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**Article**

# Hans Ertel's life and his scientific work

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**Abstract**

Professor ERTEL was born on March 24, 1904. He died July 2, 1971. He lived and worked in Berlin. His scientific career began at the former Preußisches Meteorologisches Institut in Berlin. Here he was encouraged and intellectually formed by Professors Heinrich von FICKER and Albert DEFANT. He continued and completed many of the contributions made by the then leading theoretical meteorologist Felix EXNER, who lived in Vienna at that time. ERTEL developed into a very able theoretical physicist who became noticed in this field already when still a young man. In 1943 he became a full professor of meteorology and geophysics at the Universität Innsbruck, Austria, and in 1946 he became a full professor of geophysics at the Universität Berlin, since 1949 named Humboldt-Universität zu Berlin. In both instances he was the chairman of the respective departments. As a member of the Deutsche Akademie der Wissenschaften zu Berlin he founded and chaired in addition an Institut für Physikalische Hydrographie of that academy. From 1951 to 1961 he was vice-president of the academy. ERTEL was an excellent scientific teacher who set standards for his students scarcely found elsewhere. Many of the students of the 40s and later admired him not just as a teacher and superior scientist, but also as an amiable and generous human being. ERTEL was a very versatile scientist. He enriched the literature with important and very original contributions in fields such as meteorology, geophysics (narrowly understood), oceanography, physical hydrography, particle physics, cosmology, mathematics, and even philosophy of science. Up to 1948 he made scientific contributions particularly to problems concerning theoretical meteorology, which had not been fully recognized on an international level. He made a number of contributions (including the well-known vorticity theorem) between 1936 and 1948 long before they were newly discovered on an international level. From 1948 on, following the founding of the Institut für Physikalische Hydrographie in the Akademie der Wissenschaften, he devoted his effort to theoretical contributions, which were rather rare in physical hydrography (more than 60 papers). On the other hand, owing to his great expertise in mathematics and his rather rare visions in physics, he became an internationally recognized and leading theoretical hydrodynamicist. In this paper the life of Hans ERTEL is followed chronologically together with his papers, which at his time were at top level internationally.

**Zusammenfassung**

Professor Hans ERTEL, geboren 24.03.1904 und verstorben 02.07.1971, lebte und arbeitete in Berlin. Seine wissenschaftliche Karriere begann am früheren Preußischen Meteorologischen Institut, wo er durch Vertreter der österreichischen Schule der Meteorologie (Heinrich von FICKER und Albert DEFANT) geprägt und nachhaltig gefördert wurde. Die Arbeiten des damals noch in Wien lebenden Felix EXNER, führender theoretischer Meteorologe seiner Zeit, setzte er fort und vollendete viele davon. Früh entwickelte er sich zu einem fähigen theoretischen Physiker, der in diesem Fach schon als junger Mann durchaus wahrgenommen wurde. Die Position eines Ordinarius für Meteorologie und Geophysik erhielt er 1943 zuerst an der Universität Innsbruck und dann ab 1946 für Geophysik an der Universität Berlin (ab 1949 Humboldt-Universität zu Berlin), in beiden Fällen verbunden mit der Leitung eines zugehörigen Instituts. Als Mitglied der Deutschen Akademie der Wissenschaften zu Berlin (ab 1948) gründete und leitete er ab 1948 zusätzlich ein Institut für Physikalische Hydrographie dieser Akademie. Von 1951 bis 1961 war er Vizepräsident der Akademie. ERTEL war ein vorzüglicher akademischer Lehrer, der seinen Schülern Maßstäbe setzte, die sonst kaum zu finden waren. Die große Zahl seiner Schüler aus den 40er Jahren, sowie die späteren, verehrten in ihm nicht nur den Lehrer und ganz überragenden Wissenschaftler, sondern auch den sehr liebenswürdigen und großzügigen Menschen. ERTEL war ein sehr vielseitiger Wissenschaftler. Mit bedeutenden und stets sehr originellen Arbeiten bereicherte er die wissenschaftliche Literatur von Meteorologie, Geophysik (im engeren Sinne), Ozeanographie, Physikalische Hydrographie, Atomphysik, Kosmologie, Mathematik und sogar die der Naturphilosophie. Bis 1948 lieferte er insbesondere der theoretischen Meteorologie wissenschaftliche Beiträge zu Problemen, die bis dahin international oft noch nicht im Bewusstsein gewesen waren. Viele Beiträge zwischen 1936 und 1948, darunter der bekannte Wirbelsatz, gehören zu denjenigen Arbeiten, die oft lange vor internationalen Neuentdeckungen erschienen. Ab 1948, nach Gründung des Akademieinstituts, widmete er sich einerseits mit in diesem Fach seltenen theoretischen Beiträgen der Physikalischen Hydrographie (über 60 Arbeiten), andererseits entwickelte er sich mit seinem hohen mathematischen Können und seinem seltenen physikalischen Durchblick nun zu einem international sehr anerkannten theoretischen Hydrodynamiker. In der Arbeit wird die Lebenslinie Hans ERTELs nachgezeichnet und es werden diejenigen Arbeiten besprochen, die zu seiner Zeit zur internationalen Spitze gehörten.

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# 1 Vita Hans Richard MAx Ertel

**1904 (March 24)** Born in Cöpenick (later Berlin-Köpenick)

**1971 (July 2)** Died in Berlin

## 1.1 Education and predoctoral appointments

**1910–1918** Elementary school and school for teacher apprentices

**1918-1922** Teachers seminary

**1922–1923** The great inflation terminated his education as a teacher

**1922–1925** Bank employee in Berlin

**1925** Worker and assistant to a mechanical engineer in a Berlin factory

**1926–1929** Assistant to the librarian in the library of the Preußisches Meteorologisches Institut. Director was Professor Heinrich von FICKER. During these years he published his first four scientific papers.

**1929** Passing of a very difficult examination with high honours for admission to the university without having had high school education or any equivalent.

**1929** ERTEL studies mathematics, physics, meteorology, geophysics, oceanography, and philosophy at the Friedrich-Wilhelms-Universität zu Berlin. Prior to his Ph.D. thesis, he published another fifteen scientific papers.

**1932** He passed the Ph.D. examination with distinction. His dissertation was: "Theory of earth currents in soil with inhomogeneous conductivity which are caused by variations of the magnetic potential".

