A Review of “Marine Turbulence: Theories, Observations, and Models”

Dr. R. Norris Keeler

A Review of "Marine Turbulence: Theories, Observations, and Models"

In 2005, a large encyclopedia was published by the Cambridge University Press entitled Marine Turbulence: Theories, Observations and Models, Results of the CARTUM Project; it was edited by Baumert, Simpson, and Sünderman. This work was sponsored by the European Commission's Marine Science and Technology Programme, under the Comparative Analysis and Rationalization of Second-Moments Turbulence Models (CARTUM) Project.

A natural question arises, "Who are the principals whose views and ideas are represented, and what community do they represent?" The answer is that the three principal editors all represent the European community, except for a Professor from Princeton (Mellor) who spent three days reviewing the manuscripts. Additionally, the other contributors with US or Canadian affiliations are originally from Europe. Contributions from the Russian School, the Scripps Institution of Oceanography, and Woods Hole Oceanographic Institute are not present.

In the foreword of the text, the editors cite the motivation and benefit of the CARTUM Project. This program was instituted to examine and explain various complex turbulent systems. Combining theoretical ideas, laboratory experiments, turbulence designs, and simulations, this project developed further analysis of marine and geophysical turbulence and fluid dynamics. This book, Marine Turbulence: Theories, Observations, and Models, addresses the developments of the project while also presenting the concepts and analyses gained from it.

This is a commendable ambition, and in many ways, the staff accomplished it. Unfortunately, the date of the manuscript submission and the unfortunate loss of Joel Ferziger prevented awareness of what is a new revolution in our understanding of ocean turbulence. Ferziger's last cited reference is from 1996. Some of the new discoveries in the field would undoubtedly have been of great interest to him. Nevertheless, some of the newer discoveries about turbulence negate or at least run contrary to his views on the subject. Ferziger was a numerical modeler whose modeling was not based of first principle solutions of the Navier-Stokes Equation, but rather was based on certain conventions and assumptions. These efforts were useful to engineers, but were not helpful in advancing the field in a fundamental way. For example, Ferziger consistently refused to consider what has become known as the reverse cascade (postulated by Linden and Sutherland, and demonstrated by Kathleen Dohan at Scripps) in his many discussions with Bill Schwarz at Stanford. These issues will be discussed more extensively later.

Turbulence is one of the most complicated and least understood aspects of classical physics. Part I of the textbook explains why this is the case, and introduces the fundamental concepts of turbulence, citing the defining elements: three-dimensionality, unsteadiness, strong vorticity, unpredictability, and broad spectrum. The idea of shear-driven turbulence is introduced, and spatially non-uniform and intermittent conditions are examined. Two different mathematical representations of turbulence equations are included as well. Part I suggests that important aspects such as the Reynolds numbers, internal waves, and Richardson's spreading law could link different approaches and theories together to form a more complete picture of oceanic turbulence.

Also, throughout Part I, discussion of Kolmogorov's work is disjointed. For example, on page 68, the authors confuse the direction of the energy cascade with the validity of Kolmogorov's laws. Further ideas concerning this matter will be discussed at the end of this review.

This is followed by Part II, which describes numerous strategies and instruments that can be deployed for marine turbulence observations. Towed bodies and vertical profilers are described, both of which were used in the RASP III and IV Project. Also included in the textbook are descriptions and limitations of acoustic Doppler techniques, which caused RASP investigators difficultly with respect to the TOMI, the large device deployed as part of the 2004 experiments. The highlight of this portion of the book is the chapter written by Hartmut Prandke. He is the most talented instrumentalist in the field today, and his MSS sensor package was deployed in the RASP experiments; these instruments are described in this report in Sections 7 and 15. Prandke combines instrumental ingenuity with a deep understanding of the ocean turbulence field. With continued research and innovative ideas, the authors claim, the oceanic community will be able to better measure turbulent kinetic energy, as well as other turbulent processes in the ocean. This thinly veiled push for more funding is understandable; however, better insights would help direct the focus of such new efforts. The section starting on page 89 is so full of errors and inaccuracies that it will be dealt with separately at the end of this review, as will other sections.

Part III attempts to explain different models and simulations for turbulent processes. While models have been developed, for example, for large eddy-like structures, improved versions will more effectively summarize separating and reattaching flow. Numerical analysis can also be employed as described in the chapters in Part III. Such analysis can be used effectively when addressing the energy conservation law, which in the past has not played a key role in turbulence analysis. Three important quantities, TKE, TKE dissipation rate, and turbulence length scales are outlined for modeling, as well as vertical mixing in a variety of ocean regimes. The authors claim that it will be key to improve upon the models already designed in order to form a more complete and accurate description of ocean turbulence.

