Meteorologische Zeitschrift, Vol. **20**, No. 3, 361-365 (June 2011)

Comments on: "The thermal zones of the Earth" by Wladimir Köppen (1884)

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Abstract

The classical paper of Köppen (1884a) on "The thermal zones of the Earth according to the duration of hot, moderate and cold periods and of the impact of heat on the organic world", published in the first volume of the *Meteorologische Zeitschrift*, is considered today as an early forerunner of the most widely used Köppen-Geiger climate classification. We depict the historical background of the evolution of Köppen's climate classification from the beginning in the early 19$^{\text{th}}$ century until the present. An overview on 21$^{\text{st}}$ century applications demonstrates the high scientific impact of Wladimir Köppen's historical work.

Zusammenfassung

Die klassische Arbeit von Köppen (1884a) über „Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet", publiziert in der ersten Ausgabe der *Meteorologischen Zeitschrift*, wird heute als früher Vorläufer der weit verbreiteten Köppen-Geiger Klimaklassifikation betrachtet. Wir beleuchten den historischen Hintergrund der Entwicklung der Köppen'schen Klimaklassifikation von den Anfängen im frühen 19. Jhdt. bis zur Gegenwart. Ein Überblick der Anwendungen im 21. Jhdt. demonstriert die große wissenschaftliche Bedeutung der historischen Arbeit von Wladimir Köppen.

1 Introduction

The second half of the 19$^{\text{th}}$ century was characterised by the installation of first monitoring networks and the establishment of national meteorological societies. Scientists from many disciplines aimed to create the first world maps of meteorological and environmental parameters based on observations. Therefore, available data at that time were collected in painstaking detailed work, evaluated, classified and mapped. Like most other sciences at that time, climatology was predominantly descriptive practised by meteorologists and geographers in equal measure. Two of the leading scientific journals were the *Meteorologische Zeitschrift* and *Petermanns Geographische Mitteilungen*, both preferably read and selected for publication of his work by Wladimir Köppen (1846–1940). Supan (1879) published a paper on "The temperature zones of the Earth" and Grisebach (1866) as well as Drude (1884) presented their global plant geography in *Petermanns Geographische Mitteilungen*. Inspired by these works Köppen developed over decades of work his famous climate classification, which is based on the distribution of plants. The classical paper of Köppen (1884a) on "The thermal zones of the Earth according to the duration of hot, moderate and cold periods and of the impact of heat on the organic world", published in the first volume of the *Meteorologische Zeitschrift*, is considered today as an early forerunner of the most widely used Köppen-Geiger climate classification.

Historically, the ancient Greecs had developed a concept of different climatic zones of the Earth. Based on this concept a tropical zone, a temperate zone and a polar zone were distinguished in the early 19$^{\text{th}}$ century. These zones were limited by the parallels of latitudes, whereas for their differentiation no exact directives existed. For example the 23.5° N-S-belt was defined as tropical zone, followed by the temperate zones between 23.5° and 66.5° geographical latitudes and the adjoining polar zones (Hann, 1908). For the first time Supan (1879) proposed isotherms instead of parallels to define the major climate zones. He defined three zones separated by the mean annual isotherms of 20°C and 10°C, whereas the cold zones corresponded to the polar forest line, the so-called Köppen-Supan line.

Köppen (1884a) adopted the 10°C and 20°C thresholds, but expanded the concept to the duration of temperature during the annual cycle. He defined 5 thermal zones as main climates. These are the tropical zone (all months warm), subtropical zones ($4-11$ warm months, $1-8$ moderate months), moderately temperated zones ($4-12$ moderate months, ≤ 4 warm months), cold zones ($1-4$ moderate months, other months cold) and polar zones (all months cold). Warm months were defined by a mean temperature of $T > 20$°C, moderate months by $T =$ 10–20°C and cold months by $T <$ 10°C. Additionally, Köppen subdivided the moderate temperated zones in zones with warm summer, zones with constant

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DOI 10.1127/0941-2948/2011/0258
0941-2948/2011/0258 $ 2.25

temperature and zones with cold winter. With these altogether seven thermal zones Köppen laid the foundation for his well-established climate classification.