## 1.2 Postdoctoral appointments

**1932–1934** Scientist at the Meteorologisch-Magnetisches Observatorium Potsdam of the Preußisches Meteorologisches Institut

**1934–1937** Scientist and assistant at the newly founded Meteorologisches Institut der Universität Berlin. Director: Professor Heinrich von FICKER (FICKER left for Vienna in 1937)

**1935** Associate member at the institute

**1937** Participant, "International Project on Isentropic Analysis", Massachusetts Institute of Technology, Cambridge, Mass. USA

**1938** Lecturer in theoretical meteorology at the Meteorologisches Institut der Universität Berlin

**1941** Associate professor of theoretical meteorology at that institute

**1942–1943** Associate professor at the Zentralanstalt für Meteorologie und Geodynamik in Wien

**1943–1945** Professor of meteorology and geophysics at Leopold-Franzens-Universität Innsbruck and Director of the Institut für Meteorologie und Geophysik

**1945** Unofficial professor of meteorology und oceanography, in charge of the Meteorologisches Institut der Universität Berlin and the Institut und Museum für Meereskunde der Universität Berlin (both institutions were heavily damaged during the war)

**1946** Reopening of the Universität Berlin (from January 1949 named: Humboldt-Universität zu Berlin)

**1946** Professor of geophysics and director of a newly founded Institut für Meteorologie und Geophysik der Humboldt-Universität zu Berlin (January 1947)

**1948** Founder and the first director of the Institut für Physikalische Hydrographie of the Deutsche Akademie der Wissenschaften zu Berlin

**1949** Full member of the Deutsche Akademie der Wissenschaften zu Berlin

**1951–1961** Vice-president of that academy

**1955** Member of Deutsche Akademie der Naturforscher, Leopoldina (Halle)

**1956** Corresponding associate member of the Österreichische Akademie der Wissenschaften (Wien)

**1957** Member of Kungl. Vetenskaps Societeten Uppsala

**1960** Professor of geophysics *and* theoretical mechanics at the Humboldt-Universität zu Berlin

**1962** Professor emeritus at the Humboldt-Universität zu Berlin

**1969** Professor emeritus at the Institut für Physikalische Hydrographie of the Deutsche Akademie der Wissenschaften zu Berlin

**1971** ERTEL died in Berlin

## 2 Hans Ertel's life and his scientific work[1]

### 2.1 Education and pre doctoral appointments 1904–1932

Hans ERTEL[2] was born on March 24, 1904, in the town of Cöpenick that later became the suburb Berlin-Köpenick of Greater Berlin. His father was a wood turner; the family was middle-class. When he was nine, his parents separated. He got a stepmother who turned his youth into a rather unhappy period of his life.

School education in those days had three branches. More than 90 per cent of the children went to the public school from age 6 to 14. Higher education was given at schools (called gymnasium) for selected children from age 10 to 18 where Greek and Latin were main subjects. Hans ERTEL wanted to become a teacher and future teachers for children from age 6 to 14 were trained in a special portion of the third branch of education. They received special training between age 10 and 18 in some sense at a similar high level as at gymnasia. Their main subject of education was spoken and written German. Furthermore, education in music, drawing, arithmetic, natural sciences, geography, and sports was important for these candidates.

Hans ERTEL was a brilliant pupil in all of these fields during his teacher training school courses, except in sports. His later scientific publications are masterpieces in precise and concise formulation of complicated subjects. His education as a teacher ended as a result of the great inflation (1922/1923). His parents became unable to finance the final phase of his education as a teacher. His high expertise in mathematics led him to the job as a bank employee in March 1922. Soon he became a successful young banker. During this time, he took a long holiday and went to Finland as a hiker. He came home with a large number of watercolour paintings. It is not known why he discontinued this job and then worked in a factory. In one of his documents he described this job in the factory as that of an engineer.

Since he did not want this kind of job to be his final goal he looked for other jobs and found an announcement of the Preußisches Meteorologisches Institut (Berlin): They were looking for a technical draftsman. ERTEL took his Finland paintings to the director of that institute, Professor Heinrich von FICKER, and applied for that job. Although he was not a suitable candidate, FICKER employed the young man as someone to assist him for calculations and in the library.

ERTEL's new career in the library of the institute began in June 1926. He used the books he had access to for reading and learning. Soon he was able to help students of meteorology in mathematics when they worked in the library. Early in 1928 he presented to his director his first scientific manuscript (**1**)[3]: "Heat conduction and quasi-static atmospheric change of state". This paper, written in 1927, shows that he already was able to use the basic concepts of hydrodynamics and thermodynamics to give an answer to a problem in theoretical meteorology. Beyond this he knew the latest papers on the subject of his own paper. It is certain that he had read and understood EXNER's book, EXNER (1925). Scientific level and style of presentation in that paper were already as perfect as all of his later papers. The director, a well-known meteorologist, did not understand ERTEL's paper. So, he consulted his colleague Professor Albert DEFANT, a theoretician in meteorology and oceanography. From that day on, both FICKER and DEFANT emphatically supported ERTEL. First of all he was admitted to the university after having passed brilliantly a very rigid examination. Prior to his admission to the university he additionally had published three more papers. (**2**): "On the energetics of an atmospheric air column". This paper was closely connected to one of ROSSBY's early works. Paper (**4**) was his first paper on a problem in atmospheric turbulence. ERTEL especially evaluated EXNER's work very high. In 1943/44 he prepared a new edition of EXNER's book. Due to the circumstances at that time the new edition could not be printed.

On April 20, 1929 ERTEL became a student of mathematics, physics, meteorology, geophysics, oceanography, and philosophy at the Friedrich-Wilhelms-Universität zu Berlin. At this time this university was one of the leading universities worldwide especially in natural sciences. ERTEL told the present author that he had rarely attended the lectures, even those of the most famous professors. He just looked in to see how far the lecture had gone. This was even the case when Albert EINSTEIN gave one of his few lectures: ERTEL already knew EINSTEIN's theory. This style of study allowed him to work more on scientific projects.

During his six semesters (three years) of study at the university he published fifteen papers: From (**5**): "Theoretical proof of some of Guilbert's rules" to (**19**): "On the theory of electric earth currents". These papers covered a wide range of geophysical problems. Problems in atmospheric turbulence attracted him from the beginning of his scientific work. We already mentioned (**4**). Further papers were (**7**):"Eddy diffusivity and fluctuation velocities", (**8**): "Theory of Maxwellian distribution of eddy

[1] See also the obituary MAUERSBERGER (1971).

[2] The present author owns a complete collection of ERTEL's papers. A second collection can be found in the library of the Meteorologisches Institut der Freien Universität Berlin. Publications on ERTEL's life and his work are contained in SCHRÖDER, 1991, 2000, 2001; SCHRÖDER and TREDER, 1993, 1995, 1997, 1998.

[3] Papers of ERTEL are cited in the present article according to the consecutive numbers of the *Kobe Register*. The *Kobe Register* is completely reprinted in this issue. Kobe Register. – Meteorol. Z. **13**, 577–589.

velocities", where he applied his knowledge of statistical mechanics, and (**9**): "Vertical distribution of pressure in turbulent flow". Paper (**13**): "On the circulation of eddy velocities in incompressible fluids" is very remarkable. ERTEL shows that the circulation of the eddy velocity in a turbulent fluid can be a preserved structure if the material line of integration is identical with the vortex line of the mean 3D-vortex. Today we would call this: "Preserved structures in chaos". In (**16**): "Theory of atmospheric turbulence" ERTEL, among other results, shows that in three dimensions the distribution function of eddy velocities is not Maxwellian. This paper is written in tensor notation and is especially remarkable because ERTEL wrote it as a student in his first semesters.

The papers (**10**) and (**12**) "On the curvature of three-dimensional discontinuities in atmosphere and ocean" were quite original extensions of the well-known MARGULES formulae for the conditions at a plane sloping surface of discontinuity. They showed that the young student had reached a very high degree of mathematical skill (Ricci-Calculus). Additionally, ERTEL wrote two papers on continental drift following Alfred WEGENER's latest papers on that subject: (**14**), and (**15**), later again (**26**) and (**49**).

