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REVIEW

Geodetic grids in authoritative maps – new findings about the origin of the UTM Grid

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ABSTRACT

Recent discoveries of Wehrmacht Maps in the Military Archive of the Federal Archive of Germany in Freiburg im Breisgau raised the motivation for further investigations into the history of the internationally employed Universal Transverse Mercator (UTM) projection which actually represents a prerequisite for the global use of Global Positioning System (GPS) – and thus of any type of navigation – instruments. In contrast to the frequently stated opinion that this map projection was first operationally used by U.S. Americans it turned out that presumably the first operational maps with indication of the orthogonal UTM grid were produced by German Wehrmacht officers prior to the post World War (WW) II triumph of this projection. Based on the authors´ recent discoveries this article reveals some hitherto hardly known facts concerning the history of cartography of the 1940s.

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Introduction

Recent discoveries of Wehrmacht Orthophoto Maps in the German Federal Archive motivated the authors of this article to investigate into the origin of the Universal Transverse Mercator (UTM) Projection (cf. Section "The findings in the German Federal Archive"). Neither the seminal textbooks by John Snyder and Lev Bugayevskiy (Snyder 1982, 1993; Bugayevskiy and Snyder 1995) nor the recent U.S. American monographs about datums and map projections by Carnes (2007) and Iliffe and Lott (2008) give any indications about the early history of development of the UTM projection. During the investigations it turned out that this information was even missing in the German cartographic literature (cf. Heriszt 2001; Linke 2011).

In 2017, a rather important event in German authoritative cartography[1] celebrates its 100th anniversary: the "Treaty of Budapest" between the Second German Empire and the Austro-Hungarian Monarchy regarding the introduction of a uniform coordinate grid in topographic maps issued by authorities (Mang 1988). Since then, over a period of some 80 years, planar orthogonal coordinate systems were developed for both civilian and military applications. In June 1997 the "Arbeitsgemeinschaft der Vermessungsverwaltungen (AdV) der Länder der Bundesrepublik Deutschland" (Consortium of the Surveying and Mapping Authorities of the Federal Republic of Germany) decided to integrate those into their authoritative topographic map series. In addition to the previously used "Gauss–Krüger Grid", the map series had a "UTM Grid". Based on this act, Germany has, after a gap beginning in 1942, again a joint coordinate system for both civilian and military purposes.

Until today, apart from various Internet links by serious organizations/authors (cf. Section "Development until the beginning of World War II" of this article), many papers dealing with the development of the UTM Coordinate System have been published (i.a. Snyder 1993; Yang, Snyder, and Tobler 1999; Kennedy and Kopp 2001; Spata 2011; Hofmann-Wellenhof, Lichtenegger, and Collins 2001). All of them claim that this is a U.S. American development which, by the end of World War (WW) II, arrived in Europe and, hence, also in Germany. The recent discoveries in the Federal Archive of Germany, Section Military Archive, in Freiburg im Breisgau present this history in a different light. In this article, they will be described in some more detail.

Historical development until WW I

The military topographic survey of the 19th and 20th centuries was based on angular surveys of triangulations with the calculation of geographic coordinates of the geodetic data or control points on a mathematically

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constructed Earth body (ellipsoid). It resulted in detailed-scale topographic map series. These maps, however, did (mostly) not yet display orientation grids, and if, then only regionally. They were designed in different map projections: Prussia, the small North-German countries and Saxony had ordnance maps at a scale of 1:25,000 in polyedric projection, while Baden had a 1:25,000 topographic map series in polyedric projection, Hessen had an elevation contour map a scale of 1:25,000 in Cassini Cylindrical Projection, the first Kingdom and then Free State of Bavaria a 1:5,000 cadastral survey in Soldner Projection, and Wuerttemberg had a "Höhenflurkarte" (topographic land-register map) at a scale of 1:2,500 in Cassini Cylindrical Projection (cf. Deetz and Adams 1921). They served as basis for the derivation of a number of map series of smaller scales which were published without any grid. Due to the development of modern weapon systems, which permitted the abatement of targets over large distances, the military needed a means to quickly determine the exact position of targets on topographic maps.

