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CHANGES IN DYNAMICAL METEOROLOGY

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Synopsis: This report attempts to show the change of dynamic meteorology from a field of applied classical hydrodynamics to an independent science of energy-transformation in the atmosphere.

1. Content and Extent of the Concept of Dynamic Meteorology

The creation and initial development of a special meteorological work orientation, that of dynamic meteorology, occurred during the lifetime of R. Suring. Primarily it was thought of as a mathematical physics of the atmosphere in motion, and was meant to be an extension of the statics already in existence. These two concepts adopted from mechanics should not erroneously lead to the assumption, as happens in mechanics, that one principle corresponding to d'Alembert's Principle would be sufficient by itself to make this transition possible. The difference is based on the fact that the irreversibility of the motion phenomena associated with heat transformation cannot be neglected. These phenomena are mathematically expressed in the unbalanced equation given by the Second Law of Thermodynamics for the change of entropy in a cyclical process. Theoretical physics has not yet conquered the difficulties encountered here, so that the theory of atmospheric motion has not yet been completed by an efficient mathematical-physical theory of the weather. This theory is only in its beginning stages. Nevertheless it is worthwhile to follow the traces of the present development in order to obtain a better outline of future working aims.

Compare: V. Bjerknes, Die Meteorologie als exakte Wissenschaft, Antrittsvorlesung in Leipzig am 8.1.1913 und Leipzig-Bergen, Festvortrag zur 25-Jahr-Feier des Geophysikalischen Institutes der Universitat Leipzig, 1938. ["Meteorology as an exact science", inaugural lecture at Leipzig on 8 January 1913 and Leipzig-Bergen, lecture in honor of the 25th anniversary of the Geophysical Institute of the University of Leipzig, 1938.]

2. The Meteorologische Zeitschrift [Meteorological Journal] in the Service of Development

An important source for tracing the development of dynamic meteorology is the Deutsche Meteorologische Zeitschrift (M.Z.), [German Meteorological Journal] or its successor, the Zeitschrift fur Meteorologie (Z.M.) [Journal of Meteorology]. R. Suring, who edited this magazine for decades, was always interested in accepting papers in this field and generously provided sufficient space for all serious investigations of this type in the M. Z. He hesitated, however, where purely climatological papers were concerned, in order to preserve its character as an organ reporting the progress of meteorology from a statistical science, which is orientated more geographically, to an abstract natural science. Such a science sees as its goal the reduction of all natural phenomena to a few basic laws abstracted from them, so that from these laws the phenomena, including future ones, may be deduced by mathematical operations. The famous question "What is truth?" is answered by science as follows: It is all that has been found common [interrelated] through comparison in all that part of nature accessible to our cognition and by means of which, with the aid of synthetic thinking, we impress the properties of nature upon our memory in such an arrangement that we master them [sic!]. The choice of the M. Z. as a source makes giving preference to German intellectual material in this investigation understandable. It must be pointed out that since only certain representative writings have been selected here, no judgment of other pertinent writings not mentioned here is implied.

3. Primacy of the Observations

The encouragement which R. Suring gave to all relevant instrumental and experimental work in the pages of the M. Z., was also in harmony with the above-mentioned search for truth. Successful theoretical studies have always had their point of departure in the experience acquired by conscientious observation of nature. According to E. Mach and G. Kirchhoff these are most simply described by means of a theory. The original establishment of the required chains of reasoning is a difficult task. As already mentioned, its method is the comparison of phenomena and the isolation of common factors. The smaller the phenomena, the smaller is the range of what is common. The conceptual content of what is common must be altered when when new experiences are added, in order to obtain valid laws. With every unintentionally made experience or observations of phenomena on whose progress we have no influence, certain parts important for the comprehension of the whole remain outside the understanding of the conscious. The alpha and omega of a theoretical science that wants to be all-inclusive is therefore to have a clear conceptual grasp of these processes of the external world. This extension of the comprehension of nature can today be obtained only by a most carefully thought-out set of instruments and in meteorology often only by great daring on the part of the observer, which R. Suring demonstrated so frequently. To understand the development of dynamic meteorology, attention had to be called here to the primacy of the observations and to the difficulties connected with them, as, for example, the analysis of daily weather reports on the weather map. In this connection V. Bjerkness in his official address of 1938 said: "It was soon clear to me that I could not compete with my younger colleagues in this respect. I therefore found it definitely advantageous in the interest of success to let these colleagues do the empirical work on the weather map, to let them have full credit for their accomplishments and to concern myself with the background of theoretical questions while expectantly following their results".

