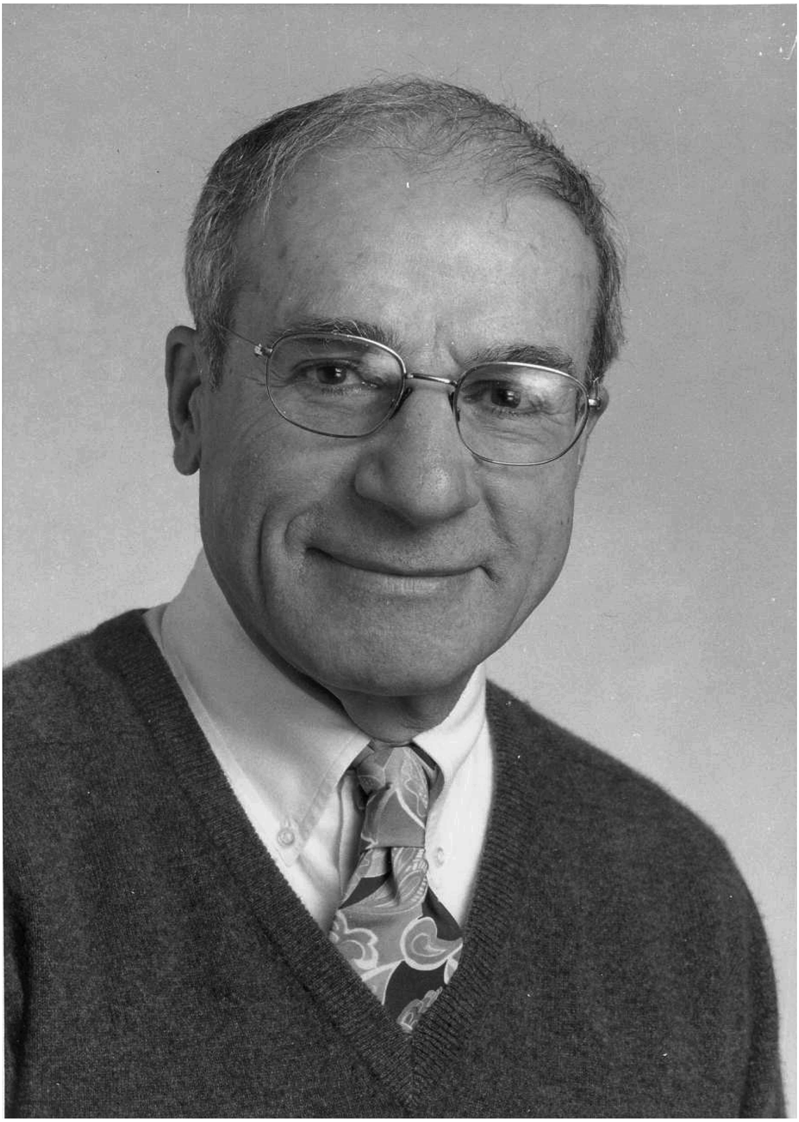

George Veronis

Journal of Marine Research, 68, iii–xix, 2010

Journal of
MARINE RESEARCH

Volume 68, Numbers 3–4

George Veronis: An appreciation

by K. H. Brink[1] and K. K. Turekian[2]

1. Passages

George Veronis was born in New Brunswick, New Jersey on June 3, 1926, one of six accomplished children of a Greek immigrant couple. He grew up in Easton, Pennsylvania, where his talent for mathematics was recognized early on. World War II interrupted his education, however, and he enlisted in the U.S. Navy where he served aboard submarines in the Pacific Ocean. With the end of the global conflict, George entered college on the G.I. Bill and graduated with a B.S. in Mathematics from nearby Lafayette College in 1950.

George's enthusiasm for mathematics took him to Brown University to study under Henry Morgan. At the time, oceanographic influences there were substantial, with Ray Montgomery also being on campus, Hank Stommel an occasional visitor, and Nick Fofonoff as a fellow student. Thus, it is not surprising that George was drawn to the interface between mathematics and the ocean sciences, and this connection is demonstrated even in his earliest publication (Veronis and Morgan, 1955). After completing his Ph.D., George moved on to the Institute of Advanced Studies at Princeton where he worked with the Electronic Computer Project. At the time, Princeton was the home of John von Neumann and Jule Charney who were developing the theoretical and computational underpinnings of numerical weather forecasting. It was a remarkable time to be at Princeton.