After the first world map of mean annual precipitation compiled by LOOMIS (1882), it was again SUPAN (1898), who presented the first global precipitation distributions of annual and seasonal means. But it was the merit of KÖPPEN (1900) to compile, restricted to these two parameters, the first serious climate classification (GRIFFITHS, 1977). Thereby he considered recently published world maps of phytogeography, e.g. by GRISEBACH (1872) and especially the temperature related classification of plants developed by DE CANDOLLE (1874). Phytogeography and temperature zones are traced back to VON HUMBOLDT and BONPLAND (1807), VON HUMBOLDT (1817) and GRISEBACH (1838), who proposed early concepts concerning the effect of temperature on plant growth. For an overview on climate classifications known in the 19th century we refer to WARD (1905). In succession Köppen perfected his climate classification (KÖPPEN, 1918), whereas he focused particularly on the relationship between tree line and temperature (KÖPPEN, 1919). In KÖPPEN (1936) he presented the last version of his climate classification, which was published after his death by Rudolf Geiger (1894–1981) in a final version (GEIGER, 1954, 1961).

Today the climate classification of Köppen and Geiger is assigned to the classical climatology and is called a generic climate classification. This is a classification that identifies climates in similarity to their effects on plant growth, which rely mainly on aridity and warmth. Numerous authors made detailed improvements of it or proposed alternative classifications as reviewed by HANTEL (1989) and ESSENWANGER (2001). One of the best known, that after THORNTHWAITE (1948), is frequently cited for its rational approach, however, infrequently used because it is too complex. Recently, however, FEDDEMA (2005) presented a revised Thornthwaite-type climate classification based on a more rational approach for everyday use in a classroom setting. A detailed account of classification methods is also offered in the textbook of TREWARTHA and HORN (1980); it introduced the modified Köppen-Trewartha classification[1]. A modern representation of the so-called world map of Köppen-Geiger climate classification, calculated from digital data, was presented by KOTTEK et al. (2006).

BAILEY (1983) extended the concept of Köppen by defining a four level hierarchical classification to delineate ecological regions. For his world ecoregions map, he divided land areas into very large climate regions which he subdivided based on dominant potential vegetation, geomorphology and soil characteristics (BAILEY and HOGG, 1986). Almost simultaneously OMERNIK (1987) presented an alternative concept of ecoregions, which he recently defined as areas within there is spatial coincidence in characteristics of geographical phenomena including geology, physiography, vegetation, climate, hydrology, fauna, and soils. Additionally, impacts of human activity such as land use patterns and vegetation changes may be considered. Thus, we conclude that Köppen's climate classification is today embedded in biogeographical concepts such as the definition of ecoregions and biomes.

Modern climatology, however, is less concerned with the description of the climate than its prediction. Global biome models to predict the response of vegetation patterns to climate change start from the climatic tolerances of different types of plants (BOX, 1981), rather than from the apparent climatic distributions of biomes as they exist today[2]. Such a predictive model for potential natural vegetation was presented for example by PRENTICE et al. (1992). Results from recent dynamic global vegetation models projecting transient terrestrial ecosystem responses under rapid climate change were presented by CRAMER et al. (2001).

During the Köppen era the process of classification was exclusively based on human expertise. Today, however, human expertise is complemented by various statistical techniques. For example, HOFFMAN et al. (2005) applied multivariate spatio-temporal clustering to compare predictions from atmosphere-ocean general circulation models (AOGCMs) and also MAHLSTEIN and KNUTTI (2010) proposed the application of cluster analysis to objectively define global climate classifications.

2 Recent applications of Köppen's climate classification

The Köppen-Geiger climate classification fulfills the criteria listed in ESSENWANGER (2001), that a good climate classification must satisfy four principles: (1) It must be able to collate the mass of climatic data into a manageable and meaningful form, (2) it must be easy to apply, (3) it must be directed toward limited, well-defined objectives based on atmospheric parameters and (4) it must be based on meteorological principles. Especially the last point is not or insufficiently fulfilled by statistical methods, like the above mentioned cluster analysis. Although, unlike Köppen type classifications, cluster analyses produce extensively objective borders, their results are sometimes difficult to interpret. It is therefore not surprising that even today, almost 130

[1]Note that it goes beyond the scope of this article to give a complete overview of all authors significantly contributing to climate classifications.

