Meteorologische Zeitschrift, Vol. 25, No. 4, 521–526 (published online April 29, 2016)
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MetZet Classic Papers

Aerological data spurred dynamical meteorology: Richard Scherhag's contribution of 1934 as an early milestone

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(Manuscript received January 21, 2016; in revised form February 3, 2016; accepted February 10, 2016)

Abstract
A brief note is presented on a paper of Richard Scherhag that first appeared in the *Meteorologische Zeitschrift* in 1934. At the outset some biographical information about Richard Scherhag is given, who provided important stimuli to synoptic meteorology before and after the Second World War, working first at national weather services and later as founding chair of the meteorological institute of *Freie Universität Berlin*. Thereafter the essentials of his ground breaking study of 1934 about the theory of pressure systems are summarized. Related contemporary studies by Scherhag are also mentioned together with a brief account of his reception in the English-speaking world.

Keywords: Classic paper, Scherhag, synoptic meteorology

1 Introduction

The question of what causes pressure variations in the horizontal or, more generally, the generation, progression and decay of low pressure areas (depressions or cyclones) and high pressure regions (anticyclones) and how they can be forecast has been at the core of dynamic meteorology for more than a century. Vilhelm Bjerknes (1904 and 2009) postulated meteorological prediction to be an initial value problem of theoretical physics and identified the governing equations of partly prognostic, partly diagnostic character (i.e. with or without a time-derivative; see also Gramelsberger, 2009). Exner (1908) demonstrated that a single and computationally tractable equation can be deduced from the primitive equations when strong approximations are prescribed yielding realistic short-range surface pressure forecasts for favourable episodes. The influence of a large mountain range as the Alps on the genesis of depressions in its lee was investigated by Ficker (1920 and 2010). He distinguished between upper-level and near-surface processes conducive to cyclogenesis as a prescient foreshadowing of current concepts (Davies, 2010). All these studies, published in *Meteorologische Zeitschrift*, put their focus on gaining physical insight about the atmosphere rather than attempting pioneering steps with regard to actual forecasting.

After the First World War, the availability of meteorological data continued to increase, both at the surface and at higher levels, often designated as the "upper-air", and probed by aerological ascents with balloon or aircraft. The bulk of such synoptic observations became increasingly used for extended case studies, not the least after strong windstorms in the vicinity of pronounced depressions had occurred. The publication "*Zur Theorie der Hoch- und Tiefdruckgebiete*" (Scherhag, 1934a) originated from such investigations, e.g. regarding the *Ostsee-Orkan* episode of 8 and 9 July 1931 and the case of extreme upper-level winds across central Europe on 11 December 1931, even if the title attains textbook-type generality. The author, the merely 27-year old Richard Scherhag, had joined the German Naval observatory in Hamburg – a state institution for, e.g., the provision of guidance for civil and military shipping – a year before and was apparently given the task to investigate in detail situations when gale-force winds occurred.

In this note we provide a biographic sketch of Richard Scherhag (Section 2) before the key elements of his 1934-paper are discussed in Section 3. A documentation of published traces around the work for the 1934-paper (Section 4) reveals how fast the ambitious post-doctoral researcher progressed from case-study results to a conceptual model, which he chose to term "a theory", a practice not uncommon at the time. Some hints to the reception of the 1934-paper (Section 5) and a few general remarks conclude the note.

2 Richard Scherhag: a school-building academic in German meteorology

Richard Scherhag was born on 29 September 1907 in Düsseldorf as the son of a merchants' family. As a teenager he installed a small climate station in his parents' garden and cared for it with great diligence. From 1926, he studied science and philosophy in Bonn, Cologne and Berlin; at the latter location with a focus on meteorology under the tutelage of Heinrich von Ficker (1881–1957) and Albert Defant (1884–1974). His PhD dissertation dealt with "atmospheric conditions during thunderstorms" and contained

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DOI 10.1127/metz/2016/0784
Gebrüder Borntraeger Science Publishers, Stuttgart, www.borntraeger-cramer.com

