

Editorial

Personal Recollections on Jack Herring and Developments in Theory of Turbulence, Atmospheric Sciences, and Computational Fluid Dynamics

Boris Galperin ^{1,*}  and Semion Sukoriansky ^{2,*} 

¹ College of Marine Science, University of South Florida, St. Petersburg, FL 33701, USA

² Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel

* Correspondence: bgalperin@usf.edu (B.G.); semion@bgu.ac.il (S.S.)

The majority of articles in this Special Issue illuminate various aspects of Jack Herring's contributions to the theory of turbulence, atmospheric sciences, and computational fluid dynamics (CFD), be it through his publications, presentations, collaborations, work with colleagues and students, or personal contacts. Our (BG and SS) interactions with Jack took place mostly at meetings, conferences, and during visits to NCAR, particularly those organized under the auspices of the Geophysical Turbulence Program (GTP). These interactions were also both professional and personal. Jack was deeply interested in our progress with the development of the quasi-normal scale elimination (QNSE) theory, particularly after it expanded into anisotropic turbulence with dispersive waves excited under stable stratification or system rotation. These issues were discussed at length during Jack's visit to the Abdus Salam International Center for Theoretical Physics (ICTP) in Trieste, Italy, in August 2011, which was one of the last scientific conferences he attended. We shall come back to that conference later on.

To set up the background, we start with a recollection of our time at Princeton University, where BG was affiliated with the Program in Atmospheric and Oceanic Sciences, AOS/GFDL, and then with the Program in Applied and Computational Mathematics, PACM (1983–1989), while SS was affiliated with PACM during his entire stay (1989–1991). The PACM during that time was led by Steve Orszag and Andrew Majda.

Both of us were working on the development and implementation of theoretical and semi-empirical models of turbulence in different systems. BG's focus was on oceanic and atmospheric flows, while SS was concerned with engineering flows and magneto-hydrodynamics (MHD). Our collaboration was significantly enhanced by contributions from Ilya Staroselsky, who joined Orszag's group, coming from the Landau Institute of Theoretical Physics.

During that time, Steve Orszag and Victor Yakhot, who have just relocated to Princeton from MIT, were working on the renormalization group approach to turbulence theory, in particular its application to modeling and simulation of turbulent flows [1], and we joined that effort.

It should be noted that the application of the field-theoretical methods to turbulence started in Princeton much earlier. One of the most significant and far-reaching breakthroughs was the application of the quantum field theory methods, initiated by Robert Kraichnan around the 1950s. His interest in turbulence was stimulated by the search for highly nonlinear, particle-like solutions to unified field equations.

To put the narration in a proper frame, recall that Kraichnan's earliest studies, undertaken on his own starting at age 13, were in general relativity [2]. Reaching the age of 18, he wrote an insightful undergraduate thesis at MIT, *Quantum Theory of the Linear Gravitational Field*. In 1949, he earned a PhD in physics from MIT for his thesis, *Relativistic Scattering of Pseudoscalar Mesons by Nucleons*. His thesis advisor was Herman Feshbach. Upon graduation from MIT, he was accepted as an assistant to Albert Einstein at the Institute for Advanced Study in Princeton. The IAS has kindly provided to us Kraichnan's



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original application and two files (one from the Director's Office and one from the School of Mathematics/Natural Sciences of the IAS) that include the original correspondence from the Director of IAS Robert Oppenheimer and IAS staff confirming Robert Kraichnan's application, and then, later, referring to his work as a Research Assistant to Professor Einstein. The letter of acceptance, signed by Robert Oppenheimer, is shown in Figure 1. Kraichnan's work from that period has not lost of its breadth and significance, e.g., [3]. As a background reflecting these historic years of the interdisciplinary, breakthrough research in the quantum field theory, gravitation, and fluid turbulence, the photo in Figure 2 captures a moment of a vivid discussion between Albert Einstein and Robert Oppenheimer, the interaction that was one of the high points in the book [4] and the following up movie *Oppenheimer*.