Since the modern topographic land surveys have been carried out according to rigid mathematical methods, as of the beginning of the nineteenth century planar coordinate systems and projections evolved (primarily) for the cadastral survey, which were adopted and modified for the purposes of topographic survey and map production. The map projection which was for the first time developed and applied by Gerardus Mercator (1512–1594) for his large world map entitled "Nova et aucta orbis terrae descriptio ad usum navigantium" displays the earth in the form of a cylinder in polar-axial vertical position, i.e. parallel to the equator, where the projective cylinder touches the equator. "Mercator Projection", however, greatly enlarges regions which are far from the equator. Hence, Johann Heinrich Lambert (1728–1777) proposed a country-specific transversal axis of the cylinder, i.e. transverse to the poles and oriented along a meridian, whereby the projective cylinder touches this meridian (tangent meridian). The Frenchman Adrien Germain (1866, 347) called this Lambertian Projection for the first time "Transverse Mercator Projection". This term was then picked up by Carl Friedrich Gauss (1777–1855) and also for the first time practically applied to the Hanoverian Arc Measurement (1820–1823) and the Hanoverian Topographic Survey (1828–1844). Gauss called the mathematical basis of his "Gauss Projection" "conform".

Since 1876, the Prussian Topographic Survey used the Gauss Projection for the planation of the geographic coordinate system and for the calculation of the trigonometric nets and the data. The coordinates generated this way were called "Schreiber Coordinates", named after the initiator of this calculation method, Oskar Schreiber (1829–1905) (Mielert 1981). Geometric basis were the earth dimensions derived from numerous arc measurements carried out between 1735 and 1834 by Friedrich Wilhelm Bessel (1784–1846) which he published in 1841 and which later found international use under the name "Bessel Ellipsoid". In order to reduce the distortions in the Gauss Projection which increased in the West–East direction with increasing distance from the tangent meridian, the German Professor Wilhelm Jordan (1842–1899) suggested to limit the Schreiber Coordinates of the Gauss Projection to "konforme Koordinaten bis auf 200 km rechts und links vom Meridian mit den gewöhnlichen Formeln für ebene rechtwinkelige Koordinaten" (conformal coordinates limited to 200 km to the right and left of the meridian, using the common formulas for planar orthogonal coordinates).

In 1909, surveyor Heinrich Böhler (no lifetime information retrievable in available literature, cf. Hafeneder 2008) drew upon this idea when introducing a 3°-wide meridian strip system for the surveying of farm land in Deutsch-Südwestafrika (German South–West Africa). Also Louis Krüger (1857–1923) who, in his 1912 publication "Konforme Abbildung des Erdellipsoids in der Ebene" (Conformal Projection of the Earth Ellipsoid into the Plane) proposed so-called "Meridionalstreifen" (meridian strip) for the surveying of larger regions, adopted Jordan's idea. In honor of his development the new projection was named "Gauss–Krüger Projection". After 1912 the Prussian Survey introduced his projection for the triangulation in German East Africa.

From Budapest 1917 via Kassel 1923 to Moscow 1930

During the position warfare of WW I topographic maps with indicated uniform coordinate grids gained enormous importance. This caused the meeting of representatives of the "Oberste Militärische Vermessungsstelle im Deutschen Reiche und seinen Schutzgebieten" ("Supreme Military Survey of Deutsches Reich and its Protectorates", OMV) and the "K. u. K. Militärgeographisches Institut" (Imperial and Royal Military-Geographic Institute) on 21 July 1917 in Budapest and on 8 and 9 November 1917 in Berlin. In a final conference during these days in Budapest both powers agreed:

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> Further on, for surveying the Bessel Ellipsoid has to be applied. [. . .] As common coordinate systems orthogonal, conform, planar coordinates based on Gauss's meridian strips have to be introduced according to the formulas elaborated by "Geheimrat" (Privy Councilor) Prof. Dr. Krüger. This is to say with an extension of 3° in length, i.e. with 1.5° distance on both sides of the axis of abscissas (Central Meridian); further it has to be extended on both sides by 0.5° (over the border meridian) regarding overlap purposes for coordinate calculations. [. . .] The strips which effect both states have to be counted in their longitude based on Ferro. (cf. Krüger 1912. For the original German text see Appendix 1).