[2]The discussion of KÖPPEN (1884a) on this topic may be summarized as follows: "Through the extinction of the large mammals in the temperate zone, humans have divided tropical and arctic animals already in the early days of civilization far more than given by nature. I refer to the Amur River area where just recently, the tiger chased the reindeer. The inference on climatic changes from the spatial distribution of higher animals is therefore only possible by considering the question comprehensively."

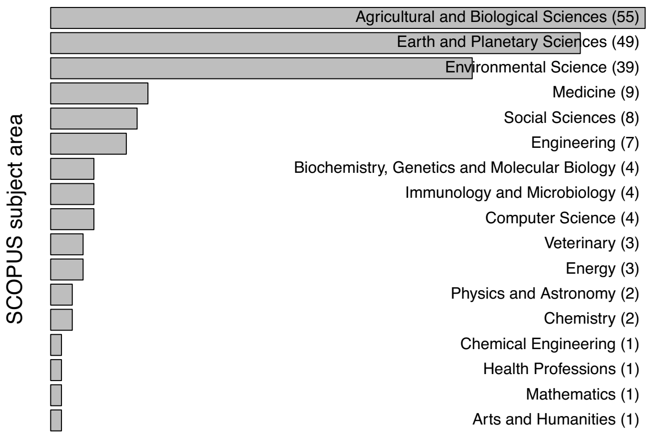

Figure 1: Absolute frequency of applications citing the updated world map of Köppen-Geiger climate classification (Kottek et al., 2006) according to Scopus research areas, received Dec. 29, 2010.

years after Köppen began to develop his climate classification, it is the one most widely used. Various authors proposed improved climate classifications based on those of Köppen, recently GUETTER and KUTZBACH (1990) for the verification of AOGCMs. Most of them are more suitable for selected applications than the original Köppen classification, but failed to match its popularity.

The final version of the Köppen's climate classification was edited by GEIGER (1961) in form of a large wall map for use in seminar rooms. An updated version of this map was compiled by KOTTEK et al. (2006); it was based upon global gridded temperature and precipitation data provided by the Climatic Research Unit (CRU) of the University of East Anglia and the Global Precipitation Climatology Centre (GPCC) at the German Weather Service. Fig. 1 depicts the frequency of applications citing the world map updated by KOTTEK et al. (2006) according to research areas listed in Scopus[3]. Acting as an indicator for todays applications, 28 % of the applications of the Köppen's climate classification were related to agricultural and biological sciences. At second place, 25 % were related to earth and planetary sciences, including climatology. At third place, environmental sciences are listed with 20 %, followed by medicine (5 %) and various other research fields (together 22 %). It is remarkable that Köppen's concept remains to be well-established today and applicable in almost all scientific disciplines.

In the following we reconsider an application which was not existing during the Köppen era, but combines traditional and modern climatology: The development of AOGCMs, especially the evaluation, comparison and presentation of AOGCM results. One of the first applications calculating Köppen-Geiger climate classifications from temperature and precipitation projections was presented by MANABE and HOLLOWAY (1975). They used the climate classification to simply verify the output of a global climate model. In consequence their concept was taken up by a number of authors. Recently ZHOU et al. (2010), for example, applied the main Köppen climate classes to investigate trends in the surface diurnal temperature range of observations compared to the projections of 12 AOGCMs. They found a decrease in the observed diurnal temperature range that was not realistically simulated by state-of-the-art AOGCMs depicting need of future research. In summary, we confirm the statement of GNANDESIKAN and STOUFFER (2006) that bioclimatic schemes, such as the Köppen climate classification, have to be considered as a standard part of future efforts to develop and evaluate AOGCMs.

It should also be mentioned that time series of Köppen's climate classification are strongly correlated with other well-established climate indices such as the North Atlantic (NAO) and Pacific Decadal Oscillation (PDO) as demonstrated by FRAEDRICH et al. (2001), who investigated observed climate shifts during the 20th century. Thus, Köppen's climate classification has found its place in modern climatology. Moreover, a study from JYLHÄ et al. (2010) suggested that maps illustrating projected shifts of Köppen climatic zones are an effective visualization tool for disseminating climate change information to experts as well as to the public. Nonexperts may benefit from this kind of information, because Köppen's climate classification is generally introduced already at school. RUBEL and KOTTEK (2010) contributed to the dissemination of climate change information by compiling world maps of Köppen-Geiger climate classification for the period 1901–2100.