ERTEL endeavoured to support scientifically the ideas and the work of his teacher and patron Professor von FICKER. Still in 1930/31, there were controversial discussions between the Austrian school of meteorology and the Norwegian one on the role of the upper atmosphere (stratosphere) in forecasting weather in the troposphere. In (**11**), (1931), "The influence of the stratosphere on weather in the troposphere", the student of meteorology remarks: "Dynamics of the atmosphere takes place in the upper atmosphere. Within the troposphere the physics of weather is important".

In connection with the thesis of his Ph.D. dissertation ERTEL got interested in the problem of electric earth currents as a result of magnetic variations (**19**). Julius BARTELS, a well-known geophysicist, initiated his thesis (**20**) in that field: "Theory of earth currents in soil with inhomogeneous conductivity which are caused by variations of the magnetic potential". In this dissertation on a problem in geophysical electrodynamics, ERTEL formulated the problem in spherical coordinates, developed an integro-differential equation for the solution of the problem, and solved this equation by means of multipol-potentials. This remarkable dissertation was written during his last (seventh) semester in summer 1932. In later years, ERTEL again published very readable papers in geophysics: (**98**), (**113**), (**130**), (**134**), and (**137**). It should be added that ERTEL also worked as a reviewer for scientific journals during these years at the university. Between 1931 and 1933 he reviewed more than 80 papers.

## 2.2 Postdoctoral appointments 1932–1945 in Berlin, Vienna and Innsbruck

Even before leaving the university, ERTEL accepted a permanent job at the Meteorologisch-Magnetisches Observatorium Potsdam that was part of the Preußisches Meteorologisches Institut and was directed by its director Professor von FICKER. ERTEL had no routine obligations of observing meteorological parameters. Instead, he was able to pursue challenging scientific work almost undisturbed. From October 1932 to the end of May 1934 he published 25 papers.

It is important to notice that six of these early papers were presented to and published by the then famous Preußische Akademie der Wissenschaften (Berlin). These are the papers: (**28**): "General theory of eddy stress and eddy flux", where he discusses various representations of Reynolds' stress and where he derived that version, that is used nowadays, (**29**): "A new proof of V. BJERKNES's circulation theorem", a very elegant proof of this theorem on the basis of Lagrangian equations of second kind, (**30**): "The variation principle of atmospheric dynamics", where he extends HAMILTON's principle and derives a variation principle including thermodynamics of the atmosphere, (**31**): "Free oscillations in lakes of arbitrary shape", (**32**): "Generalization of a DEFANT-theorem on streamlines and trajectories", and (**33**): "Integration of the hydrodynamic equations for incompressible fluids by means of HEAVISIDE's operational calculus". The latter paper was written at that time when the Norwegian school of meteorology concentrated on the system of linear perturbation equations. ERTEL made an attempt to find general solutions of the same system of equations by applying the elegant operational calculus of O. HEAVISIDE. Later presented papers to the academy were (**46**): "EINSTEIN's cosmological constant", (**59**): "Pressure change and singularities of the field of momentum-density", (**82**): "On a general variation principle of hydrodynamics", where the atmospheric variation principle is formulated in Lagrangian version of hydrodynamics, and (**83**): "Perturbations of ocean salinity, which are caused by precipitation, are levelled out by turbulence". At that time Professor von FICKER was secretary of the section physics and mathematics of that academy.

Going back to the year 1932, ERTEL again wrote papers on atmospheric turbulence and boundary layer theory: (**23**): "Coefficient of eddy viscosity and vertical profile of temperature", (**40**): "Mean eddy fluctuations and eddy flux", (**41**): "Proof of Wilhelm SCHMIDT's theorem on the interrelationship between mean wind structure and eddy stress, valid in the boundary layer", and (**45**): "Integration of EKMAN's equations for atmosphere and ocean allowing variable Reynolds stress". In paper (**66**): "Tensor theory of turbulence", ERTEL showed that

turbulent exchange should be described by a symmetrical tensor if one intends to cover all applications known at this time.

In support of FICKER's work he wrote the paper (**25**): "On the energetic influence of stratospheric pressure change on the troposphere". An interesting paper is (**37**): "Thermodynamic founding of criteria for atmospheric static stability". The known criteria are derived on the basis of the entropy equation. His derivation easily can be extended to cases where heat flux and entropy production interact.

Beginning in 1933, ERTEL wrote several articles on atmospheric variation principles, which belong to the field of geophysical hydrodynamics. He argued that approximate methods in the calculus of variations (method of W. RITZ) could be useful in solving the non-linear equations of geophysical hydrodynamics: (**30**): already mentioned, (**39**): a version of (**30**), and later (**79**): "A general variation principle of atmospheric dynamics". This was ERTEL's most general formulation of the variation principle in connection with HAMILTON's principle, (**82**): see above. Other papers during this time and in later periods of his life show that his interests covered a large range of fields in natural sciences.

In 1934, the Preußisches Meteorologisches Institut was reorganized. The weather service was attached to the Reichswetterdienst, and the scientific part of the institute formed a newly founded Institut für Meteorologie der Universität Berlin. Professor von FICKER became the director of the new university institute. At the same time the Friedrich-Wilhelms-Universität zu Berlin was named Universität Berlin.

At the new institute, in the same place where the former Preußisches Meteorologisches Institut was located (it was the building of the famous academy for construction (Bauakademie), a masterpiece of K. F. SCHINKEL), ERTEL must have had an academic life that he always liked the most. He was progressively promoted (assistant, June 1, 1934, lecturer in theoretical meteorology, November 30, 1938, and associate professor, March 12, 1941), the load of teaching was moderate, and time for scientific work must have been ample.

Between 1934 and 1939, ERTEL was very much interested in contemporary problems of physics. He published papers in journals of physics: (**42**): "On the motion of electrons in magnetic fields", (**46**): "On EINSTEIN's cosmological constant and the connections between atomic and cosmological constants". He carried this concept to an expanding universe (**52**), as well as to EINSTEIN's field equations (**53**). More papers in this field, including cosmology, were (**54**), (**56**), (**57**), (**58**), (**70**), (**72**), (**73**), (**75**), and (**271**). Some of these papers "by a young physicist (meteorologist)" were mentioned in a fundamental work of these days BAVING (1944). The young meteorologist became noticed in the field of theoretical physics. Besides this, the publication of papers in theoretical meteorology continued.