4. The Development of Mathematical Physics in the last 60 Years

Extraordinary difficulties confront questions arising in the field of dynamic meteorology. This is largely due to the failure to find the common factors in comparing the various weather phenomena throughout the world and to express them in a suitable mathematical form by means of which the mathematical operations to be performed will already be prescribed. The "dynamicists" of the atmosphere have therefore initially followed the teachings of the great theoretical physicists. R. Suring used to attend the university lectures of H. v. Helmholtz and kept a careful lecture notebook. In his work Uberdie Erhaltung der Kraft [On the Conservation of Energy] the inventor of the ophthalmoscope had even in his younger years shown his mastery of the art of deriving the concept and the law of the conservation of energy from the general equations of motion. A decade later he succeeded in obtaining the concept of the velocity potential, the vortex motion, and the geometrically similar flows from Euler's hydrodynamic equations. In his later life he explained the phenomena of undulating clouds and discovered the existence of discontinuity surfaces in the atmosphere. His thermodynamic accomplishments were similar to those of R. Clausius, to whom we are indebted for the formulation of the First and Second Law of Thermodynamics. Subsequent development of theoretical physics will be indicated in a small time table under I and II. Important dates of theoretical physics are given under A, and those of meteorology under B. Neither completeness nor valuation is even remotely claimed.

I A.

14 December 1900.	Introduction of the finite energy quanta by M. Planck.
1905.	Relativity theory by A. Einstein.
1913.	Quantum theory of spectra by N. H. Bohr.

B.

31 July 1901.	R. Suring and A. Berson attain the height of 10,800 meters in a free balloon.	
26 Apr. 1902.	L. Teisserenc de Bort,	)announce de dis-
1 May 1902.	R. Assmann	)covery of the
		)stratosphere
1910.	The spreading of cold air in Russia and Northern Asia, by H. v. Ficker.	

5 November 1918. On the structure of moving cyclones, by J. Bjerknes.

1924. Determination of points of symmetry in the variation of air pressure at stations in middle latitudes, by L. Weickmann.

II A.

1925. Quantum statistics by W. Heisenberg.

1926. Wave mechanics by E. Schrodinger.

1939. Discovery of uranium fission.

B.

1936. Remarks on the heat exchange within the trade-wind circulation by H. v. Ficker.

1937. Lectures on cosmic radiation published by W. Heisenberg.

1940. On the origin of thunderstorm electricity by W. Findeisen.

The list shows that while theoretical physics experienced a fundamental change during the first quarter of the 20th Century, meteorology was still engaged in gaining knowledge from practical observations, especially of the free atmosphere, which, to be sure, also fundamentally increased its scope. In the second quarter-century significant theoretical works also make their appearance in meteorology, and these must be considered important milestones in the development of dynamic meteorology.

5. The Influence of Classical Hydrodynamics and Classical Thermodynamics

The foundation for the building of a theory of the motion of the atmosphere was laid by the American W. Ferrel between 1856 and 1885. He utilized the deviating force of the earth rotation, and the principle of the conservation of the moment of rotation in order to explain the general wind systems on the earth. The theoretical work by J. v. Hann and W. v. Bezold on the behavior of quasi-static ascending and descending dry or wet air, as well as the first use of an adiabatic sheet by H. Hertz, also dates from this period. In 1876, the Swedes C. A. Guldberg and H. Mohn introduced Euler's hydrodynamic equations into dynamic meteorology, which they extended by an expression for the "friction" of the wind on the surface of the earth. A beginning was thus made towards the mathematical-physical penetration of atmospheric phenomena of motion, but no more than that. At any rate, the theory of the gradient wind was in a position to explain the empirically-found Buys-Ballot wind law for the high and low pressure areas appearing on weather maps. In 1885 the expertly written Lehrbuch der Meteorologie (Compendium of Meteorology) by A. Sprung was published under the auspices of the Directorate of the German Naval Observatory. It corresponded to the teachings of classical hydrodynamics and thermodynamics. The book was cooly received by the meteorologists. These were, in the majority, experimentally trained physicists with geographical background. In their climatological and synoptical work they had gained a deep insight into atmospheric processes and had noticed that the few basic analytical expressions and the limited mathematical operations to be applied to them could not possibly be capable of explaining the manifold weather phenomena of one year or even of several years.