George then moved on to the Woods Hole Oceanographic Institution, which was also in a golden era. His colleagues included Fritz Fuglister, Joanne Malkus, Willem Malkus,

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Melvin Stern, Hank Stommel, and Val Worthington. At this time, both the dynamical and observational aspects of today's oceanography were taking shape, and George was right at the center of it. By the early 1960's, however, much of this talent dispersed to other institutions. George was a part of this diaspora, and he then settled at the Massachusetts Institute of Technology from 1961–1966.

George was then drawn to the Yale Department of Geology and Geophysics, a remarkably diverse organization that proved to be an enduringly congenial setting. George took charge of Yale's Applied Mathematics Program from 1979–1993, and was named Henry Barnard Davis Professor of Geophysics and Applied Science in 1985. Although always intensely loyal to Yale, George often found time for sabbatical leaves, especially to Sweden and Australia. Yale provided ample opportunity for involvement in education on all levels. George is an excellent classroom instructor: clear, interesting and very well-organized. As a mentor, he has very high standards, and works hard to see that they are met.

George took on his role of Editor of the *Journal of Marine Research* in 1973 and only relinquished it in 2010. It was natural for this responsibility to settle onto him, because the sponsoring Sears Foundation for Marine Research operates through a Yale endowment. Associate Editors Don Rhoads and, later, Don Rice provided crucial services during these years, dealing with many of the manuscripts outside of physical oceanography. During George's 36-year tenure as Editor, he published 36 volumes and more than 1,400 papers, all the while enhancing the standing and strength of the Journal. He leaves very big shoes to be filled by his successors.

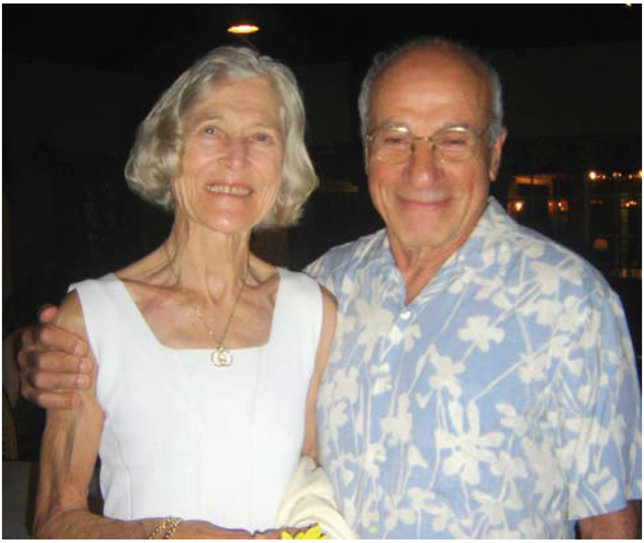
Anyone who knows George knows the central importance of his wife Kim, and of the pride and affection that he feels for his children Ben and Melissa. His family is a theme in his life that is no less important than his many intellectual achievements.

2. Scientific landmarks

a. Ocean circulation and its variability

The first published work of George Veronis, in 1955, involved the basin-scale response of an ocean to wind variability, and he continued to work on this general class of questions intermittently until the late 1960's. As context, these were the years of exploding growth in the study of the physical dynamics of the ocean. Many of George's works from this era were breaking new ground, and so remain standard references to this day. For example, the Veronis and Stommel (1956) paper describes how a stratified ocean responds to wind variability over a wide range of time scales. As such, it clarifies the types of waves that might be generated for different time scales of forcing, and the gross differences in time and length scales between barotropic modes and the internal mode associated with density stratification.

If there is a single topic with which George is most strongly identified, it may be the dynamics of steady flow in the ocean. His first publication on the topic appeared in 1960 (Veronis, 1960), and his contributions continued for more than 35 years. A particularly fine



George and Kim enjoying summer at Cape Cod.

example of his scientific skill is Veronis, 1963, which used physical reasoning and lucid presentation to provide a clear understanding of how an idealized ocean would respond to a particular wind stress pattern. The Veronis (1973, 1976, 1978) papers, together, represent a remarkable and novel synthesis of ocean circulation. They use realistic winds and straightforward dynamics to piece together a theory for the entire world ocean's circulation. Along the way, he makes important points about western boundary currents, and how the wind-driven and thermally driven circulations coexist.

