

Lagrangian Fluid Dynamics

By Andrew Bennett, Cambridge University Press, 2006, 286 pages, ISBN 0521853109, Hardcover, \$95 US

REVIEW BY RUSS DAVIS

Many students, when first learning fluid dynamics, are intrigued by the dichotomy between Eulerian and Lagrangian approaches. Most master the Eulerian frame that is so much the foundation of dynamics that concepts like “advection,” “enstrophy production,” and “vortex tipping” are immediately associated with particular terms in the Eulerian equations of motion. Other students, intrigued by how the Lagrangian formulation seems more directly related to the way properties are distributed and fluids accelerate, strive to master the mathematics of the Lagrangian frame, including the complex, and to my mind less than intuitive, nonlinearity of the spatial gradient in Lagrangian coordinates. The challenge is great enough, and the examples of successful analytical work in Lagrangian coordinates are rare enough, that most abandon the Lagrangian approach before mastering it.

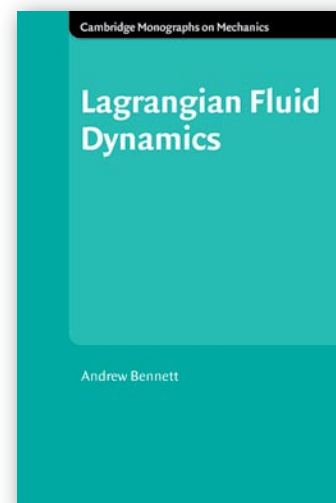
Andrew Bennett's *Lagrangian Fluid Dynamics* is the first book devoted to providing a unified exposition of dynamics in the Lagrangian frame. The treatment is comprehensive, making the book valuable to all fluid dynamicists seeking to expand their backgrounds in the Lagrangian perspective, but the tone and numerous problems left to be worked out by the reader make it well suited as the text for an advanced graduate course. The mathematical level is high and the

reader is expected to fill in the steps of many demanding developments, but the story starts at an introductory level and blocks of explanation are provided to motivate a flow that is often mainly mathematical. Bennett makes no apology for the mathematical density of the development, explaining that his goal is to provide modern students the opportunity and encouragement to develop the kind of mathematical acumen he feels the older generation had.

While the foundation and theme of this book is theoretical, Bennett does a good job of bringing in observational data from the ocean and atmosphere when pertinent to the development. He explains how some of the data are obtained and devotes the last section of the book to the Lagrangian analysis of data, including assimilation of data from current followers into dynamical models. There is, however, little effort invested in trying to develop in the reader the physical intuition that helps some experienced researchers think outside the framework of advanced mathematics.

The book is divided into four sections, each with an introduction and several chapters. It begins with a preface “better tailored to experienced researchers and teachers than to students,” which showcases Bennett's broad and up-to-date understanding of things Lagrangian. It is filled with little gems deserving further thought. I would encourage every student who works their way through the book to go back and reread the preface for perspective on what they have mastered.

The first section introduces the



Lagrangian frame and the labeling theorem, Lagrangian statistics, various conservation laws (many familiar from the Eulerian frame), and the inconvenient Lagrangian representation of viscous and diffusive fluxes. Notation, often a weakness of exposition in Lagrangian coordinates, is clear. The section's pace will be rapid for the target student having only introductory knowledge of fluid mechanics, advanced calculus, and Cartesian tensors; the guidance and encouragement of a mentor will be helpful.

The second section presents a number of Lagrangian-frame analytic solutions, some old and some quite modern, in an expository style often reminiscent of Lamb's *Hydrodynamics*. The section closes with a rather esoteric investigation of the solvability of the Lagrangian equations of motion.

The third section, which begins about halfway through the book, addresses the statistical description and prediction of particle dispersion in complex and turbulent flows. Evolution equations for the probability densities for particle position (pertinent to the spread of the mean concentration of particles released at a point) and of particle separation

(pertinent to the typical size of dispersing clouds) are developed based on simple closure theories. These evolution equations involve measurable one- and two-particle diffusivities and lead to useful descriptions of dispersion and the difference between Eulerian-mean and Lagrangian-mean velocities. The role of different parts of the canonical turbulence spectrum in establishing particle-pair statistics is discussed as are observations of pair statistics. I am disappointed that the dependence of the pair diffusivity on the time since labeling in addition to the particle separation is glossed over, but this is conventional and probably satisfactory in many circumstances.

The final section addresses Lagrangian analyses of data from current follow-

ers. Many analyses of current-following floats and drifters are done in the simpler Eulerian framework, but the subtleties of these analyses are not considered. Rather, the exposition focuses on Lagrangian analyses of single-particle and particle-pair dispersion, on analysis of the local kinematics and implied dynamics of coherent clusters of many particles, and on assimilation of data into dynamical models. The dispersion and cluster analyses are clearly and usefully described, but it is the data-assimilation development that breaks the newest ground. The assimilation question is how to exploit the Lagrangian history of particles to provide more information than is extracted by treating the particle time series as sequences of

measurements along arbitrary paths (the Eulerian approach); the reader will not find the answer but will be better prepared to seek it out.

