a few of the fundamental results, such as that the tide-generating forces on Earth's surface are inversely proportional to the cube of the distance from either the moon or sun, and then referred the interested reader to a Web site such as NOAA's "Our Restless Tides," which at least has some nice graphics. Actually, the only mention of an inverse cube relationship (page 276) is incorrectly stated (it would be correct if the words "tide-generating forces" were substituted for "gravity"). The inverse cube relationship is always surprising when first encountered by anyone with basic physics training, in which one is taught that the gravitational attraction between two bodies varies as the inverse square.

In Chapters 8 and 12, much is made of the shortcomings and ultimate failure of the "progressive wave theory." This emphasis is a bit misleading because Laplace's progressive wave theory and dynamics remain the foundation of modern tidal hydrodynamic modeling. It was really only the highly simplified version (for which Laplace found analytic solutions) that turned out to be unrealistic.

My few remaining negatives are minor. First, the reproductions of photographs mostly look like poor scans of color prints. Second, I am allergic to the "National Geographic School of Writing" (the tale begins with a dramatic state of affairs, then reverts back to tell how it came to pass, and finally reveals the finale). Luckily, Koppel did not overuse the formula and my allergic rash disappeared quickly. Third, although in several places the book discusses phenomena that are in fact circadian rhythms, the term itself is not used, which seemed like a missed opportunity in terms of organizing things. Fourth, the book would have benefited from an index. Fifth, showing the sense of rotation around the amphidromes in Figure 12 would have helped elucidate the text. Finally, I noticed a couple of typos.

This book will be of interest to those with affinities for natural history, seafaring, and tides in general—and even tidal scientists will learn a few things about their science.

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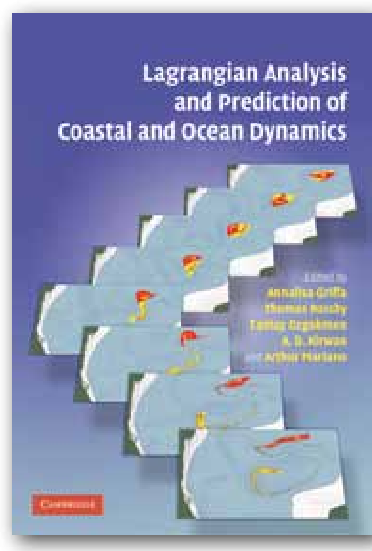
Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics



Edited by Annalisa Griffa, A.D. Kirwan Jr., Arthur J. Mariano, Tamay Özgökmen, and H. Thomas Rossby, Cambridge University Press, 2007, 487 pages, ISBN 9780521870184, Hardcover, $160 US

REVIEWED BY JOSEPH H. LaCASCE

During a colloquium on Lagrangian dynamics in Liège, Belgium, in 1999, several participants discussed convening a meeting devoted to Lagrangian studies in the ocean and atmosphere. The European Science Foundation program TAO (Transport in the Ocean and Atmosphere) had previously sponsored similar meetings, which mostly involved European researchers; the proposed LAPCOD (Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics) would offer greater participation by American scientists. Several of the organizers were from Miami and Italy, and thus there have been meetings in Ischia, Italy (2000); Key Largo, Florida (2002); and Lerici, Italy (2005). (I recall thinking, while enjoying several outstanding fish dishes near the harbor in Lerici, that having an Italian as one of the organizers was a good choice.)

Lagrangian studies have always had an eclectic flavor. Although current meters produce fairly straightforward data (e.g., a time series of velocity at a fixed location and depth), floats and drifters move about, providing the drifter posi-

UPCOMING BOOK REVIEWS

Arc Marine: GIS for a Blue Planet
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Climate Change: A Multidisciplinary Approach
by William James Burroughs, Cambridge University Press, 378 pages

Oceans Past: Management Insights from the History of Marine Animal Populations
by David J. Starkey, Paul Holm, and Michaela Barnard, Earthscan, 223 pages

Our Changing Planet: The View from Space
Edited by Michael King, Claire Parkinson, Kim Partington, and Robin Williams, Cambridge University Press, 390 pages

Tides of History: Ocean Science and Her Majesty's Navy
by Michael S. Reidy, University of Chicago Press, 392 pages

tion as a function of time, and perhaps also the ambient temperature and salinity. Because the positions vary continuously, it can be difficult to interpret the results. So what exactly can one do with Lagrangian data?