Perhaps it is not surprising that, as computers began to be more widely available, George took advantage of the opportunities they presented. Beginning in 1963, he began to explore the nonlinear aspects of ocean circulation that were not readily understood previously. His exploring works in this regard treated new conditions where the ocean could respond in a time-dependent way to steady winds or in a steady way to time-dependent winds (Veronis 1963, 1966). Another of his enduring modeling contributions is the articulation of the "Veronis effect," describing how physically unrealistic mixing occurs in western boundary currents in many classes of numerical models and thus affects the entire ocean basin (Veronis, 1975). Although he made some of the initial exciting discoveries in numerical modeling, it was only a brief excursion for George. As his work with numerical models waned, he became increasingly involved in laboratory models of the ocean circulation. This work was often carried out in collaboration with students or postdocs, and often brought out interesting insights on the ocean's behavior (e.g., Veronis and Yang, 1972).

Given George's interest in ocean circulation, it was only natural that he turn to questions of quantifying the actual mean flow in the ocean. His chosen approach involved tracers. Properties such as dissolved oxygen or nutrients, in addition to physically active quantities like temperature and salinity, are carried about by the ocean's circulation and are gradually changed by mixing or other processes. These quantities thus provide insight as to where ocean currents go, and how quickly. His initial approach to this problem was to use simple, dynamically based circulation models, and then vary parameters to estimate circulation or biological rates (e.g., Kuo and Veronis, 1973). This class of work naturally led to interactions with chemists and to an interest in global sampling schemes. George's growing interest in formal inverse methodology was also a natural outgrowth of the study of tracers. These methodologies gather together available observational information, impose constraints, and then estimate ocean currents, mixing rates and errors. His explorations of inverse methodology led to a variety of analyses, including his solution of the classic "Bermuda Triangle" problem to estimate currents on a line from Bermuda to the mainland, crossing the Gulf Stream (Veronis, 1983).

One oceanographic paper falls into a special category of its own (Veronis, 1972). Here, George considered the classical properties usually characterizing sea water (temperature, salinity and density), and realized that information could be optimized by using a new quantity, which he called "tau," that is mathematically orthogonal to density. This was an entirely new concept in the western oceanographic literature, and the calculation of "spiciness" (the popular name that quickly replaced "tau") soon became a standard tool for treating ocean observations (e.g., Niiler *et al.,* 1989, to pick a reference almost at random).

b. Convection and fluid mechanics

Convection is the process by which lighter fluid at depth causes overturning and so transports heat upward. George's interest in the topic began by 1957, and was evidently motivated by the ocean's thermally driven circulation. He quickly cut to the heart of the matter with the landmark Malkus and Veronis (1958) paper that paved the way toward understanding convection at finite amplitude. The insights on how to solve for convective amplitude and form enabled a wide range of important results by subsequent scientists. George himself went on to make a range of important contributions on thermally driven convection, including his treatment of rotation (1959) and his early application of a numerical approach (1966). George's mathematical and physical insights made him a leader within this field.

The convection problem takes some very interesting turns when the density is determined by two components having different diffusivities (temperature and salinity), as is found in the ocean (Stommel *et al.,* 1956; Stern, 1960). Even when the density profile is gravitationally stable, it is still possible to have instabilities occur, a concept that might at first appear to be a mere curiosity, but that has since been confirmed in the ocean (e.g., Turner, 1973). George made important early contributions to this class of problems, such as Veronis (1968), where he treated the finite-amplitude case with a stable salinity gradient, and his results opened the way to making quantitative estimates of the net vertical heat and salt fluxes. George's publications on the subject carried on intermittently for another 40 years, and included a wide range of approaches, ranging from laboratory experiments to ocean data analysis.

Some of George's contributions can only be described as fundamental fluid mechanics. One was to establish a rigorous basis for fundamental assumptions, such as the Boussinesq approximation (Spiegel and Veronis, 1960), that are essential for theoretical progress. A second, more philosophical, approach has been to examine the analogies between rotating homogeneous flows and stratified non-rotating ones (Veronis, 1970).

c. Geophysical Fluid Dynamics (GFD)

In 1959, George was a co-founder of the Woods Hole program in Geophysical Fluid Dynamics (GFD). This nascent field of study embraced theoretical aspects of a wide range of fields, including astrophysics, geophysics, meteorology and oceanography. Early and loyal program participants also included Lou Howard, Joe Keller, Willem Malkus, Ed Spiegel, Melvin Stern, and Hank Stommel. The founding committee's approach was to set up a summertime program where a small group of graduate students and postdocs would be introduced to classes and research on a topic within GFD. The talented young scientists participating in GFD continue to come from a very wide range of intellectual and national backgrounds.