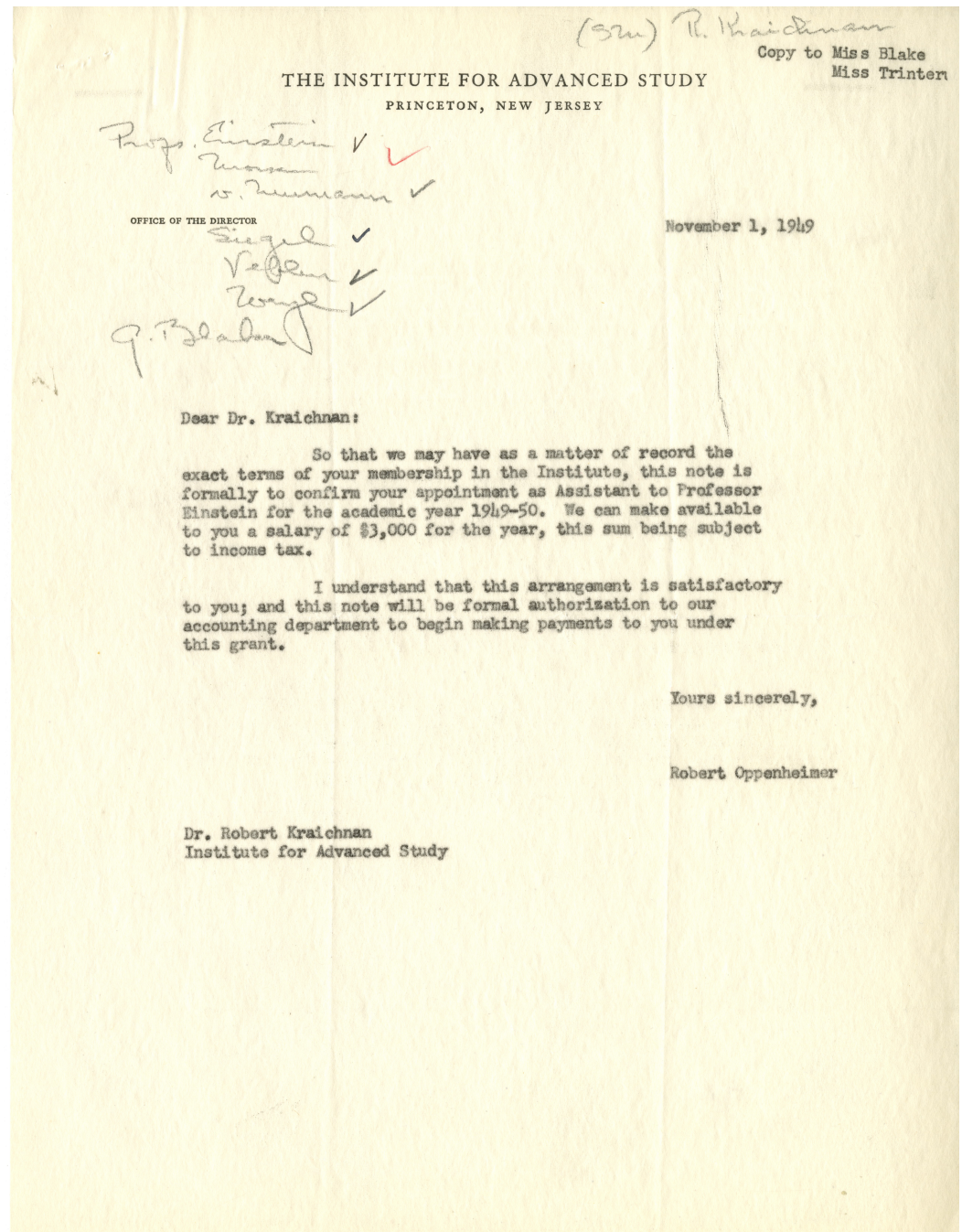


Figure 1. A letter of appointment of Robert H. Kraichnan as Assistant to Professor Einstein at the Institute for Advanced Study in Princeton.



Figure 2. Robert Oppenheimer with Albert Einstein in LIFE Magazine, 1947. Photograph by Alfred Eisenstaedt. Courtesy of LIFE Magazine, 1947, Time Inc. Copied from J. Robert Oppenheimer, *Uncommon Sense* (Birkhäuser Boston, 1984).

As documented in [2], in the early 1990s, Kraichnan wrote to Jack Herring, who was his close friend and colleague for many years, that he “realized I had no real idea of what I was doing and turned to Navier–Stokes as a nonlinear field problem where experiment could confront speculation. After initial surprise that turbulence did not succumb rapidly to field-theoretic attack, I have been trapped ever since. My overall research theme regarding turbulence has been to understand what aspects of turbulence can and cannot be described by statistical mechanics; that is, what characteristics follow from invariances, symmetries, and simple statistical measures, and what, in contrast, can be known only from experiment or detailed solution of the equations of motion. The principal tool I have used is the construction of a variety of stochastic dynamical systems that incorporate certain invariances and other dynamical properties of actual turbulence but whose statistics are exactly soluble. The similarities and differences between these model solutions and real turbulence help illuminate what is essential in turbulence dynamics. My interests have centered on isotropic Navier–Stokes and magnetohydrodynamic turbulence in two and three dimensions”.

The quest to find an analytical solution of Navier–Stokes equations and, thus, fully solve the problem of turbulence has remained one of the oldest and most famous challenges of classical physics for centuries. When Kraichnan started looking at turbulence, the community was trying to turn A.N. Kolmogorov’s 1941 ideas into a quantitative theory. However, it withstood attacks employing advanced statistical and perturbation methods borrowed from the quantum field theory and statistical mechanics [5]. In fact, Kraichnan was the first one to really make a difference in this endeavor, based on pioneering applications of the field theory methods of theoretical physics.