Figure 1: Richard Scherhag at *Freie Universität Berlin*, left: 1952 on the meteorological observing platform (adapted from Wehry, 2012), centre: As dean of the Mathematics and Natural Science faculty presenting a *doctor honoris causa* diploma to Lise Meitner on 11 May 1957 accompanied by Max von Laue (far right; Nobel-laureate of 1914 in physics; adapted from http://web.fu-berlin.de/chronik/b-picts/1949-1960/meitner.html), right: At his desk with hand-written manuscript in front of bound volumes of weather-charts in the late 1960s (adapted from http://wkserv.met.fu-berlin.de/Beilagen/2007/Scherhag.pdf).

detailed decadal statistics as well as thorough weather map analyses of prominent cases. Parts of the monograph were published as two short contributions in *Meteorologische Zeitschrift* (Scherhag, 1931a and 1931b). Especially formative for his scientific career was the period at the *Deutsche Seewarte* in Hamburg from 1933 to 1937, when first regular upper-air charts started to be integrated in the daily weather bulletins. Under this affiliation, the ten-page paper "On the theory of high- and low-pressure areas" appeared 1934 in the April-issue of *Meteorologische Zeitschrift* (Scherhag, 1934a).

From 1937 Scherhag worked as a *Referent* (section head) at the newly established *Reichsamt für Wetterdienst* specialising in upper-air analyses and the construction of forecast maps from 1939 onwards. During the war, he built-up and directed the upper-air section of the central *Wetterdienstgruppe*. The daily preparation of synoptic-scale forecast maps was the main task of his team. The developed methods and empirical findings constituted the core of a manuscript "New methods of weather analysis and prognosis" (Scherhag, 1948), which he had compiled during the war starting in 1944 and encouraged by his superiors. After the war, American officers in the Allied Control Council supported the publication of the 430-page textbook, which appeared in 1948 and found widespread attention, also internationally.

The last stage of Scherhag's life and career is closely linked with the foundation and direction of the *Institut für Meteorologie* from 1949 onwards as part of the *Freie Universität Berlin*, newly founded in the American sector of the politically divided German capital (Fig. 1, left). Synoptic meteorology became a special focus of the growing institute in combination with the unique feature that university staff and many student helpers produced forecasts and published weather maps for all public purposes (except aviation; Wehry, 2012; forecasting duties continued until 1993; the publication of *Berliner Wetterkarte* is ongoing). Systematic ascents of the routine radiosonde to stratospheric heights led to the discovery and detailed description of a first sudden warming at the 30-km-level in the stratosphere during the winter of 1951/52, sometimes referred to as "Berlin phenomenon". A highlight during Scherhag's term as dean of the science faculty was the presentation of an honorary doctorate to Lise Meitner (a physical chemist of world-renown who had worked in Berlin for more than three decades before she was forced to emigrate in 1938; Fig. 1, centre). Other technological innovations for routine usage included the observation of precipitation complexes by radar (from 1957) and cloud-structure composites determined from data of polar orbiting satellites (from 1966). In 1969 the begin of a cooperative research centre (*Sonderforschungsbereich*; funded by *Deutsche Forschungsgemeinschaft* [DFG]) termed "Synoptic Meteorology" marked another milestone in Scherhag's career at the interface of academic research and applications with relevance to weather services (Fig. 1, right). His sudden death during the summer vacations in 1970 shocked his many collaborators and students to the utmost and had serious repercussions to the institute, although his personal impact could still be sensed many years later (e.g. by the author as a meteorology major at FU Berlin from 1977 to 1980). Let us now turn to Scherhag's early milestone-paper of 1934.

3 The paper of 1934

Scherhag (1934a) gave his ten-page publication a rather general title: "On the theory of high and low pressure areas". Apparently he intended to contribute to the considerable number of, in modern terms, conceptual models to explain the observed transient nature of pressure systems. The restrictive subtitle "The significance of divergence in pressure areas" placed the emphasis on a specific dynamical process in moving air rather than on pure thermal effects of differently temperate air-masses. Let us quickly move through the introduction and a selection of the thirteen short sections (cf. the translation by VOLKEN et al., this issue).