A number of papers published between 1935 and 1939 were devoted to the theory of pressure change caused by advection. The first one of this series of papers, (**48**): "Calculating advection", (a correction of ROSSBY's general theory of advection) was written together with the Chinese meteorologist Sjan-zsi LI. Prior to World War II the institute frequently had guests from the Far East. ERTEL loved the polite and reserved manner of these people as they corresponded to his own way of dealing with people. The following papers (**51**), and (**60**) with the same title: "Advective-dynamical theory of pressure changes and its periodicities" were the first papers on two-dimensional advective-dynamical theory. These were important papers in as far as ERTEL integrated dynamical equations on the sphere which were reduced versions of equations derived later during times when the vorticity equation formed the basis of (barotropic) prediction equations. He used an equation containing the Laplacian of pressure tendency and a term that later (1939) became known as the Rossby-term ($\beta$-term). The remaining non-linear dynamic momentum-terms were called by ERTEL advective-dynamical perturbation terms and were taken as the inhomogeneous right hand side of the equation. The resulting equation, including the $\beta$-term, then was solved in spherical coordinates. Later papers were (**55**): "The mechanism of atmospheric pressure changes", and (**59**), (**61**), (**63**), and (**64**), generally speaking, "On singular advection". The possibility of pressure changes at a moving sharp surface of discontinuity, first mentioned by SHAW, BRUNT (1952), led ERTEL to work out this idea. These papers are interesting with regard to the mathematical skill applied. With regard to prediction of pressure changes, however, progress in pressure forecasting by this effect certainly could not be expected. Related papers are (**80**) and (**81**). In (**62**): "Divergence of flow and change of pressure", ERTEL gave an explanation of SCHERHAG's so-called "Theory of divergence". The paper (**65**): "Types of discontinuities at the tropopause" is a remarkable paper in as far as for the first time ERTEL transformed the system of equations into time dependent curvilinear coordinates.

In 1937, ERTEL wrote another interesting paper in physics: (**68**): "The hydrodynamic version of wave-mechanics". In this paper he transformed SCHRÖDINGER's relativistic equation of wave mechanics such that a close analogy to the system of hydrodynamic equations resulted. Again, he hoped to apply methods of solution from wave mechanics to hydrodynamics. This paper, a real masterpiece in theory, shows that ERTEL was a full-scale theoretical physicist.

In 1937 he attended an international workshop on

isentropic analysis at Massachusetts Institute of Technology (Cambridge, Mass. USA) where he met C.-G. ROSSBY. His book "Methoden und Probleme der Dynamischen Meteorologie" (**69**) (translated later as "Methods and Problems of Dynamic Meteorology") was completed while he was there. This book was followed in 1939 by his article "Die theoretischen Grundlagen der dynamischen Meteorologie", (**74**), that was part of volume V of the "Meteorologisches Taschenbuch", edited by LINKE (1939). The book as well as the article in the handbook, are extremely valuable to the theoretician even in present times. Consequently, the book (**69**) was reprinted in 1972.

In 1937 Professor von FICKER left Berlin and became director of the Zentralanstalt für Meteorologie und Geodynamik in Vienna. ERTEL lost a trusted friend and mentor. ERTEL was quite individualistic and he could not adapt to the political conditions of that time. Thus, in 1942, he followed FICKER to Vienna where matters were not quite as suppressive as in Berlin. Also, at this time there was heavy strain resulting from bombing raids against Berlin. So far, there was none of that in Vienna.

The outbreak of World War II changed the professional life of ERTEL and also the subjects of his scientific interests. During the war he published his most important papers in theoretical meteorology. The paper (**76**): "Prae-canonic version of the hydrodynamic equations and variation principles of atmospheric dynamics" opened an important series of papers in geophysical hydrodynamics. Papers on problems in general meteorology followed. In (**77**): "Thermodynamic proof of RICHARDSON's criterion for the onset of turbulence", ERTEL gave a new proof of RICHARDSON's criterion in turbulence theory and calculated the production of entropy connected with the onset of turbulence. Further papers, written just before the beginning of World War II were (**78**), (**80**) on advection, and (**81**). The latter paper was his final formulation on singular advection, followed by the already mentioned papers on variation principles. Particularly noteworthy is ERTEL's publication of a book on HEAVISIDE's operator calculus during that period, featuring very interesting applications to linearized problems in geophysics (**84**). This book grew out of lectures on mathematical tools for meteorologists (1939).

Beginning with the early months of 1940, ERTEL had to teach air force and navy students physics and meteorology. In Germany these students were given a complete college education in meteorology. Following the studies in eight trimesters within 2 and 1/2 years (equivalent to eight semesters within four years in our days), they received a master degree in meteorology. The first program of this kind ran from April 1940 to the end of 1942 and included about 160 students; the second program from August 1941 to the end of 1943 included about 300 students. The basic education was given at various German universities; the final stage of studies for all of the students took place at the Universität Berlin where ERTEL was teaching. In comparison, in the USA more than the tenfold number of air force and navy students were trained in meteorology for only 9 months, primarily in the preparation of weather maps and in learning techniques for forecasting. At MIT alone there were at times 500 students of this kind, HAURWITZ (1985), LINDZEN et al. (1990).

Without any doubt, ERTEL was prominent among the professors involved in this program, as far as high quality teaching was concerned. Presumably this was the reason that he did not get drafted into the military. ERTEL was able to teach very successfully in a wide area of fields: In mathematics, theoretical physics, and in theoretical meteorology. In 1940 he taught primarily differential and integral calculus as well as an introduction in theoretical physics. In 1941 he taught not only regular and partial differential equations in physics and geophysics, but also full courses in mechanics, hydromechanics, thermodynamics, theory of electricity and magnetism, all included in a complete course in theoretical meteorology. Ten hours of lectures per week was his regular teaching curriculum. Prior to his move to Vienna in June 1942 he completed his main teaching program in Berlin with lectures on modern problems of dynamic meteorology and about graphic methods in this field. Later, when he was in Vienna (1942) and in Innsbruck (1943/45), he still had some teaching obligations in Berlin.

During this period of strenuous teaching workload, he still made some of his most important contributions to theoretical meteorology. In 1940/41 he wrestled with the problem of forecasting atmospheric pressure on the basis of the quasi-geostrophic version of the dynamical equations: (**86**): "New atmospheric equations of motion and the theory of cyclone-motion", and (**87**), a correction of (**86**). In chapter 11 of the J. CHARNEY memorial volume, LINDZEN et al. (1990), N. A. PHILLIPS describes "The Emergence of Quasi-Geostrophic Theory". His part 2.6 is devoted to ERTEL's contributions to this theory. In that review PHILLIPS gives not much credit to ERTEL's work. Towards the end of the paper he criticizes ERTEL: "...ERTEL's writing style in these papers, in which there is little or no appeal to observation, and primary emphasis is placed on duplicating ROSSBY's frequency formulas" (what certainly was not ERTEL's primary emphasis). However, he positively remarks: "(ERTEL's) result is equivalent to the non-linear equation for the advection of vorticity in a non-divergent model. This is the same forecast model as would be used in the first numerical forecasts with an electronic computer CHARNEY et al. (1950)". Regrettably, PHILLIPS

did not mention that ERTEL's perturbation equation (60) in (**86**), including the $\beta$-term and Rossby's deformation radius, is equivalent to CHARNEY's equation (58a) in CHARNEY (1948). In paper (**87**) (equation (10)), ERTEL already obtained the two-dimensional non-linear vorticity equation including the $\beta$-term formulated for pressure. ERTEL seems to deserve the credit for deriving this type of approximation of the dynamical equations.