3 Biographical notes

The meteorologist Professor Dr. Wladimir Peter Köppen was born in St. Petersburg, Russia, on September 25, 1846. His parents were German, and after attending school in the Crimea, he entered the University of St. Petersburg in 1864. He continued his studies at the Universities of Heidelberg and Leipzig. In Leipzig he completed his dissertation on the relationship between temperature and plant growth (KÖPPEN, 1870). From 1872 to 1873 he was employed in the Russian meteorological service and in 1875 he returned once again to Germany to take up an appointment as chief of the new Division of Marine Meteorology at the German naval observatory (*Deutsche Seewarte*) based in Hamburg where he established a weather forecasting service covering north-western Germany and the adjacent sea areas. During his time at the *Deutsche Seewarte* he primarily worked on sailing handbooks for the Atlantic, Indian and Pacific Oceans, respectively. In this sailing handbooks Köppen's well-known wind charts were included, which were used by Bergeron to develop his

[3]A citation database of peer-reviewed literature and quality web sources, available at www.scopus.com

classical map of climatological positions of air masses, fronts and weather (BERGERON, 1930). A comprehensive history of Köppen's contributions to wind climatology of the oceans was given by LEWIS (1996). Further work at the *Deutsche Seewarte* comprises the investigation of the upper air using kites and balloons. As a pionier in this upcoming research field Köppen became head of the Aerological Commission of the 1879 formed International (World) Meteorological Organisation.

In 1866 the journal of the Austrian Society for Meteorology, the *Zeitschrift der Österreichischen Gesellschaft für Meteorologie*, was founded and Köppen submitted his first scientific paper to it still in the same year. It appeared two years later (KÖPPEN, 1868) and was one out of 49 papers published by Köppen in this leading meteorological journal. The *Zeitschrift der Österreichischen Gesellschaft für Meteorologie* was replaced 1884 by the *Meteorologische Zeitschrift*, a joint journal of the meteorological societies of Austria and Germany (EMEIS, 2008). Köppen edited the *Meteorologische Zeitschrift* from its beginning 1884 to 1891, as from 1886 together with Julius Hann, the director of the *Austrian Central Institute for Meteorology and Geodynamics*. In the first issue he published two seminal papers: The first is the paper discussed here, the forerunner of his climate classification (KÖPPEN, 1884a) which appeared in full in KÖPPEN (1918), and after several revisions as final version in KÖPPEN (1936). The second described an early contribution to the statistical verification of weather forecasts (KÖPPEN, 1884b). His latest paper in the *Meteorologische Zeitschrift*, one out of his 227 contributions to this journal, appeared in 1940. In 1944, during world war II, the *Meteorologische Zeitschrift* was terminated but, after the German reunification, revitalised 1992 as new series (EMEIS, 2008). With the English translation of the classical paper of KÖPPEN (1884a) we appreciate the lifelong work of Köppen.

In addition to his numerous articles and scientific papers, a total of 526 listed in WEGENER-KÖPPEN (1955), Köppen was author of several textbooks. He coauthored with Alfred Wegener *Die Klimate der geologischen Vorzeit* (The climates of the geological past) published in KÖPPEN and WEGENER (1924). It is one of the funding texts of paleoclimatology providing crucial support to Milankovic's theory on ice ages. Furthermore he wrote *Grundriß der Klimakunde* (Outline of climate science), which was first published in 1923 and as revised version in KÖPPEN (1931). In 1927 he entered in collaboration with the German climatologist Rudolf Geiger to produce the five-volume work, *Handbuch der Klimatologie* (Handbook of Climatology). The handbook was not completed as he died on June 22, 1940, at age of 94.

Acknowledgments

We are grateful to Prof. Michael HANTEL for useful comments and suggestions and to Dr. Vincent LAPERRIÈRE for assistance in translating French historical papers.

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