The, compared with the following sections, detailed introduction contains a number of references to both textbooks (e.g. by HANN-SÜRING, EXNER, and SHAW) as well as contemporary research papers (e.g. by PALMÉN, DINES, SCHEDLER) written by German-speaking as well as foreign authors. It was argued that dynamic effects were at least of similar, but in most situations of larger importance in comparison to thermal ones. SCHERHAG concluded that the primary driver for the generation and maintenance of differences in surface pressure have to be situated at upper (i.e. mid-tropospheric) levels. This stood apart from the prevailing practice which emphasized low-level frontal analysis and forecasting. Altogether, the broad overview and critical assessment of the existing literature, including older studies of Austrian and English meteorologists appear remarkable, especially for a young author.

A salient point of the study is presented in next section entitled "The relation of upper-level flow and pressure change" alongside with a juxtaposition of manual analyses over central Europe on 11 December 1931 for *(i)* the geopotential height contours including wind observations at the 600-mbar (hPa) level and *(ii)* three-hourly surface pressure tendencies. While at the surface pressure horizontal pressure variations were slack, the extraordinary temperature gradient aloft along 50 ° N in combination with high meridional winds was identified with a distinct bands of surface-pressure rise (fall) below the convergent (divergent) parts of the mid-tropospheric wind fields. A sketch of an idealized upper-level pressure field (straight and stationary isobars) was used for a qualitative explanation.

The remainder of the paper attempts to relate the observation – and similar cases as the summer storm over the Baltic Sea (SCHERHAG, 1934a; a footnote mentioned the simultaneous case-study type investigation in another journal) – with contemporary investigations, notably the "theory" put forward by RYD who worked at the Danish national meteorological service. Details like cyclogenesis in the "Delta" of frontal zones (following recent studies by BERGERON and by SCHINZE), cold air outbreaks as in the textbook by EXNER and the relation to an empirical rule put forward by GUILBERT (falling pressure in the area of divergent winds) are discussed qualitatively in short sections.

Two schematic sections conclude the paper. First, idealized pressure and temperature distributions that are stationary or fast moving are distinguished and related to the climatological occurrence of cyclones and anticyclones on the northern hemisphere. And finally, five "weather rules with regards to divergent upper-level winds" are formulated including certain caveats and a distinct regard of cyclones and anticyclones, respectively. Implications for practical forecasting are mentioned. The last sentence refers to synoptic aerology, the future furtherance of which was considered the to be crucial in order to critically evaluate the presented views for many more cases.

From today's perspective, the complete lack of mathematical formulae appears strange in a paper claiming to make a contribution to the *theory* of pressure systems. However, it was common practice during the first half of the 20th century that conceptualizations on physical grounds were labelled as theory. The mentioned papers of BJERKNES (1904) and FICKER (1920) also belong to this category, whereas EXNER (1908) presented equations and a calculated gridded dataset displayed on a map. Looking back to operational meteorological practice during the 1920s and '30s it becomes evident that SCHERHAG (1934a) had challenged the then conventional paradigm of near surface level frontogenesis, started to lay the groundwork from a major departure thereof (i.e. regular upper-level analyses) and in the process set the scene for subsequent studies that were to dominate theoretical meteorology for decades (cf. e.g. DAVIES, 1997). Technically, the 600 hPa geopotential chart (Fig. 1a) including some 20 "station" observations is worth to be remembered. The caption mentions its construction by graphical addition of the 1000-hPa absolute topography and the relative topography of 600 over 1000 hPa using commensurable isoline intervals of 5 hPa for surface pressure and 40 gpm for geopotential. SCHERHAG's later renown as a master of manual data analysis and his deep desire to squeeze the utmost out of, by today's standards, very fragmentary datasets is clearly visible already from his early post-doctoral publication. But it was not his only one at the time.