[Note: For the sake of scientific transparency and traceability all the original text passages we are referring to in this article are cited in their original German phrasing in the Appendices a–d. The frequently antiquated and peculiarly formulated mixture of administrative/authoritative and military German make for difficult translation into English.]

Bulgaria and the Ottoman Empire were also supposed to be included into this agreement. However, the upcoming end of WW I in the first instance stopped these already initiated works (Mang 1988). In this context, the history-related statements by Mark Monmonier that "the conformal cylindrical projections gained further converts during WW I, when military mapmakers adopted the transverse Mercator projection, centered on a regional meridian rather than the equator, for large-scale maps" are also of interest (Monmonier 2015b, 871). He draws upon Snyder (1993).

Nevertheless, primarily from the military side, this request was kept up, so that the "Reichswehrministerium" (German Federal [Reich] Ministry of Defense) suggested to the "Beirat für das Vermessungswesen" (Advisory Board for Surveying), which had been recruited as early as 1921 out of representatives of both Länder and Reich authorities (Imperial and States authorities), already during their first meeting in Berlin in April 1922 to change the previously used system of geographic coordinates based on the earth ellipsoid of Bessel for entire Germany to the Gauss–Krüger Projection agreed upon in 1917, with its 3°-wide meridian strips, yet based upon the longitude numbering originating in Greenwich. Moreover, it was proposed to print onto the sheets of the authoritative German map series up to a scale of 1:300,000 the derived "Gauss–Krüger Grid" of planar coordinates.

The numbering should be put into operation according to a proposal of Ministerialrat (Under Secretary) Gustav Baumgart (1873–1961) which he made already in 1919:

It has to be aspired to bring this numbering in accordance to the actual coordinate values. Thus, the numbering must not increase or decrease in relation to the position of the quadrants, but has to be realized for the whole map series in only one direction in a contiguous way. (Baumgart 1919. For the original German text see Appendix 2.)

Following his proposal the respective central meridian of a meridian strip is defined as the *x*-axis with a fix coordinate value of 500 km, denominated as "Rechtswert" (*x*-value). The *y*-axis coincides with the equator, and its coordinates are called "Hochwert" (*y*-value). The origin of each system lies at the intersection point of the respective central meridian with the equator. Hence (at least for the northern hemisphere), negative values and concomitant prefix errors are avoided. Because of the repetition of the coordinate values in every meridian strip and, consequently, due to the possibility of confusions, indices for the individual strips were introduced. Their numbering begins with the central meridian through the Greenwich Observatory, starting with "0", in the eastward direction and is applied as a prefix to the actual coordinates of the *x*-values. Thus, the strip between 1° 30′ and 4° 30′ with its central meridian at 3° gets the Index "1", the adjacent one between 4° 30′ and 7° 30′ with its central meridian at 6° the Index "2", etc. This way the strips covering Germany got the indices 2 through 8. This proposal was unanimously accepted during the second meeting of the Advisory Board in Kassel in May 1923 (Albrecht 1984).