Lagrangian Fluid Dynamics is nicely produced with several useful illustrations, many helpful references, and an extensive subject index. Mastering the subject material will require a substantial investment, but Bennett has laid out the path to an advanced level of understanding. Hopefully his book will help a new generation of dynamicists to lead a resurgence of Lagrangian methods.

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The Agulhas Current

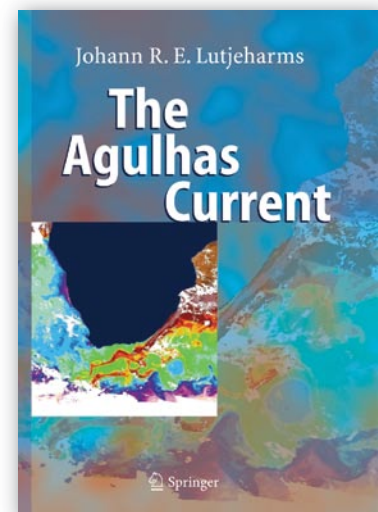
By Johann R.E. Lutjeharms, Springer, 2006, 330 pages, ISBN 103540423923, Hardcover, 129.95 €

REVIEW BY ARNOLD L. GORDON

The ocean is composed of interlocking regions, each with their own unique characteristics and advocates. All are special and worthy of study for their own complex attributes, including their impacts upon local environmental conditions. Some ocean regions, in the wider community of oceanographers and climatologists, are viewed as more important than others in that they influence the larger scale, even the global ocean and its function in Earth's climate system. Each region responds to fluctua-

tions in the large-scale wind and buoyancy-forcing fields across a wide range of time scales; a few feedback to these larger-scale fields, with far-a-field ramifications. Regional regimes may be centers of strong sea-air fluxes or conduits between larger ocean-circulation structures, such as between circulation gyres or between ocean basins, affecting the large-scale pattern of ocean temperature and salinity, ecosystems, and more exotic seawater properties. It is speculated that the behavior of a few regions might be enough to flip Earth's climate system into another mode, perhaps one associated with the shifts between glacial/interglacial climate.

Among these strategic regions is one that includes the strongest of the south-



ern hemisphere subtropical western boundary currents, the Agulhas Current system. Here, the subtropical gyres of the Indian and South Atlantic Oceans can, from time to time, join, linking and blending their properties across the southern rim of Africa. The South Atlantic subtropical gyre, when linked

UPCOMING BOOK REVIEWS

The Equations of Oceanic Motions

by Peter Müller, Cambridge University Press, 291 pages

Fundamentals of Geophysical Fluid Dynamics

by James C. McWilliams, Cambridge University Press, 249 pages

The Gulf Stream

by Bruno Voituriez, UNESCO Publishing, 221 pages

to its Indian cousin, is denied access to the low-salinity subpolar water streaming eastward along the circumpolar belt, thus altering the freshwater budget or salinity of the South Atlantic, a factor that has far-reaching effects on the deep-ocean overturning circulation associated with the northern North Atlantic (Weijer et al., 1999; Gordon, 2001). However, while large-scale consideration might draw one to these key regions, it is important to remember that these regions have their own intrinsic values and complexities (and impacts to the larger scale yet to be discovered).

While books and collections of articles in journals are devoted to specific regions, they often do not garner interest beyond the specialists of those regions. The Agulhas system is different, or at least should be (Gordon, 2003). It is the best example of a retroflection-type circulation, a pattern shared by other regions, such as the Brazil Current and the North Brazil Current. Because of the role of the retroflection pattern in the larger scale, every oceanographer might want to learn more of the Agulhas Current system. Johann R.E. Lutjeharms' book, *The Agulhas Current*, offers such an opportunity.

Lutjeharms does a remarkable job of presenting the Agulhas to the wider community. His encyclopedic knowledge nicely draws together the many research studies devoted to the Agulhas Current system to produce an excellent, objective, and well-written analysis. While the topics are mainly those associated with the physical oceanography of the Agulhas, issues of climate, biological, and geological topics are included. Most appreciated are the gray, boxed inserts that offer aspects of the rich history of the explorers, ships,

expeditions, and institutions contributing to the opening up of the Agulhas system to our consciousness. In these asides, we learn about the origin of the name "Agulhas" and of the term "retroflection" as well as about Major James Rennell, "the pre-eminent pioneer of research on the Agulhas Current." Another deals with a very pertinent question of paleoclimate importance: "How old is the Agulhas Current?" Evidently, an "Agulhas Current" following pretty much the path it does today was established five million years ago. Lutjeharms adds that "even though the leakage of Indian Ocean water is variable, over the past 450 kyr [450,000 years] it has always been present," though bursts in its strength seem to be linked to the termination of glacial ages (Peeters et al., 2004) and to the resumption of a strong Atlantic meridional overturning circulation (Knorr and Lohmann, 2003), a result recently supported by Franzese et al. (2006).