Comparable basic works in theoretical meteorology, such as ERTEL's fundamental ones during the period 1940 to 1944, are rarely found in western meteorological literature during this period. Except the only paper on potential vorticity, almost all of these papers virtually remained unknown up to now. In paper (**85**): "On the stability of zonal atmospheric circulation" he investigated the stability of the zonal circulation of the atmosphere in Lagrangian coordinates. At that time this was a singular paper in theoretical meteorology. The paper (**88**): "On the individual change of temperature lapse rate in the atmosphere" is an interesting generalization of a famous MARGULES formula for lapse rate changes by vertical motion. Here ERTEL uses isentropic coordinates in the equation of continuity. The following papers were devoted to the problem of weather prediction for limited areas of the earth, (**89**), (**109**) and later (**116**). These papers were fundamental in those days, SCHRÖDER and TREDER (1995). ERTEL states the now accepted fact that theoretical weather predictions are possible only if the whole earth is taken into account. According to CHARNEY, CHARNEY (1949), this statement was only "formally correct"at this time. Later, ERTELs statement became important in relation to long-range forecasts. The paper (**90**): "Tensor theory of stability" combines almost all criteria of stability, from the hydrostatic one to the one of the zonal circulation. At this point we mention a series of papers on turbulent transfer of heat published between 1942 and 1954: (**94**), (**102**), (**106**), (**107**), and finally (**128**): "Statistical thermodynamics of the vertical lapse rate of temperature in the atmosphere". See also BERNHARDT (1974). These papers were contributions to the then ongoing discussion on Wilhelm SCHMIDTs paradox (i.e. in case of stable stratification the eddy heat flux is directed towards higher temperatures (downwards)). Even Ludwig PRANDTL contributed to this discussion. In his 1943-paper (**101**): "Wind divergence on isobaric surfaces and change of pressure", ERTEL for the first time uses a general time dependent vertical coordinate and presents his first commutation relationship. Naturally, he introduces pressure as a special time dependent vertical coordinate and formulates the equation of continuity in this so-called p-system (1943). In paper (**105**): "The westerlies of the troposphere as zones of instability" he touched an important problem of those days. Papers on the thermodynamic efficiency of the atmosphere, (**97**), and (**117**), are very original treatments of that problem, giving reasonable results. A singular paper regarding the most general solution of the vorticity equation for non-divergent barotropic and steady state flows was the paper (**104**): "Steady oscillatory air currents on the rotating earth". ERTEL's solution for non-steady flows is mentioned only as an appendix in KOCHIN, et al. (1964). ROCHAS, ROCHAS (1984); ROCHAS (1986); ROCHAS (1993), explored this fact. He gives full credit to this work of ERTEL in as far as ERTEL really had found the most general solution to the problem. ERTEL's paper on the basic set of equations for turbulent flow (**103**): "Basic hydro-thermodynamic equations for turbulent flows", 1943, is another fundamental paper. The paper contains the full set of equations for turbulent flows including for the first time the equation for turbulent kinetic energy. Another paper, written in 1944 and published in 1946 (**111**): "Thermal and potential energy of atmospheric centres of action" deals with the thermal and potential energy of large atmospheric centres of action (highs, lows). ERTEL shows that these energies can be calculated from the knowledge of the surface pressure only. That paper almost was ERTEL's last paper devoted to problems in meteorology. He certainly had the feeling that there was virtually no audience for his theoretical work in German meteorology. That there was none in the western scientific community that was on account of the onset of World War II in 1939 and the following turbulent years.

Among ERTEL's papers from the year 1942, those stand out which are devoted to ERTEL's potential vorticity (**92**), (**93**), (**95**) and (**96**). This group of ERTEL's papers and additional ones in geophysical hydrodynamics were translated into English, SCHUBERT et al. (2004). These papers made ERTEL known internationally. The term "ERTEL's potential vorticity" is used quite often without giving reference to ERTEL's original paper of 1942 (the same is true with respect to the EULERian equations of motion). Much has been written on these papers of ERTEL. We mention here SCHRÖDER and TREDER (1993); SCHRÖDER and TREDER (1997). With regard to the previously discussed papers (**60**), (**86**), (**87**), (**89**), (**109**), and (**116**), K.-H. BERNHARDT selected these papers and comprehensively furnished them with commentary in the publication of SCHRÖDER and TREDER (1995).

Closing this section, more about ERTEL's professional positions. From June 1, 1942 to April 1, 1943 he worked as a professor of theoretical meteorology at the university of Vienna and also at the Zentralanstalt für Meteorologie und Geodynamik. Here in Vienna, ERTEL again worked together with his friend and mentor Professor von FICKER who was Director of the Zentralanstalt since 1937. In April 1943, ERTEL became a full professor of meteorology and geophysics at the Universität Innsbruck and the director of the Institut für

Meteorologie und Geophysik of that university. During the two years in Innsbruck he still had teaching obligations in Berlin. After World War II, he was expelled from Austria as a German and returned to Berlin, probably in rather adventurous ways.

## 2.3 Appointments 1946–1971 in Berlin

Back in Berlin, ERTEL faced a situation where the buildings of the Meteorologisches Institut der Universität Berlin and also that of Meereskunde, including the attached museum, were heavily damaged. Shortly prior to the reopening of the Universität Berlin (January 29, 1946), at the end of December 1945, ERTEL became director of the latter institute. Its former director, the Austrian born Professor Albert DEFANT, had left for Innsbruck where he got the chair at the university that ERTEL had left a few weeks earlier. ERTEL gave his first lectures in the building of the Institut für Meereskunde at the beginning of 1946. A few of his former students from the 1940/43 period joined ERTEL at this time and so he began his post-war career back in Berlin.

On November 7, 1946 ERTEL became full professor of geophysics and director of the newly founded Institut für Meteorologie und Geophysik. The building of the Institut für Meereskunde was closed at the end of 1946. Fortunately, in spring 1947 the new Institut für Meteorologie und Geophysik was established in a wooden house surrounded by the trees of the experimental fruit orchard of the Technische Hochschule Berlin located in the Berlin-Dahlem suburb. During World War II, this building was the home of the cosmic ray research group of the university. The institute was very small: the professor, one or two assistants, and a mechanic. From January 1946 through 1962 Dr. Gertrud KOBE (1905–1995), a former assistant of the oceanographer Professor Albert DEFANT, acted as vice-director of the institute. The mentioned few former students from wartimes formed a small research group in a building nearby. Astonishingly, ERTEL had managed to save the most valuable books and some series of journals from the almost devastated former Institut für Meteorologie.