Further developments and Jack Herring’s contributions in this area are accounted for in two articles in this Special Issue [6,7]. Jack had many other interests in turbulence. One was turbulent convection, where he produced some pioneering results in the weakly nonlinear regime, both analytical and theoretical. These contributions are discussed in [8]. Jack had an abiding interest in the universality of small-scale turbulence. Professor Katepalli Sreenivasan of New York University fondly recalls Jack’s invitation in 1978, when he was still a post-doc at Johns Hopkins University, to attend a meeting at NCAR on small-

scale universality. He is grateful to Jack for providing the opportunity to interact with a number of stalwarts, such as Stan Corrsin, Bob Kraichnan, Uriel Frisch, Carl Gibson, Steve Orszag, Eric Siggia, and others, at that meeting, which also explored the implications of Kolmogorov's work to geophysical problems.

During approximately the same time period, 1946–1953, the Meteorology Group was established within the IAS. As cited in [9], “A project whose ultimate effects on weather forecasting may be revolutionary has been quietly under way during the past year (1946) in the academic surroundings of the Institute for Advanced Study, Princeton, New Jersey... In August 1946, a conference of meteorologists met in Princeton to discuss the project... Since last summer, work has gone forward in promising fashion, though it is still far too early to expect immediate, tangible results... The immediate aims of this group are the selection and mathematical formulation of meteorological problems to be solved by the electronic computer... the most interesting feature of the project is the effort being made to link the theory behind atmospheric processes with future weather”. Among the early major achievements of the group were the first numerical weather forecasts on the Electronic Numerical Integrator and Computer (ENIAC).

Short and long stays with the IAS of such prominent mathematicians and atmospheric scientists as John von Neumann, Julius Charney, Arnt Eliassen, Joseph Smagorinsky, Carl Gustav Rossby, Norman A. Phillips, and many others facilitated the IAS becoming the world leading center for the numerical weather prediction (NWP). In 1955, the U.S. Weather Bureau created a General Circulation Research Section (GCRS) under the direction of Joseph Smagorinsky, who continued the von Neumann/Charney computer modeling program based upon a 3D, global, primitive-equation model of the general circulation of the atmosphere. The GCRS was initially located in Suitland, Maryland, but in 1959, it was moved to Washington, D.C., and its name was changed to the General Circulation Research Laboratory. In 1963, the GCRL was renamed again, to become the Geophysical Fluid Dynamics Laboratory. In 1968, the GFDL settled at Princeton University's James Forrestal Campus under the National Oceanic and Atmospheric Administration (NOAA), where it remains. The first GFDL Director was Joseph Smagorinsky.

While recruiting the personnel, Smagorinsky followed several strict principles that he developed over the years [10]; among them were

- Personnel decisions are the most important actions taken.
- It is better to not fill a vacancy than to compromise quality; patience always pays off.

An example of these rules' effectiveness was revealed in 1959, when he invited Syukuro Manabe of the Tokyo NWP Group to join the GCRL. As described in [10], Smagorinsky recalled: “I had been reading some papers about Japanese scientists, came across two names that seemed to crop up time after time. One was Manabe, the other was Kikuro Miyakoda. The thing that intrigued me about Manabe's name is that it didn't so much appear on papers that he had written, but on papers that his colleagues had written where they were crediting him with some of the basic ideas... So I made him an offer... he came as a visitor... I couldn't offer him a permanent job, he was an alien. I needed again very special permission to hire a foreigner. It really probably had never been done, but that started a precedent”.

Manabe was assigned the task of coding and developing the General Circulation Model (GCM) of the atmosphere. Manabe's group had become one of the most vigorous and prominent GCM programs in the world. He retired in 1998. In 2021, he won a Nobel Prize in Physics for his work in climate modeling.

In the late 1950s to early 1960s, it was noticed that numerical simulations with the primitive equations of the atmospheric circulation produce numerical instabilities. To ameliorate the problem, Smagorinsky introduced a nonlinear viscosity [11]. This viscosity was adopted in many other areas of CFD, and became known as Smagorinsky's viscosity.

BG left Princeton in 1989 to assume a position at the University of South Florida (USF) in St. Petersburg, Florida. In 1990, he organized a conference entitled “Large Eddy Simulation (LES)—Where Do We Stand?” that intended to summarize developments in

various areas of CFD and outline directions of future research. At that time, LES was still to gain maturity, and this conference was one of the first in this area. One of the central issues were discussions and comparisons of various formulations of the nonlinear viscosity that were used in various LES schemes, and so the first presenter was Joseph Smagorinsky. He provided a historical perspective of his approach. By that time, he had retired from GFDL, and did not know about the strong impact his formulation had on the development of LES and CFD in general. After his talk, presenter after presenter was reporting on LES results with Smagorinsky's viscosity, and Smag (the name Joseph Smagorinsky was called at GFDL) was simply overwhelmed.