This "Deutsches Einheitssystem" (German Unified System), as it has been called since its beginning, also served as master copy for the establishment of the authoritative cartography of the then young Soviet Union. It was intended that the entire territory of the largest country on earth should be triangulated and subsequently mapped following the German example (Kneißl 1943a, 1943b). However, for this mammoth task very soon the 3°-wide strips turned out to be too small and too computationally intensive, in particular for large-area surveys. Thus the Soviets decided to introduce a 6°-wide system. The distortions thereby occurring at the margins are still tolerable and fall for topographic maps within the tolerance range of drawing. During the 1930s Soviet geodesists had calculated a triangulation network for the USSR based on the Bessel Ellipsoid. On the basis of this concept a new type of topographic maps evolved, following the map index of the 1:1,000,000 International Map of the World (IMW; Internationale Weltkarte – IWK) proposed in 1891 by

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the German geographer Albrecht Penck (1858–1945) and agreed upon at the International Geographic Conferences in London 1909 and 1928 as well as in Paris 1913 (Penk 1941).[2] The meridian strips of the Soviet variant of the Gauss–Krüger Grid exactly correspond to the strips of the IMW. Thus, the central meridian of the grid and the central meridian of the map sheets of a strip of the International Map of the World are coinciding. The numbering of the meridian strips begins with the central meridian at 3° East with Index "1" eastwards and is prefixed to the actual coordinates along the x-axis. The strips covering Germany have the indices 2, 3, and 4. This, however, implies a very likely confusion with the 3°-strip numbering.

Development until the beginning of WW II

According to Smith and Black (1946)…

> Some understanding of these relationships and of the achievements of German wartime geography can be obtained from a brief discussion of the work and personnel of three of the top war agencies: Mil-Geo in the Army [OKH], Mar-Geo in the Navy [OKM], and the Forschungsstaffel of the Supreme Command of the Armed Forces (Oberkommando der Wehrmacht, or OKW). (cf. Häusler 2007a)

> […] however, the OKW did not have command power over OKH, OKL and OKM. Frequently responsibility disputes prevented a structured coordination of these three Wehrmacht units. In particular, concerning questions of tactical and operational warfare, frequently the OKW came into conflict with OKH. (Scriba 2015. For the original German text see Appendix 3.)

Interestingly enough, in their account of the "geographical" work during the war, Smith and Black (1946) are not mentioning anything about the Oberkommando der Luftwaffe (OKL).

Soon after the outset of WW II the "Deutsches Einheitssystem" (German Unified System) was extended beyond the borders of Germany by adjoining the systems of the neighboring countries. With the raid of the Soviet Union through the Deutsche Wehrmacht in June 1941 and the rapid advance of the German troops the materials of the geodetic–cartographic administrations of the USSR fell into German hands, amongst them the top-secret coordinate lists and the new topographic maps. When examining these materials the Germans were surprised by the high quality of the work of the Soviet experts. This lead to the 1:1 adoption of the Russian data by the "Deutsche Heeresvermessung" (German Military Survey) and to the war maps through the connection of the Soviet system to the German Unified System as well as the extension of the 6° meridian strips up to the Atlantic Ocean (Kneißl 1943b). This implied that subsequently in Germany two different coordinate grids were used. The Soviet system, which was developed on the basis of the German conception, was only used for military purposes and named "Deutsches Heeresgitter" (DHG, German Army Grid) or "Europäisches Einheitssystem" (European Unified System) and since 1943 used as geometric basis for all newly generated "Deutsche Heereskarten" (German Military Maps). In order to avoid confusion with the continuously used 3°-strip system of the civilian domain, the German Unified System was further on officially called "Deutsches Reichsgitter" (DRG, "German Reich Grid", Kneißl 1943a, 1943b).

With the beginning of WW II the importance of simplified locating grids on topographic maps increased in a way that the individual troop services began to develop different locating systems for their particular purposes and to insert them into the grids of the respective map series (tri-service: Air Force Locating Grid, Army Locating Grid, Navy Locating Grid).

On 18 April 1940, a "Luftwaffendienstvorschrift" (Air Force Joint Service Regulation) about "Kartengebrauch und navigatorische Flugvorbereitung" (Map Use and Navigational Flight Preparation) was issued on behalf of the "Reichsminister der Luftfahrt und Oberbefehlshaber der Luftwaffe" (Reich Minister of Aviation and Commander-in-Chief of the German Air Force 1940) by the "Chef des Ausbildungswesens" (Chief of Staff Training) (Source: RdLuObdL ChAusbW VorschLmAbtRLM/LIn12 76/40. See also: Schrödter 2015).