Apart from the extremely poor living conditions of that time, from spring 1947 to summer 1949, ERTEL must have had his happiest days as a professor. He had a permanent job, he had a small number of students, moderate-teaching obligations, and he was free to do interesting research of his own. When the present author became a graduate student of ERTEL early in 1949, he became also a member of a "family". ERTEL, at this time at the age of 45 years, was the ideal type of a professor. He was always very friendly to everyone, especially to his students. He was extraordinarily generous and he had a sparkling humour. He enjoyed life and he was very optimistic. Owing to this attitude, he was sometimes unable to distinguish between kindness and falseness of people who came to him. However, he took great interest in all of his students, considering them as his future colleagues. He even addressed the students as "Herr Kollege". If help of any kind was required, ERTEL was always ready for it. As in his former days as an academic teacher, he was the ideal teacher one could think of. The subjects taught by him in these days and later, when the institute had to move to another place, were theoretical meteorology and theoretical geophysics. Here he taught in a style that was that of a theoretical physicist. It was fun to attend ERTEL's lectures (especially for students who continued to study theoretical physics, as the present author did). On the other hand, it was challenging to attend his seminars. As a sign of his generosity, we mention that he brought cigars for the boys and chocolates for the girls. Even smoking was allowed while making a presentation chosen by ERTEL. Once this author had to present one of ROSSBY's papers: "On the Dispersion of Planetary Waves in a Barotropic Atmosphere", Tellus, Vol. 1, Nr. 1, 1949. Planetary waves, however, were not treated in ERTEL's lectures so far. ERTEL simply expected that the student had the ability to read and understand the actual literature in meteorology (as was the case with him when he was a student). It was a hard job to attend ERTEL's seminars. When students reached the time for getting a master or dissertation thesis, ERTEL gave a small sheet of paper with his idea and with suggestions how to begin research. That was all, he expected the student to work on his own. The same was true with his assistants. They knew what their obligations were and ERTEL expected this without discussion. Otherwise they were absolutely free concerning the style and the content of their lectures and their scientific work. Between 1952 and 1957, ERTEL often presented his manuscripts to his assistants for review before publication: They never had an idea how to improve his manuscripts! ERTEL was the ideal director of an (small) institute. As the vice-president of the Deutsche Akademie der Wissenschaften zu Berlin between 1951 and 1961, ERTEL showed great leadership capacity nationally as well as internationally.

In 1948, ERTEL was invited to Sweden. Between May and the end of October he was a guest of Professor Hilding KÖHLER in Uppsala. At this time ERTEL also met ROSSBY again, probably in Stockholm. The result of this cooperation with his Swedish colleagues were four papers, two together with KÖHLER, (**117**), (**119**) and two papers together with ROSSBY, (**120**), (**121**). Comments on these papers are given in connection with ERTEL's papers in geophysical hydrodynamics, SCHRÖDER and TREDER (1993); SCHRÖDER and TREDER (1997).

Apart from these papers, ERTEL was interested in the construction of trajectories in hydrodynamics (**114**), (**115**), (**118**), and later (**264**). He certainly had

manuscripts of that kind left from his times as a meteorologist. The same is true for one of his last meteorological papers (**116**) (written in 1944!): "The problem of weather forecasting in theoretical meteorology" where he discusses the problem of weather prediction viewed by a theoretical meteorologist. Here he discusses again the Bjerknes-program (1904) and stresses the fact that only global weather predictions are feasible in the future.

In December 1948, the Freie Universität Berlin was founded in West Berlin. Now, there was a Universität Berlin and a Freie (Free) Universität Berlin. This led to the renaming of the Universität Berlin, located in East Berlin, to Humboldt-Universität zu Berlin in January 1949. This change in the university-structure of Greater Berlin had serious consequences for all those institutes of the Humboldt-Universität that were located in West Berlin: The Western Allied Forces confiscated these institutes during the first months of 1949 and transferred them to the newly founded Freie Universität Berlin (how all this happened is not known to the author). ERTEL's institute was among those confiscated. Due to his personal circumstances, he lived most of his time in his office. One day he found his institute blocked with all his personal and scientific belongings inside. It is not clear whether ERTEL had been offered a professorship at the Freie Universität Berlin early in 1949. Anyway, ERTEL decided to stay as a professor at the Humboldt-Universität in East Berlin. This decision was certainly based on the fact that he already had founded the Institut für Physikalische Hydrographie as an institute of the Deutsche Akademie der Wissenschaften zu Berlin on April 1, 1948. In addition, he had become a full member of that academy on March 25, 1949, shortly before his institute in West Berlin was confiscated. ERTEL managed to retrieve not only his personal belongings but also the main part of the library. Meanwhile a new home for the institute was found in East Berlin. It was a villa at the big lake Müggelsee in the Berlin-Friedrichshagen suburb. This again was a lovely place to work for the members of the institute and to study for the students. Two former students from the wartime courses, Dr. Helmut GRIESSEIER, and Dr. Hans-Peter SCHMITZ helped ERTEL to build up the new institute. In addition they eased ERTEL's teaching burden when he increasingly became engaged within the academy. They were now members of the newly founded Institut für Physikalische Hydrographie. The university institute still was very small: the professor, an assistant acting as vice-director (Dr. Gertrud KOBE), one second assistant, one person for both the secretary office and the library, one mechanic, a maintenance person, and a cleaning lady. In 1951/52 the present author became assistant next to the vice-director Dr. KOBE. Soon thereafter, the later well-known theoretical geophysicist Dr. Peter MAUERSBERGER filled an additional assistant position. MAUERSBERGER became responsible for theoretical geophysics, the present author for theoretical meteorology. To complete the full course of lectures in meteorology and geophysics, a number of high ranked meteorologists and geophysicists out of the Greater Berlin region were engaged.

In those days there was no fund raising for research at all and therefore, there was very little administration. Nevertheless, the assistants were obliged from time to time to work in the secretary's office and learn how to run a university institute. During the period between 1948 and 1957, when the present author stayed at the institute, ERTEL had a number of famous visitors: FICKER, ROSSBY, even J. CHARNEY (1948?), and other colleagues of him. The present author remembers with pleasure these visits where the students came in personal contact especially with FICKER and ROSSBY in 1949/50.

C.-G. ROSSBY was the highly honoured teacher of the first generation of US theoretical meteorologists after World War II. According to BOLIN, BOLIN (1957), ROSSBY was someone who "had unusual insight into the fundamental processes in nature even when obscured by unimportant details. Brutal simplifications, to be justified afterwards, paved the way to the centre of the problems. A characteristic saying often used by him was: 'The proof of the pudding lies in the eating'. In contrast to ERTEL, ROSSBY certainly worked more intuitively. In spite of this difference in scientific style of work, ERTEL and ROSSBY had friendly relationships until ROSSBY died in 1957. Especially, they shared a similar style of comfortable life and of high devotion to science.

Already in 1947, ERTEL had received an offer to become president of the Weather Service in the British Zone, located at that time in Hamburg. ERTEL did not accept this offer because this job obviously was not suitable for a theoretician. In 1949 ERTEL received a call from the Universität München: Professor Arnold SOMMERFELD, a famous theoretical physicist, offered ERTEL a chair for theoretical physics. It is not known why ERTEL did not accept this exceptional offer. Later, in 1952, ERTEL was asked to become successor of his close friend and patron from earlier days, Heinrich von FICKER, in Vienna, Austria. At this time, however, he just had become vice-president of the Deutsche Akademie der Wissenschaften and was not able to follow this offer. Remarkably, in 1960, ERTEL gained an additional professorship at his university; he became a professor of theoretical mechanics.