But soon criticism appeared in the M. Z. It first turned towards the Ferrel's method of using the law of conservation of the moment of rotation. The leaders in this argument were W. v. Siemens and E. Hermann, who was divisional chairman in the German Naval Observatory. Details concerning this controversy appeared in No. 3 of the Z.M., 1950.

Investigation of the friction postulate by A. Sprung, F. Akerblom, and J. W. Sandstrom by means of the weather map did not confirm it. It had to be changed on the basis of empirical data and assumed such a form that a theoretical derivation of the new expression from the molecular properties of air was not possible. It was not until 1915 that effective progress was made as the result of the physical-meteorological impetus given by the Geophysical Institute founded shortly before in Leipzig. This was provided by the investigations of Th. Hesselberg and H. U. Sverdrup on Die Reibung in de Atmosphare [Friction in the Atmosphere], in which they introduced the theory of viscous liquids into meteorology. Using the Navier-Stokes equations, they extended the earlier works of A. Margules (1901) and V. W. Ekman (1906). The constant appearing in these equations for the internal friction was calculated by them by using the change in the velocity increase with height for various heights above the sealevel from pilot sightings. A value about 10^5 times as great as that found in the laboratory was obtained. M. Margules had already pointed to this difference, designated as that between molecular and apparent friction in his extremely thought provoking, but little-noticed work. This is a completely different definition of friction, namely as the destruction of the kinetic energy per second whose amount is proportional to the existing energy value. This definition has also proven itself valid in other areas of physics and must be recognized as the most suitable mathematical expression for everything consuming kinetic energy in nature.

The theory of discontinuity surfaces by M. Margules (1906) gave support to the use of Euler's hydrodynamic equations. The discontinuity surfaces theory was confirmed to a satisfactory approximation from weather maps and it explained the phenomenon of boundary surfaces, used especially in the Norwegian cyclonic theory.

The use of thermodynamics also made progress during these years. This progress was especially marked in the varied arrangement of the adiabatic sheet for the purpose of evaluating the constantly increasing number of ascents.

6. The Influence of the Flow Theory

The peculiarity of the flow theory in contrast to classical hydrodynamics is the extensive use of experimentation with moving air, especially with the aid of a wind tunnel. The main problem is the recognition of the properties of laminar and turbulent flow. Study of these properties led to the recognition of two types of small spaced molecular or molar movements, namely ordered [systematic] and disordered [random]. In meteorology this differentiation has caused a far reaching change in dynamic questions. A time table will again provide the most important facts to show this.

(a) Small disordered molar movements

Our actual knowledge concerning the molecular relationship of materials is still incomplete. Since 1883 it has been experimentally established by O. Reynolds that in a flowing liquid not only the molecules are in a state of disordered motion, but also entire combinations of molecules or liquid conglomerates. Concerning these see:

1912. Investigations on the structure of wind. By E. Barkov.

1915. Contributions to the structure of wind, published 1919 by M. Robitzsch.

1917. The mass exchange in the case of disordered current in free air and its consequences by W. Schmidt.

1921. The circulation of the atmosphere in the temperate latitudes of the earth (meridional large-scale exchange) by A. Defant.

1927. On the developed turbulence by L. Prandtl.

1932. Meteorological applications of the flow theory by L. Prandtl.

1936. The maritime evaporation problem by H. U. Sverdrup.

1939. Atmospheric turbulence by H. Lettau.

1948. The propagation of a pulse in the atmosphere by C. L. Pekeris (Physical Review).

1950. A note on three-dimensional turbulence and evaporation in the lower atmosphere by D. R. Davies (Proc. R. Soc., London).