Jack Herring was one of the invited presenters at the conference and his lecture, co-authored with Robert Kerr, was on the contributions of two-point closures to LES, the topic that was going back to his collaborative research with Robert Kraichnan. The conference featured numerous exchanges between scientists working in different fields, and of course, Joe Smagorinsky and Jack Herring did not miss their chances to converse. Presentations and panel discussions at the conference were summarized in the book [12].

Over the following decades, our group has developed a spectral closure based upon [1] that was named Quasi-Normal Scale Elimination (QNSE). The basic technique of this closure was described in [13]. It was extended to flows with stable stratification [14], rotation [15], and magnetic field [16]. In 2008, SS visited NCAR to implement the QNSE scheme in the atmospheric model Weather Research and Forecasting (WRF). During the visit, he had many discussions with Jack Herring about the QNSE model and its performance for stably stratified turbulence.

During the following several years, our and Jack Herring's ways crossed with IAS again in a somewhat symbolic way. In 1964, largely due to the efforts of the Pakistani Nobel Prize winner theoretical physicist Abdus Salam, the International Center for Theoretical Physics (ICTP) was founded in Trieste, Italy. Robert Oppenheimer was the first Chairman of ICTP's Scientific Council. The first Council's meeting, chaired by Robert Oppenheimer, took place in May 1964 at the International Atomic Energy Agency (IAEA) Headquarters in Vienna. The meeting is pictured in Figure 3. From that meeting arose ICTP's scientific reputation and steadfast support for scientists from developing countries. In 1965, Robert Oppenheimer wrote: "It seems to me that the Centre has been successful in these eight or nine months of operation in three important ways. It has cultivated and produced admirable theoretical physics, making it one of the great foci for the development of fundamental understanding of the nature of matter. The Centre has obviously encouraged, stimulated and helped talented visitors from developing countries who, after rather long periods of silence, have begun to write and publish during their visit to the Centre in Trieste. This is true of physicists whom I know from Latin America, from the Middle East, from Eastern Europe, and from Asia. It is doubtless true of others. The Centre has become a focus for the most fruitful and serious collaboration between experts from the United States and those from the Soviet Union on the fundamental problems of the instability of plasmas, and of means for controlling it. Without the Centre in Trieste, it seems to me doubtful that this collaboration would have been initiated or continued. In all the work at the Centre of which I know, very high standards prevail. In less than a year it has become one of the leading institutions in an important, difficult and fundamental field" [17].

The ICTP building still features the Oppenheimer Meeting Room with a large portrait of Robert Oppenheimer on the wall.

Years later ICTP was headed by Katepalli Sreenivasan, who also developed close collaboration with both Robert Kraichnan and Jack Herring. He worked with Victor Yakhot on further development of the statistical theory of turbulence. The ICTP hosted many conferences in various areas of Physics, including Fluid Dynamics. Jack Herring, SS, and BG took part in one of these conferences in 2011. During one of the break days at the conference, he and BG planned to visit several historic landmarks around Trieste including the ruins of a Roman Amphitheater (Figure 4) and a beautiful synagogue built in Italian architectural style. Jack was very curious during the visit, asked many questions about the

history of Trieste and events during the WWII. After the visit, he said that he had learned a lot and was humbled by what he learned.



Figure 3. Abdus Salam, left, Paolo Budinich, second left, and Robert Oppenheimer, right, attend the first meeting of the ICTP Scientific Council at the IAEA Headquarters in Vienna in May 1964.



Figure 4. Jack Herring and Boris Galperin at the ruins of a Roman Amphitheater in Trieste while attending a conference at ICTP in August 2011.

Upon return to the US, he sent BG a message that spoke volumes about his human side and high moral standards:

9/4/2011, 7:18 PM
Dear Boris.

Thanks for the web site about the Jews in Trieste during the NAZI era. It is indeed a sad story. I looked up the quote from Rousseau about the Jews, and have copied it here:

The Jews, said Rousseau afford an astonishing speckle. The laws of Salon, Numa, and Lycurgus are dead those of Moses, much more ancient, continue to live. Athens, Sparta, and Rome have perished and left no offspring on the earth. But Zion destroyed, has not

lost her children, they are preserved, they multiply, they spread through out the world. They mingle with all peoples yet are not confused with them; they have no rulers, yet they are always a people. . . What must have been the force of a legislator capable of effecting such a marvel! Of all the systems of legislation now known to us, this one has undergone tests, has been steadfast.

In Masson, *La religion de Rousseau*, II, 240.

I did enjoy the conference, and thank you for including me.

Best, Jack

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