With regard to geophysical fluid dynamics, it was mentioned earlier in this paper that ERTEL began his career as an internationally well-known expert in that field already in 1942. One of the leaders in hydrodynamics, C. TRUESDELL, cites ERTEL with high credit in his books,

TRUESDELL (1954); TRUESDELL AND TOUPIN (1960). In connection with potential vorticity, the theorems in (**92**), (**93**), (**95**), (**96**), and later ones, were named: "EULER-ERTEL conservation theorem", and "ERTEL commutation formula". These papers and seventeen others by ERTEL in this field were translated into English: (**124**), (**132**), (**133**), (**138**), (**139**), (**152**), (**153**), (**158**), (**183**), (**185**), (**197**), (**201**), (**207**), (**209**), (**260**), (**263**), and (**265**), SCHUBERT et al. (2004). Compared with earlier papers by ROSSBY, ROSSBY et al. (1939), who coined the notion potential vorticity, and with other papers in the US, HAURWITZ (1940a); ROSSBY (1940); STARR and NEIBURGER (1940); HAURWITZ (1940b), the latter paper with spherical geometry, ERTEL's paper (**95**) had a much more general basis. On the one hand there was the linearized two-dimensional vorticity equation for incompressible or barotropic flow on a $\beta$-plane, on the other hand there was ERTEL's fully general system of equations: the three-dimensional Eulerian equations, the equation of continuity, and the first law of thermodynamics. Nowadays we know that ERTEL's work in this respect is not only far reaching in modern geophysical fluid dynamics but it is the basis of a very advanced new theory in this field, NÉVIR and BLENDER (1993); NÉVIR (1998); NÉVIR and BRAND (2003); NÉVIR (2004). The result in the already mentioned papers (**120**), and (**121**): "A new conservation theorem of hydrodynamics", published together with ROSSBY 1949, was named by TRUESDELL (1954), "ERTEL-ROSSBY convection theorems" (permanence of complex lamellar motion). Paper (**119**): "Theorem on steady vortex motion of compressible fluids" is mentioned by TRUESDELL as: "The ERTEL-KÖHLER description of steady motion." ERTEL's paper (**124**): "The physical meaning of functions that enter in CLEBSCH transformation of hydrodynamics" got the name "ERTEL's potential theorem". TRUESDELL states in this connection: "an ingenious modification of WEBER's transformation", followed by the statement: "the elegant ERTEL theorem on circulating motions". In this paper, ERTEL gave one possible explanation of MONGE's potentials in CLEBSCH's transformation. Finally in TRUESDELL-TOUPIN's work, the most important generalization of ERTEL's earlier vorticity theorem, the papers (**132**): "Canonical algorithm of hydrodynamic vorticity equations", and (**133**): "A new vorticity theorem of hydrodynamics", are mentioned. In these papers his famous 1942-theorem is generalized by applying an arbitrary vector instead of a scalar in the earlier theorem.

All these papers are landmarks in geophysical fluid dynamics up to 1955. In addition to the translated papers of ERTEL by SCHUBERT et al. (2004) in this volume, the present author wishes to mention additionally the papers (**123**): "Asynchron-periodical vortex motion of compressible fluids", (**163**): "A system of identities with application on transformations of hydrodynamic vortex equations", (**188**): "Implicit representation of hydrodynamic vortex equations by means of projection-operators", (**189**), and (**190**): "Commutation relationships in hydrodynamics", (**200**): "Invariants with respect to unimodular transformations of initial coordinates in (Lagrangian) hydrodynamics", (**208**): "Commutation operators", (**209**): (see (**200**)), and (**212**): " On maximum number of independent invariants in hydrodynamics". ERTEL's papers in geophysical hydrodynamics are of great value for the theoretician. The time to use his results in meteorology and in general hydrodynamics still has to come. Peter NÉVIR made the beginning NÉVIR and BLENDER (1993); NÉVIR (1998); NÉVIR and BRAND (2003); NÉVIR (2004). Besides this, a mathematical summary of the most important papers of ERTEL has to be written.

From 1948 through 1969, ERTEL was director of an Institut für Physikalische Hydrographie and so, he was engaged in physical hydrography and in hydrology. Although he had written papers in that field much earlier, (**31**) and (**44**), he continued in 1954 with a long series of papers on such fields as theory of lakes, of rivers, costal hydrodynamics, and geomorphology. In all of these papers (almost 70) ERTEL demonstrated his brilliance in solving hydrodynamic problems in a wide range of fields other than meteorology and geophysical hydrodynamics. These often very short papers are precious in every respect. Of special interest, even for the meteorologist, are his papers on waves (**136**): "Relation between phase velocity, particle velocity, and energy in permanent waves", (**146**) to (**151**), (**159**), (**228**), (**243**), and (**244**).

It has been said that ERTEL had been a master mathematician. He demonstrated this in all of his papers. In his papers (**140**) to (**143**), (**160**), and (**161**), however, he wrote on a mathematical problem in pure mathematics. ERTEL generalized STIRLING's formula that is valid for large numbers of n only, with great accuracy for application to small numbers of n as well. It is said that ERTEL was proud of these results, which took much of his time. At this point we mention that ERTEL also was much interested in mathematical statistics. Sometimes he gave lectures in this field.

In 1954, ERTEL wrote a paper on problems in philosophy (**129**): "Causality, teleology and freedom of will, a complex of problems in philosophy of nature". The problem of causality in physics was discussed by most of the great physicists in the past. In biology problems of teleology and freedom of will were equally important. As a physicist, ERTEL showed that nature allows all three: causality, teleology and freedom of will all are realized in nature. He assumed causality for a "large" system (his world) that can be divided into two subsystems. This situation is typical for most of physical

systems (the atmosphere has many sub-systems). Then, he assumes that solutions of an evolution equation for the system as a whole exists, and he shows that by special arrangement of the solutions for the partial systems all three possibilities can be realized. Today we know that there are no solutions to a multi-dimensional non-linear equation of evolution and that deterministic chaos prevails. Nevertheless, it can be shown that ERTEL's statements are correct even under non-linear conditions (FORTAK (2000), printed in SCHRÖDER (2000)). It will take much more time to find out what ERTEL really had achieved during his scientific life.

ERTEL was a very erudite person, not only in natural sciences as physics, mathematics, meteorology, geophysics, oceanography, hydrology, and even in geomorphology. His paper (**129**) shows also that he had very solid knowledge in philosophy. From his very early days as a youngster he admired the work of Alexander von HUMBOLDT, especially HUMBOLDT's "Kosmos". Generally spoken, HUMBOLDT was (the last) universal scholar in natural sciences. ERTEL was so much interested in HUMBOLDT because he himself was so close to him in his thinking and in his scientific work. In 1959, the year of the centenary of HUMBOLDT's death, ERTEL was chairman of the committee organizing the national event. Even long before that, like HUMBOLDT, ERTEL was much interested in Spanish life and language. He had at least two Spanish-speaking friends from earlier days, Prof. Francisco MORÁN (Madrid) and Prof. Gonzales RAINER (Mexico). They invited ERTEL to work at their institutes in Mexico and on the Canary Islands (Mexico, 1957, Canary Islands 1958 to 1960, later he was invited to Cuba, 1966/67). Many of the mentioned papers on coastal waves and others resulted from his observations when he was staying at the coast of the Canary Islands. ERTEL wrote about 35 papers in Spanish. Firstly he wrote in Spanish because he liked the Spanish language that he had learned easily, secondly he wrote in Spanish out of respect for his hosts.