Boundary layers comprise the topic of Part IV of the text. There are turbulent structures within the oceanic surface and the bottom boundary layers; the various layers are affected by water depth, sedimentation, erosion, winds, and currents, all of which help to form these structures. The layers addressed in Part IV are the surface mixed layer, the near-surface boundary layer, and the near-bottom boundary layers. Also, chapters are devoted to the modeling of breaking waves, Langmuir circulation, and equatorial turbulence. Many of these topics circle back around to discussions of kinetic and potential energy in the water, as well as TKE.

Part V addresses fjords, lakes, and estuaries, which are not particularly relevant to the RASP Project. Various environments ranging from weakly stratified and swift moving estuaries to turbulent mixing regimes in lakes are compared. Turbulence characteristics are dependent upon the shape and type of the water source, as well as the salinity and animals living in it.

While only 8% of the global ocean is made up of shelf seas, their effect on ocean turbulence is great. Shelf sea analysis makes up Part VI of this book. This complex topic houses discussions on internal waves, as well as regions of stratified water, tidally mixed water, and surface waves. Waves are one way in which energy is transferred throughout ocean waters. One chapter discusses all four shelf-sea regimes, and a case study on the shelf-sea of the Baltic provides a deeper analysis of the shear, viscosity, and diffusivity of this region of the world. One major result of these chapters is that the role of internal waves in the thermocline is important, yet not well-understood. This is one area where the oceanic community struggles and the authors and these reviewers agree that we must strengthen our understanding in these areas of oceanography.

Part VII addresses a wide range of topics. First, it presents the challenges faced when trying to connect the idea of two and three dimensional turbulence. Although turbulence research has grown to a complex level, fundamental questions concerning the mechanisms behind it remain unanswered. Research functions to keep the theoretical models in check. Turbulence clearly varies over space, and also over time; classical representations of two-dimensional turbulence, however, do not fully include all of these aspects of turbulence. According to the authors, newly developed approaches may lead to better representations of the complicated structures and eddies. Furthermore, Part VII includes chapters on the spreading of turbulence, as well as new computational techniques for describing flow fields. By incorporating dynamic and thermodynamic analysis into turbulent systems, more general theories can result.

The book concludes with Part VIII, which describes that which is included in the attached CD-ROM. Furthermore, an extensive list of resources and references is included. The references will be discussed later.

This text is a rather extensive compilation of both theory and experimental results in the field of open water turbulence. One clear conclusion drawn from this book is that there is much more to be learned about marine turbulence and the turbulent structures in the ocean; unfortunately, certain notable advances that have been made in turbulence and ocean turbulence in the past three or four years were too recent to have been included in this text. Overall, while this text is a valuable asset for those working in the field, it must be used with several caveats in mind.

As mentioned earlier, the sources for this book are basically European and Canadian. Russian and Western authors are not present, unless as émigrés to the US and other places; such experts are only cited as references. Scripps Institution of Oceanography and Woods Hole Oceanographic Institution are both reputable organizations on matters of turbulence; however, neither institution is represented in the book.

Second, this book was published with complete absence of awareness of some significant, new developments. It was generally known that a number of US and Canadian investigators had claimed that Kolmogorov's laws did not hold in the ocean (see, for example, Gargett, A. E., "Evolution of Scalar Spectra with the Decay of Turbulence in a Stratified Fluid", Journ. Fluid Mech. **159**, 379 (1985)"). Over the years, Gargett has come to reconsider this view and accepted fossil turbulence as a concept which is helpful in understanding ocean turbulence; additionally, she recently included a chapter on fossil turbulence in a review she was editing.

As part of the RASP program, a hydrodynamics workshop was organized, to investigate the status of US views on Russian work in this field. One of the documents reviewed was a so called "FASAC" report on "Soviet Oceanography," whose completion was chaired by Mike Gregg. The report was highly critical of Russian efforts, and also other measurements involving towed bodies. One reference that was used as a point of discussion was "Diapycnal Mixing in the Thermocline: A review" by M. C. Gregg (Journ. Geophys. Res. **92**, 5249 (1978)). This represented the technical basis for the conclusion that submerged turbulence would just die away. However, at the workshop, Harry Robey presented his work, which was the first paper which dealt with new internal wave phenomena. He worked in collaboration with the Russian team at Nizhny Novgorod headed by Academician V. I. Talanov and carried out the cited experiments. This work was presented in the following reference: Robey, H. L. III, "The generation of internal waves by a towed sphere and its wake in a thermocline", Phys. Fluids, **9** (11), 3353 (1998). This reference was not cited in the book, despite having appeared in late 1998.

One workshop participant, Walter Munk introduced the panel, and remained for all the presentations. He was particularly interested in the Robey paper, as it tended to refute work he and Gregg had done years before. At the end, Munk commented, "You guys are right, and we were wrong."