The "Luftwaffenmeldenetz" (Air Force Locating Grid; "Gradnetzmeldeverfahren", grid-locating method) consisted of so-called "Zusatzzahlgebiete" (add-on number areas) with an extension of 10° in both geographic latitude and longitude, originating at 0° in eastern and western directions, and setting out from 1° southern latitude in northern and southern directions (Oberbefehlshaber der Luftwaffe & Chef des Nachrichtenverbindungswesens 1943). The index of the add-on number area was derived from the first digit of the value of the intersection point of longitude and latitude of its northwest corner with indication of the hemisphere. The trapezoid between 0° and 5° eastern longitude and 49° and 59° northern latitude reads thus "05 Ost" (05 East). Subsequently, it is partitioned into 100 "Großtrapeze" (large trapezoids, 10 in the N–S direction × 10 in the W–E direction) of both 1° geographic latitude and longitude, originating at the southwestern corner of an add-on number area with

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a two-digit number consisting out of band- and column numbers between 0 and 9. This results in a labeling from 00 to 99. Each large trapezoid is then divided into 8 “Mitteltrapeze” (middle trapezoids) of 30′ geographic longitude and 15′ geographic latitude, starting in the northwestern corner, using numbers between 1 and 8. These are, again, segmented into 9 “Kleintrapeze” (small trapezoids) of 10′ geographic longitude and 5′ geographic latitude, numbered according to the middle trapezoid from 1 to 9. Each small trapezoid was divided into 9 even-sized “Meldetrapeze” (location-reporting trapezoids), and those again into 9 even-sized “Arbeitstrapeze” (working trapezoids), labeled “a” through “i”. As a result, coordinate reporting was executed through the declaration of add-on number area, large, middle, small trapezoids, location-reporting and working trapezoid. This implies that an add-on number area consisted of 100 large trapezoids, 800 middle trapezoids, 7200 small trapezoids, 64,800 location-reporting trapezoids, and finally 583,200 working trapezoids. Thus, we are dealing with a very complex and error-prone system which did not allow position fixing by means of planar orthogonal coordinates (Source: RdLuObdL ChAusbW VorschLmAbtRLM/LIn12 76/40. See also: Schrödter 2015).

The “Deutsches Heeresmeldenetz (geographisch)” (German Military Reference Grid [geographic]) also consisted of large trapezoids, however only between 2° 30′ longitude and 1° 40′ latitude, starting from the Zero Meridian according to Greenwich in both eastern and western directions and from 1° northern latitude (!) in both northern and southern directions, drawing their naming/labeling from the name of the most prominent settlement located in the respective trapezoid. These large trapezoids are subdivided into 625 (25 × 25) small trapezoids of 6′ geographic longitude and 4′ geographic latitude, starting from the northwestern corner of the large trapezoid toward southeast, with a labeling consisting of a letter-pair formed by the band- and the column-letter (A through Z each, without “I”s). This results in labeling from AA to ZZ. Each small trapezoid is then subdivided into 9 location-reporting trapezoids of 2′ geographic longitude and 1′ 20″ geographic latitude, originating at the northwestern corner with continuous numbering from 1 to 9. Each location-reporting trapezoid is eventually consisting of four working trapezoids, called a, b, c, and d. The coordinate determination thus follows the listing of large, small, location-reporting and working trapezoid as well as through an estimate of the object distance from the southwestern corner of the working trapezoid in tenths toward east and north. This system simplifies the grid-locating method significantly, it can, however, not deliver unambiguous orthogonal coordinates (Source: RdLuObdL ChAusbW VorschLmAbtRLM/LIn12 76/40. See also: Schrödter 2015).