The present book seeks to answer that question. Rather than being a proceedings volume, collecting a set of specialized papers, the book presents reviews that flesh out different aspects of Lagrangian studies. Thus, the chapters take a broader perspective than individual authors' own work. The result is a potpourri of different results and analyses, and a useful volume for anyone interested in Lagrangian data.

The first two chapters concern the instruments—the subsurface float and surface drifter. Chapter 1 (by T. Rossby) discusses float development. The author either witnessed the invention of many of the instruments or invented them himself, from Swallow's float in the 1960s, to the SOFAR float in the 1970s, and the RAFOS float in the 1980s. He also discusses recent designs, like the profiling ALACE, and floats that track vertical motion in the mixed layer or motion along constant-depth contours. The chapter is full of technical information, for instance, how to make an isopycnal float using a spring and a piston, and how sound is transmitted via the SOFAR channel. It also considers significant findings from a number of float experiments. The anecdotes from the early experiments, at a time when ocean theory and float engineering were in their infancy, make entertaining reading.

Chapter 2 (by R. Lumpkin and M. Pazcos) deals with surface drifters. The focus here is less on their development (although a short history is given in the introduction) than on the present-day drifter. There are currently 1312 surface drifters in the main ocean basins as part of the Global Drifter Program (GDP), and the authors discuss how these drifters track currents with a subsurface drogue, how they are tracked by satellite, and how the satellite positions are interpolated. The authors even suggest the best way to deploy drifters from a boat (from the stern, not more than 10 m from the surface). They examine such issues as wind slippage and the Ekman drift and then summarize results from a number of studies, concerning, for instance, surface kinetic energy, diffusivities, and the synthesis of drifter and satellite data. The chapter is a concise and useful overview of the subject.

Chapter 3 was inspired by a Key Largo meeting section entitled "My Favorite Trajectory." Drifters often seem to have minds of their own, and their paths can be surprising. The chapter provides examples from floats in the Red Sea, North and tropical Atlantic, and South China Sea. Three SOFAR floats from the POLYMODE experiment in the late 1970s traveled some 700 km without separating (counter to expectations about turbulent dispersion). My favorite trajectory, though, was from a surface drifter launched off Iceland. This drifter rounded the tip of Greenland, crossed the entrance to the Labrador Sea, left the slope at Newfoundland, and continued (albeit chaotically) back to Iceland. From there, it retraced its original track, down to Newfoundland again. I was reminded of Farley Mowat's schooner in *The Boat Who Wouldn't Float*.

One way to understand drifter behavior is by using models. Similarities between in situ dispersion and that seen in a model, whose dynamics we (hopefully) understand, can help unravel what is happening in the full system. In addition, model statistics are generally much better. A typical float experiment may have 50 to 100 instruments, but it is feasible to have thousands of particles in a model.

Chapter 4 (by C. Pasquero and others) discusses dispersion in turbulent flows. Numerical simulations show that coherent vortices play an important role in turbulent flows, and these flows affect Lagrangian dynamics. Vortices trap fluid, preventing it from mixing with the surroundings, and also produce anomalously large advection speeds. The authors discuss how vortices, superimposed on a random background flow, can be represented with stochastic models, which in turn could be used for simulating marine dispersion. They also discuss how turbulent dispersion affects plankton distributions and hence the carbon cycle. Chapter 5 (by N. Paldor) considers a specific phenomenon—particles undergoing inertial oscillations on a sphere—and examines the behavior analytically. The particles exhibit a Stokes-type drift, which can be derived using Hamiltonian methods.

Chapter 9 (by V. Rupolo) is also concerned with stochastic models and how they can be exploited to understand dispersion and the Lagrangian power spectra. There is a hierarchy of stochastic models, from the simple random walk up to higher-order models, which resolve the decorrelation of the Lagrangian acceleration or even simulate looping motion. Choice of model depends on the temporal resolution of the in situ data. Simulating floats in energetic regions demands higher-order models, while floats in less-energetic regions (i.e., the eastern Atlantic) can be studied with lower-order models. This distinction provides a useful way of categorizing trajectories.

I recall an oceanographer who remarked that we didn't have much to show for our years of Lagrangian study. "What use are floats to a modeler?" he wondered. The answer may well be Lagrangian data assimilation. Global ARGO array floats and GDP drifters offer sampling that was unimaginable until recently. Assimilation offers a way to exploit these data in models.