Also, throughout the Marine Turbulence text, various sources and sections are questionable. For example, documents authored by M. C. Gregg, T. Osborn, and A. E. Gargett were referenced in the back of the book. However, as mentioned previously, several of these have now been shown to be inconsistent with that which is now known to be physically true.

Further flaws exist in the basic definition of turbulence used by Joel Ferziger as alluded to previously. He assumes that turbulence cascades from large scales to smaller ones. However, this does not take into account the inertial vortex force, which is the nonlinear term that causes turbulence eddies to merge or diverge. According to Carl Gibson of SIO, turbulence grows by a cascade from small scale eddies produced at the Kolmogorov scale to larger scales by a merging process driven by inertial vortex forces.

Additionally, contributors to this book do not properly use the concept of fossil turbulence, a concept originally conceived by George Gamow. It has been postulated that radiating fossil turbulence waves mix the water column and carry information about submerged turbulence to the sea surface. These radiating waves are believed by some to cause the anomaly area detected by the Isintech team in RASP (see Section 22). Without these traveling waves, the RASP detections might be impossible; however, distinct anomalies were observed throughout the course of the program. Also, fossil turbulence appears to have been observed in the recent laboratory work of Sutherland, as well as in the theoretical studies of Dr. Peter Diamessis at Cornell.

A good example of the poor writing and dubious assertions occurring throughout the book begins on page 68. The first paragraph is full of insignificant thoughts. The author refers to work done by Harold Grant in 1962. However, the author does not cite what was really accomplished in that work: observation over three decades of -5/3 spectral slope in Seymour Narrows, which gave the first verification of Kolmogorov's first law. The paragraph is also peculiar in that it indicated that the Cold Was did not exist, or that the author, Lueck disapproved of it. This is followed by an assertion that Grant was unable to detect turbulence in the wake of a submarine, and backs it by a reference (Stewart and Grant, 1999). However, by 1999, both Steward and Grant had long since retired, and no such reference exists. Lueck then calls the situation a "complete military failure," but follows with an assertion that it was a "scientific success" because "it validated Kolmogorov in Fourier Space." Not only is it unclear what "Kolmogorov in Fourier Space" means, but it is ambiguous as to how it follows from the null result. Lueck was never involved in any of these programs, and was not even around when the measurements were made. Furthermore, the work of Robey indicates that submerged turbulence can generate a strong signal in the laboratory.

Additionally, Lueck speaks about the "prolific work at Scripps under C. Cox." In fact, this work consisted of Cox and two graduate students, Tom Osborn, and Mike Gregg. Their work was cited previously and on the basis of this work, they claimed to have disproved Kolmogorov's Laws. It should be noted that after receiving their degrees, both Osborn and Gregg left Scripps.

This textbook contains a large number of references to work carried out in the European/Western community. This list of references is outdated and incomplete. It should be noted that two of the most important books ever written on the subject of turbulence, the two volumes by Monin and Yaglom, were cited here. It is interesting to scan the references to these two books. There is no mention of Cox, Gregg, or Osborn because their work was not considered to be of fundamental importance. However, Carl Gibson and his work have several lines of citations. Again, this shows the degree of isolation between Western oceanographers, and others, principally in the Russian group.

In this text, some oceanographic hardware is discussed, and one such piece of equipment is noted in the section "Optical Sensors." Described was a crude optical fluorometer. The measurements obtained with this device cannot, unfortunately, be related to the intrinsic or apparent optical quantities of absorption, scattering, phase function, and so on. Ocean optics specialists, such as Robert Maffione, designed such probes which do not have the accuracy of the AC-9, for example, but are still quite useful. Understandably, the very recent work of Dr. Darek Bogucki at the University of Miami is not cited. However, it should be noted here that Bogucki has invented a new device for obtaining large amounts of turbulent spectra over very short time intervals; he developed a new optical sampling technique using laser transmissions through media with a variable refractive index.

A following section prepared by an Adolph Stips writes about the theory of dissipation measurements. Unfortunately, he and the references he cites do not take into account intermittency, patchiness, and fossil turbulence, and so this material is of marginal value.

It should also be noted in this review that this book is rather expensive. However, it is already reaching the internet at much reduced prices, as booksellers begin to unload their unsold copies.

This volume is flawed because of its lack of breadth, and because it does not reflect the change in perspectives of turbulence and internal waves that have recently emerged. Therefore, it must be purchased with these limitations in mind.

As is clear from both this text and this review, there is more to be explored in the field of oceanic turbulence. It is hoped that experiments such as RASP will be effective in answering the questions still plaguing experts about the fundamental nature of turbulence.