The *enhanced* “Heeresmeldenetz” is based upon the 6° meridian strips of the German Army Grid and its strip numbers. The old small trapezoids were converted into 625 (25 × 25) grid squares (for location-reporting) with an extension of 6 km × 6 km. Thus, along the borderlines of the “Meridianstreifen” (meridian strips) so-called “Restquadrate” (residual squares) are developing. The labeling of the grid squares corresponds to that of the small trapezoids. The origin of their labeling, however, is now located at the intersection point of the respective central meridian and the integral 150 km northing-value. This results in “Großquadrate” (large squares) of 150 km side length. The further subdivision of the grid squares corresponds to the aforementioned variant. This system unifies the grid square with a planar orthogonal coordinate system. However, this approach shows a significant deficit: every 150 kilometers the grid squares in the meridian strip are reoccurring, thus giving space for confusions. They can only be avoided through the declaration of the map sheet number of the respective map series used for location reporting (Source: RdLuObdL ChAusbW VorschLmAbtRLM/LIn12 76/40. See also: Schrödter 2015).

In a further step, attempts were made to develop a standardized and easy-to-handle location-reporting procedure for all branches of the Deutsche Wehrmacht on the basis of an orthogonal coordinate grid:

> The coordinate grids so far plotted on the map sheets including the Deutsches Heeresgitter (German Army Grid) are admittedly applicable for location reporting, but not fully practical. A big number of troops-tests tried there in different ways to bring about an improvement. All these attempts have in common the idea to substitute the coordinate determination of two separate dimensions (easting and northing values) by an areal designation with the denomination of squares or trapezoids. The Air Force Location Reporting Law doubtlessly presents the most comprehensive attempt in this direction so far, however, only the fact that it cannot [. . .] assert itself in the army, shows that it does not fully suit the needs of the army. The denotation has to contain figures and letters in continuous alternation and for shooting purposes the system has to be indispensably orthogonal. The German Army Grid combined with an areal assignment of the squares will surely represent the final solution. (Junker 1942. For the original German text see Appendix 4.)

The abovementioned solution loomed very soon. Based upon the German Army Grid a new reference system

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with grid-square was developed which went into field trial in 1944. The numbering of the meridian strips of the reference grid was unified with the IWK2 strip labeling and, hence, with the new "Deutscher Heeresblattschnitt (DHB)" (German Military Map Sheet Indexing, abbreviated DHB). It originates at 180°, numbering from there eastwards. The strips covering Germany are numbered 31, 32, 33 and 34. This avoids confusions between the strip labeling of DHG (remember: "Deutsches Heeresgitter", German Army grid) and DRG (remember: "Deutsches Reichsgitter", German Reich Grid). The problem of labeling repetition of location-reporting grid squares was solved through the introduction of new large trapezoids (cf. grid-locating method). For this purpose within every meridian strip so-called "Zonenfelder" (zones) of 8° geographic longitude were introduced, originating at 80° southern latitude and labeled with the capital letters C through X (without I and O in order to avoid confusions with the Figures 1 and 0). The polar caps are covered by separate zones labeled A and B at the South Pole and Y and Z at the North Pole. Thus, at that time Germany was covered by the zones 31U, 32T, 32U, 33T, 33U and 34U. Each zone was 6° wide (E–W) and 8° high (N–S) and thus comprehended two sheets of the IMW (IWK). This served the purpose to exclude confusions with the sheet labeling of the IMW and the German Military Maps.

