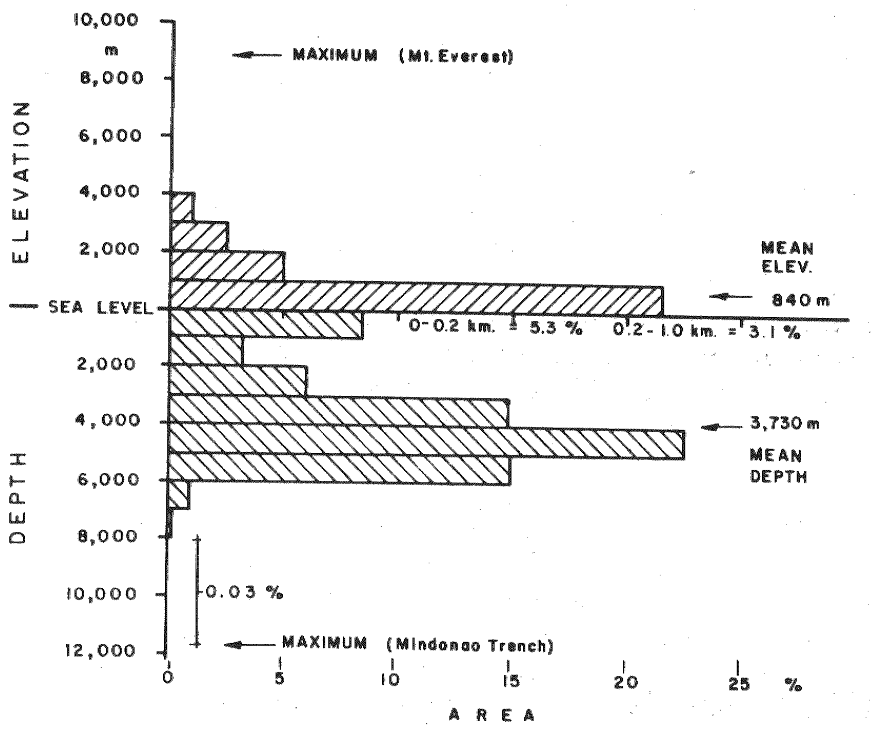

Fig. 1.5 Areas of earth's surface above and below sea-level as percentage of total area of earth (in 1000-m intervals).

The names of the subsea features have been defined by the International Hydrographic Bureau (1953), and the following definitions are taken from Dietrich et al. (1980) (see Fig. 1.6).

Basins – depressions of the sea floor more or less equidimensional in form and of variable extent.

Canyons – relatively narrow, deep depressions with steep slopes, the bottoms of which grade continuously downward.

Continental shelves – zones adjacent to a continent and extending from the low-water line to the depth at which there is usually a marked increase of slope to greater depth.

Continental slopes – the declivities seaward from the shelf edge into greater depth.

Plains – flat, gently sloping or nearly level regions of the sea floor, e.g. an abyssal plain.

Ridges – long, narrow elevations of the sea floor with steep sides and irregular topography.

Seamounts – isolated or comparatively isolated elevations rising 1000 m or more from the sea floor and of limited extent across the summit.

Sills – the low parts of the ridges separating ocean basins from one another or from the adjacent sea floor.

Trenches – long, narrow, and deep depressions of the sea floor, with relatively steep sides.

Subsea features have important influences on the ocean circulation.

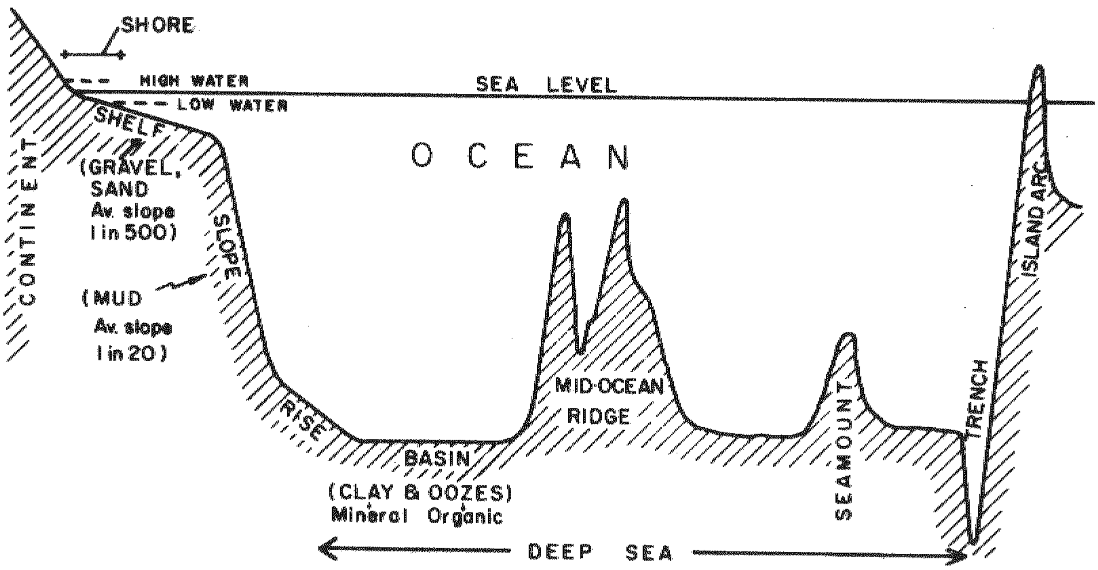

Fig. 1.6 Schematic section through ocean floor to show principal features.