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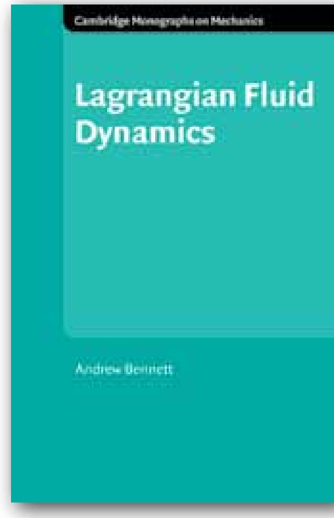
# Lagrangian Fluid Dynamics




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 followers. 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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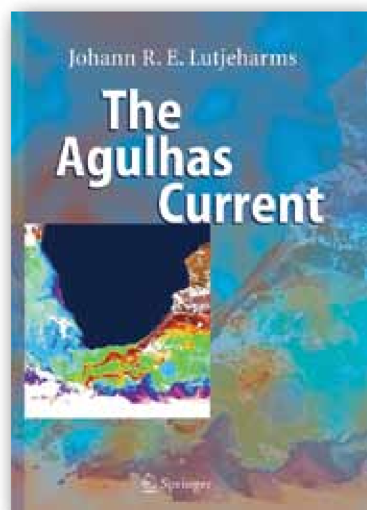
# The Agulhas Current

By Johann R.E. Lutjeharms, Springer, 2006, 330 pages, ISBN103540423923, 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 fluctuations 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