Dynamic meteorology has hereby been enriched through the recognition of the existence of turbulence bodies, air packets, or air balls, and by the transfer equation of the magnitudes which have a vertical gradient. The vertical differences in mass, impulse and kinetic energy which cause the phenomena of apparent diffusion, gustiness and apparent friction are involved. By his discovery that the exchange coefficient (gram centimeters $^{-1}$ sec $^{-1}$) is dependent on the density, the vertical velocity gradient, and the square of the mixing length, L. Prandtl was able to derive a logarithmic law for the increase in wind velocity with altitude from physical considerations. This took the place of the earlier empirical exponential expression. This was a significant step. A large group of phenomena could now be comprehended as the action of forces, as in the basic requirement of theoretical physics. The logarithm as the limiting exponential case is derived in Serret-Scheffers "Differential and Integral Calculus" 6th/7th edition, I., page 232. As result of this progress is the theoretical derivation of the evaporation law by H. U. Sverdrup which also made possible the abandonment of ad hoc expressions.

The question of the extent to which classical hydrodynamics may still be used in meteorological-dynamical work has not received a definite answer. Attention may be called to a conclusion here. In the absence of external forces Euler's hydrodynamic equation is based on the law of general dynamics, which states that the magnitude of motion is equal to the time integral of force. This is the second law in integral form which is to be used in the investigation of collision processes to which fluid motions also belong. The force applied to a mass particle in the X-direction is equal to the difference between the pressure forces which act on the two surfaces which are vertical to the X-direction. If f is the size of the surfaces, then d P = dp · f, where dp denotes the pressure differential. Thus the following equation exists:

$$m \cdot u = -\int_0^{t_0} dp \cdot f \cdot dt$$

since the motion is opposed to the gradient. Since $dp = \frac{\partial p}{dx} \cdot dx$, the expression to be integrated with respect to t becomes
Here, however, dx and f have been chosen arbitrarily, so that their product $\frac{\partial p}{\partial x} \cdot dx \cdot f$ may be placed in front of the integral sign. Then, however, it is cancelled out in the equation as a result of the volume of the mass particle $m = \rho \cdot dx \cdot f$, and we obtain:

$$\rho \cdot u = -\int_0^{t_0} \frac{\partial p}{\partial x} \cdot dt$$

In order to isolate the pressure gradient, both sides must be differentiated with respect to t, which results in

$$\frac{d(\rho \cdot u)}{dt} = -\frac{\partial p}{\partial x}$$

Only if ρ is independent of t, then with:

$$\rho \cdot \frac{du}{dt} = -\frac{\partial p}{\partial x}$$

Euler's hydrodynamic equation follows in its simplest form. The investigations of turbulence have shown that molecule aggregates

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occur during flow. These must be thought of in such a way that variations in density are also involved. The density is thus not independent of time so that the general applicability of Euler's hydrodynamic equation during flow investigations is disputable. A generally valid criterion for the changes of state of ideal gases corresponding to the aforementioned impulse law of mechanics, is the state equation $\frac{p}{\rho} = RT$. This law enables us to express the density in the equation of motion by the pressure and temperature. Thus every flow problem is at the same time a thermodynamic problem. This report differs essentially from the statements of H. Philipps on "The Main Problems of Theoretical Meteorology" Die Naturwissenschaften [The Natural Sciences] 1939, No. 25/26, as the result of the necessity to include implicitly from the very beginning the change with time of the density into the basic equation of motion of elastic mediums.

Dynamic meteorology must experience a still greater change if the arbitrary assumption of the size of the mass particle is not warranted. In that case the volume of the mass particle which appears on the right in the integrand may not be placed in front of the integral sign. The basic relation between the magnitude of motion and the pressure gradient cannot then be simplified by removal of the volume on both sides of the equation. This equation is moreover a linear homogeneous integral equation with respect to the volume. Such an equation is soluble only for representative values [eigenvalues] of the magnitude of motion ρu and will yield possible volumes only for these. A still unsolved question is the one dealing with the determination of the fundamental region over which the integration with respect to time is to be performed. An answer to this may be provided with the aid of statistical mechanics. If such a method is found, a quantum-statistical investigation of flowing masses would be possible and a union with the newest branch of theoretical physics would be attained.