4 Related contemporary publications by SCHERHAG

From 2 to 5 October 1933, the German Meteorological Society held its golden anniversary meeting in Hamburg in conjunction with its 18th scientific assembly (HUBER, 1933). The afternoon session of 3 October contained 12 presentations, among them R. SCHERHAG (1933), affiliated in Hamburg with this title: "The pressure and temperature distributions at upper levels during the generation of the Baltic Sea gale of 8/9 July 1931". The, in modern terms, extended abstract comprised three printed pages, ten footnotes including references to German-language books and articles as well as a hint to a formal article in preparation (SCHERHAG, 1934b). In the text without figures, the lucky circumstance got mentioned that "rich" aerological material happened to be available for 8 July as well as a research flight from Hamburg ("*Hamburger Wetterflugzeug*"), and the synoptic development of the storm was described. The discussion contained numerous arguments about the "divergence" at higher levels of isobars and isotherms, and an accompanying pressure fall below. Numerous senior figures from the scientific community of the German-speaking countries attended the meeting and colleagues Markgraf, Raethjen, and Reichel were recorded of having contributed to the discussion of the paper.

The complete paper of the Baltic-Sea-gale case (Scherhag, 1934b) appeared in the April-issue of the Naval Observatory's in-house journal *Annalen der Hydrographie und Maritimen Meteorologie*, i.e. the 67th volume after its foundation in 1873. It comprised ten printed pages including five tables of different observations from European aerological stations plus nine upper-level analysis charts of northern central Europe on a separate plate. The style resembled a technical memorandum, in contrast to the exposition of the "theory paper" in *Meteorologische Zeitschrift*. As technological innovation, the begin of regular upper-level analyses from aerological ascents and data gathered by regular "weather aircraft" was stressed with reference to earlier research applications by Bjerknes and collaborators. Altogether pragmatic approaches were sought for an early detection of severe weather regions connected with the unexpected deepening of secondary lows which tended to be foreshadowed by anomalous divergence patterns in the mid-troposphere. A more complete investigation based on a thorough analysis of energy conversions, from the potential energy stored within the arrangement of differently temperate air-masses to the kinetic energy of high-wind areas, and taking into account stratospheric effects was postponed to future investigations.

5 Reception of the 1934-paper

During the 1930s in England, the Met. Office scientist Reginald Sutcliffe (1904–1991) was among the atmospheric dynamicists who began to combine mathematical oriented techniques with routine analyses of aerological data for forecasting purposes. Sutcliffe (1939), one of several papers by this author focusing on the development of pressure systems, stressed the compensating role of horizontal wind divergence (of either sign) at different levels with surface pressure change being a comparatively small residual resulting from the vertically integrated divergences. Sutcliffe acknowledged that the "divergence theory" of Scherhag (1934a) "have given rise to a considerable literature where strong claims to their practical value have been put forward", but he insisted that the "term divergence had to be used in its ordinary mathematical sense" rather than too loosely in the "fanning of isobars", i.e. confluence or difluence (as opposed to the mathematical divergence operator). Sutcliffe continues his physical reasoning using mathematical argumentation by splitting the wind field in a geostrophic part (of vanishing divergence by definition) and the divergent a-geostrophic deviation. At the end he reconfirms a number if empirical findings ("rules"), which had been put forward by others for specific situations. It is worth noting that that Sutcliffe (1949) provided in his detailed review of Scherhag's textbook a fine appraisal of his German counterpart's analyzing studies in synoptic aerology right from the start at the *Deutsche Seewarte* in 1934. In his conclusion Sutcliffe granted in quite a gentlemanly attitude that Scherhag's often novel ideas developed independently from his own before the war, while resulting "differences are of surprisingly small account". In 1965, Sutcliffe retired from the Met. Office and became the head of the newly established Meteorology Department at Reading university, similar to Scherhag's move to FU Berlin some 15 years earlier. A then young post-doctoral researcher remembers: "Sutcliffe was the only person that mentioned Scherhag's studies to me, and I got the impression that he respected him highly" (Davies 2016, personal communication).

