Eddies in Marine Science

Edited by
Allan R. Robinson

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Preface

This book surveys the results of recent research in eddy science and explores its implications for ocean science and technology. It attempts a comprehensive review suitable for a wide audience of marine scientists. Much progress has occurred and the subject is rapidly advancing. However, the eddy-current phenomenon remains unexplored in vast areas of the world ocean and many of the most fundamental dynamical questions of eddy dynamics are unanswered or indeed as yet unasked. The intention of a survey now is to contribute to a global synthesis, to help facilitate researches in new regions and further reasearch into eddy dynamics, and to encourage applications. Eddy currents are energetically dominant and have the ability to transporte and to influence mixing. Thus knowledge of the physical science of the eddies has important implications for biological, chemical and geological oceanography; for modern interdisciplinary ocean science; and for practical activities in the sea including exploitation and management of the marine environment and its resources. Hopefully, this book will contribute to the communication between specialists in eddy dynamics and other marine scientists, engineers and managers, which is necessary for efficient utilization of the new physical knowledge.

The generic term "eddies" is used here without further qualification to encompass a large class of time and space variable ocean currents as discussed in the Introduction. The scales of variability range from tens to hundreds of kilometers and from weeks to months. These currents are usually approximately geostrophic, hence the name "geostrophic eddies" has been invoked. Many phenomena in the ocean are almost geostrophic and it is the nature of the small deviation from the geostrophic momentum balance which in fact subtly governs the dynamics of the flow. The general nature of this deviation for eddy currents is usually consistent with the assumption of the theory of quasigeostrophy. Thus the phenomena is sometimes referred to by the terminology "quasigeostrophic eddies". But eddies are usually, but not always, geostrophic and quasigeostrophic. Other qualifications in common usage refer to scales. Horizontal eddy scales are on the order of the so-called Rossby internal deformation radius (the product of the vertical scale and the ratio of the Brunt-Vaisala frequency to the Coriolis parameter). Motions on the scale of the atmosphere's internal deformation radius are referred to by meteorologists as "synoptic scale" motions, since they include the midlatitude cyclones and anticyclones which are major features of weather maps. By dynamical scale analogy many authors refer to oceanic eddies as "synoptic ed-

dies". Another term, in very common usage since the discovery of evidence for eddies as a major oceanic phenomena and still prevalent, is "mesoscale eddies". This phrase was coined simply to indicate motions of less than oceanic gyre scale. Referring to the overall phenomena inclusively simply as "eddies" reserves the role of qualifiers for the identification of important general subclasses of eddy-currents.

Eddies are a most important physical phenomenon in the ocean and have been the subject of a difficult and vigorous research effort which has required a large scale of international cooperation to be carried out. The foundation for eddy science today was constructed by the dedicated research programs carried out during the 1970's. A major role in the coordination, planning and communication of eddy science was performed by the Working Group on Internal Dynamics of the Sea (WG-34) of SCOR (The Scientific Committee on Oceanic Research of the International Council of Scientific Unions). This multiauthored book was produced unter the auspices of WG-34 and constitutes the final scientific report of the Working Group (see SCOR Proceedings 1982 Vol 18 Annex 5).

The wealth of material presented here results from the scientific efforts and cooperation of numerous scientists, technicians, students and other around the world. Acknowledgements for support and help by the authors and the editor appear collectively in the Acknowledgement Section. In my introductory chapter I draw freely upon the material presented in the book without specific references. The advice, encouragement and efforts of Henry Stommel, Henry Charnock, and Curtis Collins were instrumental in making this book possible.

ALLAN R. ROBINSON

Contents

Introduction

1. Overview and Summary of Eddy Science

A.R. Robinson

1.1 Eddy Currents in the Ocean

Ocean currents and their associated fields of pressure, temperature, and density vary energetically in both time and space throughout the ocean. Such variability in fact contains more energy than any other form of motion in the sea. Partly organized, yet highly irregular, these motions have dominant spatial scales in the range of tens to hundreds of kilometers and dominant temporal scales in the range of weeks to months. The variability is distributed unevenly with energy levels and dominant scales changing substantially from place to place in the ocean. These turbulent motions are the internal weather of the deep sea, and many types of synoptic events and peculiar marine internal storm systems are now known to occur. Types of variability which have been identified and studied include the meandering and filamenting of intense current systems, semi-attached and cast-off ring currents, advective vortices extending throughout the entire water column, lens vortices, planetary waves, topographic waves and wakes, etc. All of these types of variable flow are commonly referred to by physical oceanographers by the generic term "eddies".

Although energetically dominant and pervasive in the ocean, eddies have been definitively described and intensively studied only recently. The traditional descriptive picture of the ocean emerged essentially from a geographically sparse data set compositing years of discrete measurements widely spaced in the horizontal and the vertical. Thus the eddy signals were aliased in space and time and the conceptualization of currents and circulation was based upon smeared fields derived from incomplete and inadequate data sets. Except for the meandering of the strongest currents and a few ring observations, prior to the 1970's only suggestive evidence for the existence of eddies was available. Since that time, however, vigorous and dedicated investigations have been carried out with sensitive, continuously recording instruments from platforms and systems capable of providing adequate horizontal, vertical, and temporal resolutions. Variability types have been identified, kinematics described, and statistical characteristics quantified. Dynamical and energetic studies have been carried out, novel theories constructed and powerful new computer models which resolve eddies developed. However, vast areas of the oceans remain unexplored, most fundamental questions are partially or totally unanswered, important processes require accurate quantification and models need to be made more realistic. Experience indicates that as the resolution of measurements continues to increase, as observational records lengthen and as new geographical regions are opened up, totally new phenomena will be discovered. But the

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