(b) Small Ordered Motions

The mass particles carry out small ordered periodic motions around an equilibrium position during oscillation, so that only small variations of pressure, density, and temperature are produced. To every oscillation belongs an oscillator to which energy must be conducted from outside in some way. The energy radiated by this oscillator spreads in wave form thoughout the entire medium. The wave equation may be derived with certain simplifications from Euler's hydrodynamic equations. The right to assume the wave equation as valid without this derivation is obtained from the elastic nature of air. Contributions to this phase of dynamic meteorology were made by: H. v. Helmholtz atmospheric waves, M. Margules, 1890 (semi-daily pressure wave, for which an acceptable theory, however, has not yet been submitted), J. Bartels (tidal variations), A. Defant (variations of a doubly stratified atmosphere), L. Weickmann (waves in the air-ocean), G. Lyra, 1943 (theory of sea waves). The last-named work specially is at the level of a modern theoretical investigation of waves.

7. The Atmospheric Cycle

It is known that at every location on earth the atmosphere in the course of a year passes through a sequence of states which are repeated in their overall trend after a complete revolution of the earth around the sun. This justifies an attempt to study weather phenomena with the aid of the cyclical concept formed in thermodynamics. The same mass whose changes of state are investigated under the addition or removal of heat is involved in thermodynamics. The atmospheric cycle is immeasurably more complicated, even if [sic] here the addition of heat from the ground which is heated by insolation takes place at a higher temperature and the removal of heat by radiation in the upper layers of the atmosphere takes place at a lower temperature. Dynamic meteorology has been unable to answer, for the most part, the questions arising here.

The changes of state are accompanied by local movements of the masses. From the continuity of the atmosphere it follows that within the entire medium a spatially joining series of masses must also move with the change of location of a mass, so that they will form a closed chain, or an imaginary line. If a certain velocity is assigned to the individual mass-points of the line, the product of mass times tangential velocity may be formally integrated over the entire curve. The value of the integral is called circulation. The derivative of circulation with respect to time, namely circulation acceleration, is significant for dynamic meteorology. With the aid of Euler's hydrodynamic equations the pressure and density differences of the atmosphere may be expressed with it. V. Bjerknes has shown that the circulation acceleration is zero when the isobars and isosteres run parallel. He calls this condition barotropic. If these lines of state cross -- the baroclinic state -- the circulation acceleration differs from zero. A square tube which is enclosed by the two pressure surfaces (p_1, p_2) and by the two isosteric surfaces (ρ_1, ρ_2) is called a solenoid by V. Bjerknes. For quasi-static conditions this representation leads to a clear calculation of the kinetic energy content. A critical examination of how far the concept of a material liquid line and the assumed orderly motion of its mass particles agrees with the concepts of turbulence and is still outstanding.

A second object of cycle investigations is the calculation of the efficiency during heat addition and removal at different temperatures or pressures. M. Margules calculated it in 1901 from an imaginary Carnot process by plausible assumptions about the level of the addition and removal of heat and the accompanying temperatures, and obtained a figure of 21 percent. Somewhat smaller values were found by A. Refsdal from measurements. A considerably smaller value of 8 percent was found by H. U. Sverdrup during his trade-wind study using the same method. R. Wenger in 1916 suggested the Ericson cycle for the calculation of efficiency in which the addition and removal of heat occurs at different constant pressure. This concept corresponds more closely to atmospheric reality than the Carnot process. H. V. Sverdrup also calculated the efficiency in another manner by equating the difference between the added and removed heat of an isolated stationary flow system to the produced frictional heat. For the North Atlantic trade wind he obtained only 3.2 percent. H. Ertel has arranged this calculation in a more exact fashion and even obtained a value of greater than 1 percent on the basis of atmospheric friction numbers. This method of calculation is, however, questionable since it is assumed that an isolated stationary circulation in the atmosphere takes place.