Lutjeharms notes that textbooks as late as the 1970s had just a few paragraphs devoted to the Agulhas Current. The 2001 pdf version of *Regional Oceanography: An Introduction* by Matthias Tomczak and J. Stuart Godfrey (to download a copy, go to <http://www.es.flinders.edu.au/~mattom/regoc/index.html>) has five pages devoted to the Agulhas system, but still nothing like the 238 pages of text and figures of Lutje-

harms' book. The bibliography, arranged in traditional alphabetical order, consists of 24 pages. The listings referenced within the text and figures are identified with a sequential numbering system (826 entries in total), which then are listed in numerical order before the bibliography. There is a complete (34-page) name and subject index. The figures, largely drawn from other publications, many from Lutjeharms, include useful schematics that faithfully bring out the system's form and complexities. Excellent satellite views of sea-surface temperatures further imprint upon the mind the very active and fascinating oceanography of the Agulhas Current system.

Lutjeharms shows a histogram of the number of Agulhas publications by year. Their explosion in the mid-1970s has been sustained at a more-or-less constant rate of 10 per year since 1980. I'm glad I came of age as an oceanographer in the 1960s when it was possible to read all of the literature about nearly all oceanographic topics. I then grew up during the explosion of publications, so as to be able to absorb much of the evolving information at a gentle rate. I pity the students of today: How can they possibly catch up and keep pace with the hundreds of oceanographic papers published monthly? For this reason, well-prepared review articles and books are needed, such as Lutjeharms's magnum

opus. Of course, students still need to go to the originals to gather the details and nuances, but at least they can have a construct of the body of knowledge to build upon.

The book is dedicated to the memory of Günther Dietrich (1911–1972), whose Ph.D. thesis in 1935 (and subsequent journal publication) may have rekindled interest in the Agulhas (deferred by World War II—one of the gray boxes deals with pre-World War II German research on the Agulhas Current). It was Dietrich’s work that drew me to the Agulhas in 1983, particularly to investigate the Agulhas Retroflection and adjacent South Atlantic. This work eventually led me to the consideration of the larger-scale role of the Agulhas through its leakage (of Indian Ocean water) into the Atlantic Ocean.

There are eight chapters in Lutjeharms’ book, which, after a large-scale description of the current’s setting, are discussed and arranged as the Agulhas water flows: from upstream to downstream. Each chapter concludes with a section of a different name (e.g., perspective, conclusions, synopsis, recapitulation). In Chapter 3 we are introduced to the varied streams and eddies feeding the northern Agulhas Current through the Mozambique Channel and from the East Madagascar Current; then Chapters 4 and 5 take us to the jetlike boundary current pressed up along the southeast and southern margin of South Africa (waving a bit as a Natal Pulse goes by). Chapters 6 and 7 discuss the energetic loop of the Agulhas Retroflection and the Agulhas Return Current, respectively. As the name suggests, the Agulhas Return Current returns most of the Agulhas water back into the Indian

Ocean—“most” but not all. The Agulhas Retroflection is not complete, as some Agulhas water leaks, mostly within large rings of the Agulhas Current that entrap pools of Indian Ocean water.

Lutjeharms comes to the Agulhas story as an insider, one who has focused his professional life on the pursuit of “knowing” the Agulhas as a regional system. In this way, he presents a story far richer in texture than just that of interocean exchange. In Chapter 8 Lutjeharms takes the well-deserved liberty of covering “The Greater Agulhas Current: Some Reflections,” with a wonderful opening paragraph: “In looking back over this historical development one is invariably tempted to read the past by the agendas of the present. The prevailing interest in inter-ocean exchanges and their effects on global ocean circulation is fundamentally motivated by contemporary concerns about climate change and climate variability. This was not the case when the main momentum in Agulhas Current studies was initiated.” That is, there is much more to a system than just the pieces that happen to be in vogue. Aspects of the Agulhas system will no doubt be rediscovered as our overall appreciation of its complexities evolves, and as the author says, “This modern incentive has helped in lifting investigations on the Agulhas Current from a sphere of largely localized, parochial interests to one where the Agulhas Current system is instead seen in its more comprehensive role as a conduit for inter-ocean exchange of heat and salt. This wider perspective has had some distinct advantages, but may ultimately also have a few drawbacks.” Interesting.

Professor Johann R.E. Lutjeharms has produced a truly scholarly work,

drawing from a multitude of research papers, many from his own pen, and presenting to us with clarity the complex oceanography of the Agulhas Current system, including its rich history of exploration, from the early days to the current research endeavors. There is more to be done, for sure, and it will be built upon the solid foundation of work accomplished by so many and skillfully reviewed within the pages of *The Agulhas Current*. Johann Lutjeharms indeed has met his objectives, as stated in the preface: “...to bring together and synthesise what has been learnt... More than this it should be a user-friendly key to unlocking the wealth of information scattered throughout the primary literature. These are the aims of this book.” Johann: On target and well done!

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