The program has now gone on for more than 50 years, and several of the earliest leaders (including George) are still regular participants. Over 450 student fellows have taken part in the program so that its influence is widespread within the science community and beyond. A recent cataloging of former fellows and their present occupations is impressive: the former fellows are found all over the world in a range of capacities spanning the private sector, academics and even the U.S. Congress. To say that the program proved to be a success would be a wild understatement.

Another goal of the program is to have all participants share in a common, intense experience. One important means of bringing people together is the GFD softball team which competes within an informal league populated by employees of the various oceanographic institutions around Woods Hole. George is still one of the regular players on the team, and he continues to discourage hitters throughout the league with his mystifying pitching.

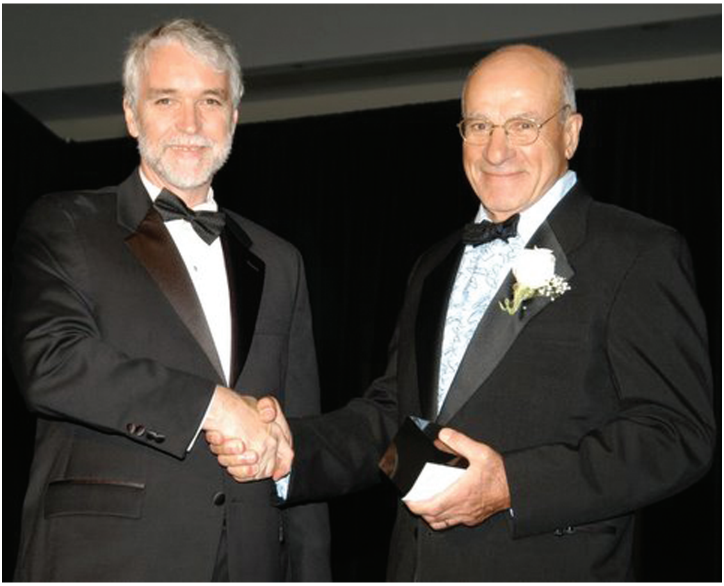
In 2008, the American Geophysical Union awarded the WHOI-GFD program its "Excellence in Geophysical Education" award and George, in a tuxedo, accepted the recognition on behalf of all. To put it mildly, the GFD program was always a focus and source of pride for George and his colleagues.

3. The back story

In April 1964, an inaugural ball was held in Ingalls hockey rink for the new president of Yale University, Kingman Brewster. There, he told some of the attending members of the Geology Department that their "revolution" was complete and that the department was now authorized to extend its purview beyond what was classically called "geology." That

George pitching for the GFD team in Woods Hole.

announcement would have a profound effect on George Veronis although not to his knowledge yet. One of the areas that the "revolutionaries" had decided was of importance to the understanding of the earth was the oceans. By 1965 the newly oriented department, eventually to be called the Department of Geology and Geophysics to show the expanded interests of the department, had settled on inviting George Veronis to join the department. Perhaps influenced by Hank Stommel, his old friend and a Yale graduate (although a major in astronomy), George decided to come to Yale in July of 1966. In June of that same year, Karl Turekian was with George at the International Oceanographic Congress in Moscow where the two celebrated George's birthday and his imminent arrival at Yale by wandering



AGU President Tim Killeen presenting the "Excellence in Geophysical Education" award to George at the 2008 Joint Assembly Awards Ceremony in Fort Lauderdale, Florida.

through the GUM department store on Red Square to see if there were beautiful Russian women to compensate for the proletarian women so evident in the streets of Moscow doing construction work. The jury is still out as to their success that day, but that did not diminish the joys of the day in remembering the past and looking forward to the future.

When George arrived at Yale, not only did he establish a program in physical oceanography, but he also decided that a much broader undertaking was required if the future were to be secure in this area. Thus, he established a program at the undergraduate level in Applied Mathematics. This effort was the first at Yale and influenced not only students interested in the earth sciences but also those interested in everything from economics to applied physics. George remains the founding idol of this important field. (For example, on April Fool's Day in 1987, the graduate students in the Department of Geology and Geophysics changed all the departmental signs to "The Department of Geochemistry and Applied Mathematics.")

George's talents extended to the role of impresario and actor when he unwittingly got involved in a construct of what the geochemists called GEOSECS (Geochemical Ocean Section Studies). Perhaps because Stommel was the instigator of this enterprise, George allowed the rowdy geochemists to meet with the staid Geophysical Fluid Dynamics Group that he headed at the Woods Hole Oceanographic Institution. There, the initial plans were made for the global expeditions of water profile sampling. It was during the famous Chappaquiddick fiasco that this meeting occurred; but if that were not the case, the noisiness of that encounter of rambunctious geochemists and polite applied geophysical fluid dynamicists might have hit the local newspapers. Later, as a reward for George's theatrical abilities demonstrated at this meeting, he was designated the chief expositor and master of ceremonies for the NSF-produced film on the exploits of the GEOSECS program.