According to thermodynamic theory the difference between added and removed heat is proportional to the work produced by the system. This work is equal to the available mechanical energy in the form of kinetic as well as potential gravitational energy. In

1905, M. Margules showed that the potential gravitational energy is the cause of all winds occurring on earth and contradicted the assumption that it is to be sought in the horizontal pressure differences. Later W. Littwin at the suggestion of H. Koschmieder extended these trains of thought to the different cases of stratification of moist air. All wind energy thus originates during the restratification of the air as the result of unstable formation, which is a link of an atmospheric cycle. The Margules question as to how such considerable potential energies can be formed without the earlier development of compensating air currents has not yet been answered. At this poing of the system the atmospheric vortex could also be studied. Its theory is also still outstanding.

The investigation of the relation between air and sea currents also belongs to the field of the atmospheric cycle. Comprehensive and important statistical works are already available for long-range forecasts. From a theoretical standpoint the 10th chapter of the work by H. U. Sverdrup, 1943, Oceanography for Meteorologists, especially the section - "The oceans and the weather" represents a considerable improvement. The closing sentence may serve as the goal for the formation of the analytical relationships which are to be set up. "Every change in the circulation of the atmosphere must lead to a change of the ocean, which again must affect the atmosphere.". Thus two circulations are involved, two cyclic processes which are connected with one another and must therefore show surges and phase displacements which shed a bright light on frequently unexpected weather phenomena.

On the basis of the above the "general circulation of the atmosphere" must be interpreted as the totality of all restratifications resulting from the varying breaking-up of the atmosphere from below by insolation and cooling in the higher levels by radiation. Its three great components, the tropical, extra-tropical, and stratospheric circulation are coupled together and produce phenomena similar to those just mentioned. The rhythm of the weather is causatively related to this coupling. Further references are given by Z. M., 1950, No. 3. Complex formations, such as lines of equal 24 hour pressure changes (N. Ekholm), the divergence of upper currents (R. Scherhag), and oscillations in the tropopause (E. Palmen) might be explained on the basis of these energy relationships.

8. Non-mechanical Energy Forms

Under this heading come the latent energy of water and water vapor, the electromagnetic field of the earth, and the atmospheric radiation energy including the solar radiation arriving at the outer atmosphere. In the case of all three forms, the determination of their properties in the last 15 years has been the object of especially subtle experimental investigations whose results cannot be indicated here because of the lack of space. Through these investigations the way has been opened for introducing the transformations of the above-named energy forms inty dynamic meteorology.

(a) Latent Energy of Water Vapor

The problem of expressing the heat of condensation or the amount of liquid and solid water which is supplied to the atmosphere every second as a function of place and time, had already confronted H. V. Sverdrup in his trade wind study. It has not been tackled elsewhere. No corresponding analytical expression exists for the

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quantities of precipitation in the various forms which is supplied every second at different times to different places of the earth. Promising theories in this respect are the works of T. Bergeron "Condensation Forms as Identification Marks of the Air Mass," and by W. Wundt "The Concept of the Water Cycle on the Basis of Earlier and Recent Investigations." The specific humidity and the density of dry air are coupled with the air currents as functions of the place and time. One may assume that these may be described by differential equations. The necessary limiting conditions must then be extensively shaped by the formation of precipitation residues and their changes, even though an almost quasi-static state must be assumed for the condensation.

(b) The Electromagnetic Field of the Earth

The question, still unsolved twenty years ago, of the cause of the maintenance of the negative surface charge of the earth in defiance of neutralization by the positive vertical conduction current, has in the meantime been solved according to the interpretation of A. Wigand. According to this/the generator of electricity is to be sought in the thunderstorms distributed all over the earth, through whose discharges positive electricity is constantly supplied to the ionosphere and negative electricity to the earth. See the end section of the text-book by Hann and Suring, 5th edition. The view that the electrical currents in the ionosphere or in the earth's crust which are related to this cause the earth's magnetic field has not been discussed much because of the efficiency of the Gauss theory. The electric and magnetic field strength of the earth are also functions of time and place which are coupled with the motions of the air. Because of the large velocity of propagation of electricity in the conducting layers almost stationary conditions are simulated which, however, prove to be fictitious when exact measurements are made. As a result of the presently only suspected coupling of the electro-magnetic field with the air currents, the atmospheric disturbance appearing at the thunderstorm origin must therefore make itself noticeable in the sequence of the air-electric and earth-magnetic elements, analogous to the effects of seismological waves (microseismology). The electromagnetic field strength can thus become an important member in the number of the functions which are subject to the mathematical operations of dynamic meteorology.