ERTEL was honoured many times. We just mention his membership in academies: Deutsche Akademie der Naturforscher, Leopoldina, (Halle), Österreichische Akademie der Wissenschaften (Wien), Kungl. Vetenskaps Societeten Uppsala. He also received the highest scientific honours in the then Deutsche Demokratische Republik. In 1989 Dr. Wilfried SCHRÖDER who initiated a number of excellent publications in memory of ERTEL, SCHRÖDER (1991); SCHRÖDER and TREDER (1993, 1995, 1997, 1998); SCHRÖDER (2000, 2001), informed the president of the Humboldt-Universität in a letter about the following: 1) Shortly before ERTEL's death The Royal Society London planned to make ERTEL a fellow of this academy. 2) The university of Uppsala planned to make ERTEL a honorary doctor on the occasion of its centenary. Furthermore, 3), SCHRÖDER writes that members of the Swedish Academy of Sciences had proposed ERTEL for the Nobel Prize. The present author has no information on all of this.

In his last years, ERTEL became a diabetic. Because he sometimes compared medicine with meteorology, he did not see the doctor. Working one day in the early morning at his desk he became unconscious and died in coma three days later on July 2, 1971.

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## References

BAVING, B., 1944: Ergebnisse und Probleme der Naturwissenschaften. – Verlag von S. Hirzel, 203 pp.

BERNHARDT, K., 1974: Die Entropiebilanz des atmosphärischen Turbulenzwärmestroms. – Z. f. Meteorol. **24**, 106–112.

BOLIN, B., 1957: Carl-Gustaf Rossby in memoriam. – Tellus **9**., 257–258

BRUNT, D., 1952: Physical and dynamical meteorology. – Cambridge University Press, 309 pp.

CHARNEY, J.G., 1948: On the scale of atmospheric motions. – Geofysiske Publikasjoner **17**, 1–17.

—, 1949: On a physical basis for numerical prediction of large–scale motions in the atmosphere. – J. Meteorol. **6**, 371–385.

CHARNEY, J.G., R. FJÖRTOFT, J. VON NEUMANN, 1950: Numerical integration of the barotropic vorticity equation. – Tellus **2**, 237–254.

EXNER, F.M., 1925: Dynamische Meteorologie (2 ed.). – Verlag Julius Springer.

FORTAK, H., 2000: Betrachtungen zur Arbeit von Hans Ertel: Kausalität, Teleologie und Willensfreiheit als Problemkomplex der Naturphilosophie. – In SCHRÖDER W., 2000.

HAURWITZ, B., 1940a: The motion of atmospheric disturbances. – J. of Marine Res. **3**, 35–50.

—, 1940b: The motion of atmospheric disturbances on the spheric earth. – J. of Marine Res. **3**, 254–267.

—, 1985: Meteorology in the 20th century. A participant's View. – Bull. Amer. Meteorol. Soc. **66**, No 3–4, 4 parts.

KOCHIN, N.E., I.A. KIBEL, N.V. ROZE (Eds.), 1964: Theoretical hydrodynamics. – Interscience Publ. 577 pp.

LINDZEN, R.S., E.N. LORENZ, G.W. PLATZMAN, 1990: The atmosphere – A challenge. The science of Jule Gregory Charney. – Historical Monograph Series, 321 pp.

LINKE, F., 1939: Meteorologisches Tagebuch (V ed.). – Akad. Verlagsges. 33 pp.

MAUERSBERGER, P., 1971: Nachruf Prof. Dr. Hans Ertel. – Z. f. Meteorol. **22**, 315–328.

NÉVIR, P., 1998: Die Nambu-Felddarstellungen der Hydro-Thermodynamik und ihre Bedeutung für die dynamische Meteorologie. – Habilitationsschrift, Freie Universität Berlin. 318 pp.

—, 2004: Ertel's vorticity theorems, the particle relabelling symmetry and energy-voricity-theory of fluid mechanics. – Meteorol. Z. **13**, 485–498.

NÉVIR, P., R. BLENDER, 1993: A Nambu representation of incompressible hydrodynamics using helicity and enstrophy. – J. Phys. A: Math. Gen. **26**, L1189–L1193.

NÉVIR, P., S. BRAND, 2003: Ein dynamischer Wetter- und Klimazustands-Index. – In: Terra Nostra, Volume 6. Deutsche Klimatagung, 311–314. Schriften der Alfred Wegener Stiftung 6.

ROCHAS, M., 1984: Comments on 'A generalized class of time-dependent solutions of the voricity equation for non-divergent barotropic flow'. – Mon. Wea. Rev. **112**, 390 pp.

—, 1986: A new class of exact time-dependent solutions of the voricity equation. – Mon. Wea. Rev. **114**, 961–966.

—, 1993: Exact solutions of the voricity equation on the sphere. – In: Theoretical concepts and observational implications in meteorology and geophysics, Internat. Comm. Hist. IAGA **17**.

ROSSBY, C.G., 1940: Planetary flow patterns in the atmosphere. – Quart. J. Roy. Meteor. Soc. **66**, 68–87.

ROSSBY, C.G. et al., 1939: Relation between variations in the intensity of the zonal circulation of the atmosphere and the displacements of the semi-permanent centers of action. – J. Marine Res. **2**, 38–55.

SCHRÖDER, W., 1991: Geophysical hydrodynamics and Ertel's potential vorticity. – In: Newsletters of the Interd. Comm. on History of IAGA **12**.

—, 2000: Hans Ertel: Kausalität, Teleologie und Willensfreiheit als Problemkomplex der Naturphilosophie. – In: Beitr. Gesch. Geophy. Kosm. Phys., Newsletters of the Interd. Comm. on History of IAGA **41**, Volume 1.

—, 2001: Wege zur Wissenschaft. – In: Beitr. Gesch. Geophy. Kosm. Phys. **4**.

SCHRÖDER, W., H.J. TREDER, 1993: Theoretical concepts and observational implications in meteorology and geophysics. – In: Newsletters of the Interd. Comm. on History of IAGA **17**.

—, —, 1995: Theoretical meteorology, weather predicition, cosmology and general applications. – In: Newsletters of the Interd. Comm. on History of IAGA **29**.

—, —, 1997: Ertel's potential vorticity. – In: Newsletters of the Interd. Comm. on History of IAGA / History Commission DGG, 175 pp.

—, —, 1998: The Earth and the cosmos. – In: Newsletters of the Interd. Comm. on History of IAGA / History Commission DGG.

SCHUBERT, W.H., E. RUPRECHT, R.F.A. HERTENSTEIN, R.N. FERREIRA, R.K. TAFT, C.M. ROZOFF, P.E. CIESIELKI, C. KUO, 2004: English translations of twenty-one of Ertel's papers on geophysical hydrodynamics. – Meteorol. Z. **13**, 527–576.

STARR, V., M. NEIBURGER, 1940: Potential vorticity as a conservative property. – J. of Marine Res. **3**, 202–210.

TRUESDELL, C., 1954: The kinematics of vorticity **19**. – Indiana Univ. sci. ser, 232 pp.

TRUESDELL, C., R. TOUPIN (Eds.), 1960: The classical field theories. – In: FÜGGE, S. Handbuch der Physik Vol. III/1, Springer-Verlag, Berlin.