George was responsible for bringing several younger faculty members to the department who later left to go on to enterprises of broader oceanographic importance. Tom Rossby went to the University of Rhode Island where easy access to a large research vessel allowed him to conduct his large-scale, neutrally buoyant float experiments. Based on these heroic experiments, Tom went on to election to the National Academy of Engineering. Manuel Fiadeiro left Yale and went on to be responsible for major parts of program management at the Office of Naval Research. Many others were influenced by George both at Yale and at the Woods Hole Oceanographic Institution's Geophysical Fluid Dynamics program.

Aside from being Chairman of the Department of Geology and Geophysics at Yale (a job he said he hated, thereby showing his usual good sense), he was responsible for building up the group in the physics of the ocean and atmosphere. He was responsible for establishing the atmospheric group at Yale starting with the late Barry Saltzman. To his credit, both these groups have grown to meet the increasing interest in our fluid environment as well as the relationship to other areas in the earth sciences.

All of this makes sense when one considers George's past history. His sister remembers that he was, in a Greek phrase, a *tsita,* which she describes as "one who cleverly and subtly set up things so that one of the other brothers got the blame." This sounds like what happened with GEOSECS!

What many don't realize is that during World War II the Navy encouraged the only sport that would fit on a ship—boxing. Every ship had boxing bouts and there were frequent inter-ship competitions. George was a star in this enterprise, boxing his way across the Pacific in the cramped quarters of a submarine! This "training" stood him in better stead as a post-war benefit than shooting torpedoes. He recounts that he beat up the town bully in Easton, PA after being discharged from the Navy—an event commemorated at his high school class reunions. This talent undoubtedly helped keep order at the Geophysical Fluid Dynamics get-togethers at Woods Hole.

Acknowledgments. Inputs from Mary Veronis Thompson, Melissa Veronis Odell, and Jack Whitehead are greatly appreciated.

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Biographical Notes

George Veronis

Curriculum Vitae

Date of Birth: 3 June, 1926
Place of Birth: New Brunswick, New Jersey
Military Service: USN—25 June, 1943 to 6 April, 1946
Education:

1950	Lafayette College, A. B. Mathematics
1954	Brown University, Ph.D. Applied Mathematics

Professional Experience:

12/53 to 6/56	Staff Meteorologist, Institute for Advanced Study Numerical Forecasting Group
6/56 to 1/64	Mathematician, Woods Hole Oceanographic Institution
1/61 to 1/64	Associate Professor of Oceanography (part time), M.I.T.
1/64 to 6/66	Research Oceanographer, Meteorology Department, M.I.T.
7/66 to 1985	Professor of Geophysics and Applied Science, Yale University
1985 to 2009	Henry Barnard Davis Professor of Geophysics and Applied Science, Yale University
1976 to 1979	Chairman, Department of Geology and Geophysics, Yale University
1973 to 2010	Editor, *Journal of Marine Research,* Yale University
1959 to 1987	Director, Geophysical Fluid Dynamics Summer Program, Woods Hole Oceanographic Institution (alternate years)
1979 to 1993	Director, Applied Mathematics Program, Yale University

Professional and Academic Societies:

Phi Beta Kappa, Sigma Xi, American Geophysical Union

Honors:

1959–1960	Guggenheim Fellow, International Institute of Meteorology, Stockholm
1963 (elected)	American Academy of Arts and Sciences
9/66 to 2/67	Guggenheim Fellow, International Institute of Meteorology, Stockholm
1966	M.A. (Hon.), Yale University
1975 (elected)	Fellow, American Geophysical Union

1/81 to 5/81	Senior Queen’s Fellow in Marine Sciences, Australia
1981 (elected)	Norwegian Academy of Science and Letters
1987	Alexander von Humboldt Prize, West Germany
1989	First recipient of the Robert L. and Bettie P. Cody Award in Ocean Science, Scripps Institution of Oceanography
1993	Distinguished Graduate Alumni citation for contributions to Applied Mathematics, Brown University
1994 (elected)	National Academy of Science
1997	DSC (Hon.), Lafayette College
1997	Henry Stommel Award (American Meteorological Society)
2008	AGU Award for Excellence in Geophysical Education to the GFD Program, Woods Hole Oceanographic Institution (Cofounder and continuing contributor)

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George Veronis

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