(c) The Radiation Energy

The most important receiving surface for insolated solar energy is the solid and liquid surface of the earth. It is the main heating surface of the atmosphere. Since the atmosphere is of an elastic nature, it can be set to oscillate by an external action such as solar radiation. This oscillation can become especially strong if the frequency, as the result of the effect of the external disturbance, becomes equal to the frequency of the natural period of the atmosphere. Drawing a bow across a violin string shows that an external cause, even if it acts steadily upon the elastic body, will set the body to oscillate. It is here postulated as a task for dynamic meteorology to show to what extent the results of present-day oscillation and wave investigation may be shown in the earth's atmosphere, or in what way they will have to be modified because of the peculiarity of the atmosphere. This task is very complicated because of the involved spectral energy distribution, and the extinction and appearance of the secondary radiators earth and atmosphere, especially since not enough relevant experimental material has been collected as yet. The formulation of such an efficient concept as that of a turbidity factor by F. Linke justifies believing a solution to be possible.

9. Features of Several Text-Books on Dynamic Meteorology

The problems of dynamic meteorology were first treated by F. M. Exner. His book has not yet been excelled in quality. His text-book is the lively and faithful report of a seeker and struggler, who, accompanied by hopes and disappointments, was guided to the end by the unyielding will to discover the truth. This scientist who critically examined his own work never hesitated after an unsuccessful attempt to assume another probable interrelation among meteorological phenomena in order to find the laws governing the weather as a whole from the conclusions to be drawn and from comparison with reality. Physical and Dynamical Meteorology by D. Brunt is similar in this respect and also in its extent of investigated phenomena. H. Koschmieder is more reserved in his use of hypotheses and particularily stresses subtle definitions and step-by-step development of equations and their solutions. E. Ertel has most consequentially thought through weather phenomena with the aid of classical hydrodynamics or thermodynamics. This uncovers the extent and limitations of the equations defined in these sciences. P. Raethjen presents his analysis from the viewpoint of the daily work of the synopticist, introduces his terminology, and thus starts out on a new promising path. His work is also very noteworthy from a didactic standpoint. G. Stuve in the Handbook of Geophysics by Gutenberg preceded him with respect to scientific synthesis. He especially presented the advances of the Norwegian meteorological school as they had already been collected in the book by V. and J. Bjerkness, J. Solberg, and T. Bergeron. The table will show the importance which the different authors assign to the individual areas of dynamic meteorology, measured according to the number of pages in their works.

Author	Statics Thermo-dynamics	Hydro-dynamics	Radiation	Electro-magnetic field	Dust Content and visibility
Exner	36	360	6	-	-
Brunt	80	230	53	-	-
Koschmieder	149	230	-	-	-
Ertel	48	48	3	-	-
Raethjen	114	260	21	-	-
Stuve	142	275	-	-	-

10. Dynamic Meteorology as a Science of Atmospheric Transformation of Energy

In conclusion let me give a brief preview of the working areas of dynamic meteorology in the coming years, as determined by the evolution of physics. Common to all atmospheric phenomena is their origin in the radiation energy of the sun. Wind, a factor so important for living conditions on earth, must be comprehended in its intensity, its direction, and its distribution as a form of energy of definite transformation value, indeed as a part of the radiated solar energy. For this purpose the First Law of Thermodynamics may be used, which indicates the division of the supplied radiation energy into heat and mechanical work. But how this quantity of work is transformed into potential gravitational energy has not been quantitatively answered despite investigations on convections, exchange, and the studies of glider meteorologists on anabatic wind. A cause for the zonal and meridional distribution of the wind fields must be found. An acceptable theory of the semi-daily pressure wave is still lacking. The problem of stratospheric currents and their dependency on the tropospheric disturbances has not been solved yet. The available theories of the stratosphere are considered unsatisfactory. Finally, a law is needed in the field of weather prediction which regulates the sequence and duration of the various weather situations in the mean latitudes. This would be the crowning glory of dynamic meteorology. It was the aim of R. Suring's self-sacrificial struggle of over half a century to provide the prerequisites for understanding the truth which concerns all of mankind.

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