We note that Scherhag's milestone-paper of 1934 was noted soon after its publication also in non-German speaking countries – it was quoted, e.g., by Brunt (1938) in England and Namias, (1939) in the USA – whereas it is not fully given the acknowledgment in the later literature that it rightly deserves. One reason may be that meteorological analyses and forecasting techniques became classified during the Second World War and that German-language research journals lost much of their prestige thereafter. The language barrier itself is regarded to have played a less important role compared to the all too common 'fashionable' tendency whereby referencing a high profile scientist is deemed preferable to quoting the originator of a concept. Another reason could be a general decline of weather forecasting methods in academic circles until the mid-1960s, which led the forecasting pioneer Jacob Bjerknes (1964) declare, not without some pathos, *weather forecasting* as meteorology's first duty to society, even if it meant showing the public how often one was in error.

6 Further remarks

Back in the second decade of the 21th century, one comes to ponder about the value of reading Scherhag's early paper more than 80 years after its publication alongside with the bit of background provided in the previous sections. At first sight, the presented data and the conclusion drawn appear rather meagre in our era of global and quasi-automated data acquisition and multi-dimensional analysis. Yet, the evident and sustained energy of a young post-doctoral researcher to organize in a meteorological service environment the construction of innovative upper-level charts, to present his results at a conference and to publish simultaneously in different renowned journals is most admirable. And more important, his careful semi-empirical consideration of the upper-level flow structure as an indicator of surface development was novel, and the set-up of consistent analysis schemes demonstrated his distinct creativity.

Even if Scherhag did not undertake a strict mathematical treatment of the vertical integral of the horizontal divergence, he had trenchantly stated in his section *Consequences for the air mass balance of pressure centres*: "Pressure changes always depend on the relationship between inflowing and outflowing air masses, that is, on the total divergence in an air column. A high pressure area can only be reinforced if more air is flowing into the upper layers than there is flowing out of the lower layers" (cf. Volken, this issue; Scherhag 1934a, p. 136). This statement, although superficially obvious, is the kernel upon which Sutcliffe proceeded to build his "development theories".

In addition, Scherhag's attitude towards detailed case-studies of dynamic weather events of synoptic or meso-scale extent is still flourishing. Some 25 years ago, the present author had the privilege to work with a Scherhag-trained co-author (Ludwig Weickmann, *1919; cf. Volkert et al., 1991) on manual jet-streak analysis during strong frontogenesis over the Alps to obtain cross-validation data for comparisons with numerical analyses. The special regard of every level in each available sounding and the amazing memory for analogous situations made a lasting impression.

Finally, the series of Classic Papers of *Meteorologische Zeitschrift* provided also in the field of dynamical meteorology a fascinating collective heritage, starting academically with Bjerknes (1904) and Ficker (1920), and later also touching on applications with Scherhag (1934a). This tradition includes more recent initiatives under the *World Weather Research Programme* of WMO, e.g. the *Mesoscale Alpine Programme* (MAP, 1995–2005; cf. Volkert and Gutermann, 2007) and the *Convective and Orographically-induced Precipitation Study* (COPS, 2004–2011; Behrendt et al., 2013). And as hidden heritage of and homage to Richard Scherhag, who organised during the late 1960s a DFG cooperative research centre (CRC) "Synoptische Meteorologie", we regard the recently started DFG-CRC "Waves to Weather" (cf. www.lmu.de/wavestoweather). Once again, weather analysis and forecasting lie at the core of the initiative, but now with an emphasis on numerical models and probabilistic methods.

Acknowlegements

The bulk of the biographical information was taken from the articles published in *Beilage zur Berliner Wetterkarte* after Scherhag's sudden death on 31 August 1970 (Hugo and Klauser, 1970) and at the occasion of the centenary of his birth (Mahlberg, 2007). Librarian Sylvia Wohofsky kindly assisted the searches for relevant literature from the 1930s. The classic paper series coordinator Stefan Brönnimann is thanked for putting Scherhag's milestone paper into the series and for patiently reminding the author to complete the re-search that he had promised to undertake. An insightful anonymous review proofed to be most valuable for a balanced international perspective. Support was provided by the "Waves to Weather" initiative of DFG (SFB/TRR165).

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