Chapters 6, 7, and 8 treat various aspects of the assimilation problem. Although there is overlap among authors and the material, the viewpoints are interestingly different. Chapter 8 (by M. Chin and others) presents a concise background on Lagrangian assimilation, from the early attempts to generate streamfunction maps from SOFAR trajectories to the incorporation of Lagrangian velocities and trajectories into models. All three chapters consider sequential assimilation, and the Kalman filter in particular, and each presents examples from idealized and realistic ocean simulations as well. But from there the material diverges.

Chapter 6 (by L. Piterbarg and others) treats the problem of Lagrangian predictability. Where will a sailor falling overboard at 39°N, 90°W at midnight be in 36 hours? The US Coast Guard performs some 5000 search and rescue operations per year, so the issue definitely arises. Predictability can be characterized by how rapidly two particles deployed close to one another separate. The authors discuss use of multiparticle stochastic models, which account for correlated motion between nearby particles, to this end.

Assimilation in oceanic general circulation models is taken up in Chapter 7 (by A. Molcard and others). They note there are three central issues: how to incorporate drifter positions or velocities into the model, how to adjust other variables (e.g., layer thickness), and how to modify variables in the layers not sampled by the drifters. Molcard et al. illustrate how each issue can be addressed using examples from single and multilayer ocean models. The results are often astonishingly good, illustrating how useful Lagrangian data can be. Chapter 8 considers interpolation techniques that conserve scalar properties, such as temperature and vorticity, and reconstruction of the velocity field in the vicinity of an observed trajectory. The advantages of various methods are considered, as are the technical and practical challenges (such as assimilating trajectories near saddle points).

Ocean biology is another area where Lagrangian processes are undoubtedly important. Plankton are advected as passive tracers, carried into the euphotic zone, and then strained laterally by the currents. Fish are also transported by currents, but they can swim, making them active tracers. In both cases, Lagrangian analyses can be used to understand and predict behavior.

Chapters 10–12 are devoted to biological processes. Chapter 11 (by G. Hitchcock and R. Cowen) focuses on passive advection, specifically plankton. Plankton were actually used in the early 1900s to identify water masses (before it was realized that they could be mixed laterally from other sources). The authors discuss a number of such studies in which plankton were observed directly, before examining studies where the motion was examined in conjunction with drifters, floats, and dye. This chapter is a very thorough overview of the subject.

Chapter 10 (by D. Olsen) is concerned more with the active tracers. Modeling these animals requires specifying how they move. Mean field models (the "average fish" representation) are inadequate at capturing the evolution except under ideal conditions, so a structured population model is used in which the dependence on space, time, mortality conditions, and metabolism are all specified. Both this chapter and Chapter 11 present specific examples from the ocean, boundary currents, eddies, and fronts. Olsen cites an example of a right whale that had become entangled in fishing net. A transponder was placed in the net and the whale was subsequently tracked as it swam along the Gulf Stream front from Cape Hatteras to the Azores.

Chapter 12 (by G. Buffoni and others) examines the application of a stochastic model to simulating plankton. To capture the behavior of a single organism, the model must represent such processes as hatching, molting, reproduction, and death. This particular model was developed to simulate insects, but is applied here to copepods, and specifically plankton in the Mediterranean Sea. While reading these chapters, I was repeatedly struck by the complexity of both observing and modeling biological processes in the presence of evolving oceanic flows.

The primary goal of the final chapter (by A. Mariano and E. Ryan) is to summarize results discussed during the three LAPCOD meetings. However, the authors take a much broader view, offering a wide-ranging overview of observations, experiments, and techniques. They discuss the use of drift information, from ships, bottles, and tracked instruments to estimate mean velocities. Mariano and Ryan also consider how seasonal variability, topography, and shear affect those estimates. They then examine single-particle and relative dispersion, and experiments measuring each. Recent studies involving dynamical systems theory are touched upon, as are biological applications, stochastic models, numerical simulations, and assimilation. The authors close by noting expected developments. It is an informative and very readable overview, and because the authors touch on the major subjects in the book, the reader could easily start here before moving on to the topic-specific chapters.

The book is a diverse and frequently illuminating statement of our current understanding of Lagrangian processes in the ocean. It perhaps lacks the coherent style that one expects with a single author, but the changes in perspective, for example, among the three chapters treating assimilation, are in themselves useful. Those attending LAPCOD meetings are struck by the energy and diversity of the participants and their dedication to this unusual study. The book captures that feeling. It will certainly be useful to anyone interested in Lagrangian dynamics, modeling, or experiments.

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