Each zone was then subdivided into 100-km squares east and west of the central meridian as well as north and south of the equator. These squares were labeled with letter pairs (always without I and O) consisting of the band- and column letters. The numbering originates at the intersection point of the 180° meridian and the equator (Strip1/Zone 1), for the bands with the letters A to V in the northern direction and for the columns with the letters A to Z in the eastern direction. In doing so, the alphabet is repeated in the West–East direction after three zones (meridian strips) and in the South–North direction after 2000 km. Consequently, each square in a zone occurs only once, and confusions are utterly out of question, a fact which is an inevitable prerequisite for a global application. For good measure, the initial letter for the numbering of the bands of all three zones changed between A and F. For a coordinate determination the grid value of the respective object represented by the vertical and horizontal grid lines immediately west and south is read and then the residual values estimated in tenths. A complete location report has to comprehend the 100-km square label and, if required, that one of the zone. This results in an alphanumerical location statement in direct connection with the planar orthogonal coordinate grid. This grid reference system was, in an abbreviated way, then called "UTM-REF" (Universales Transversales Mercator-Referenzsystem), its name being derived from the internationally common term "Transversale Mercator-Abbildung" ("Transverse Mercator Projection") for the Gauss-Krüger "Abbildung". It was only after these achievements, that, on 30 April 1943, the triggering unit for most of these developments, the "Abteilung Luftbildwesen" (Department for Aerial Photography) was dissolved (Boog 1982).

The findings in the German federal archive

The discoveries described in this section were made in 2014 by the second author of this article. Eight black-and-white orthophoto maps at a scale of 1:25,000 in the "Blattschnitt" (sheet indexing) of the German Topographic Map 1:25,000 (10′ geographic longitude and 6′ geographic latitude) covering part of the Prussian province of Ostpreussen (East Prussia) in the area of the Curonian Spit and 31 black-and-white

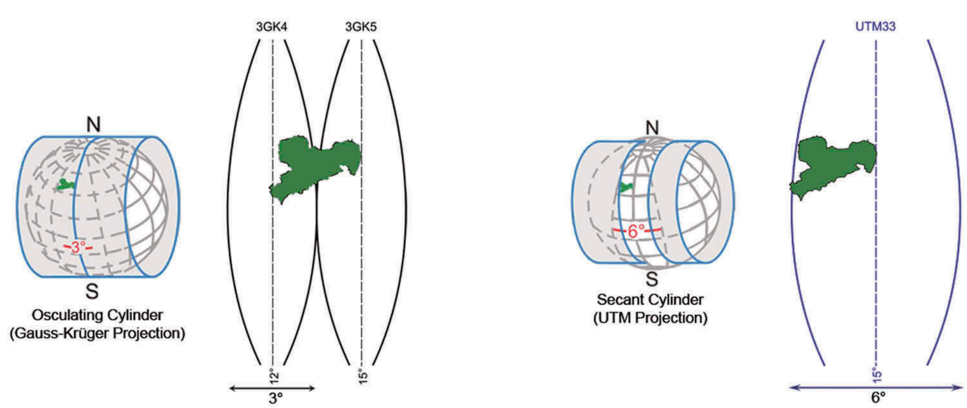

Figure 1. Comparison between Gauss–Krüger (left) and UTM projection (right) showing both the osculating cylinder of Gauss–Krüger and the secant cylinder of the UTM projection as well as the corresponding longitude zones. (http://www.landesvermessung.sachsen.de/inhalt/etrs/grund/grund.html).

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orthophoto maps 1:25,000 of the Estonian coast of the Baltic Sea between Tallinn and Narva in sheet lines of 12′ geographic longitude and 6′ geographic latitude were handed down. They bear the stamp of the Nautical Archive of the "Oberkommando der Kriegsmarine" (Supreme Command of the Navy) with handwritten signatures dating from August 1944. The orthophoto maps of East Prussia were produced by the "Stabsbildabteilung G des Luftflottenkommandos 6 (Einsatzraum im Mittelabschnitt der Ostfront, Heeresgruppe Mitte)" (Staff Air Photo Department G of Air Fleet Command 6; operational area in central portion of eastern front, Army Group Mitte/Center), while the orthophoto maps of Estonia were made by the "Bildmeßstelle Gotenhafen der Marinevermessungsabteilung" (Photogrammetric Plotting Office Gotenhafen/Gdynia/Gdingen of the Navy Survey Department).

All orthophoto maps have one thing in common: At the lower margin one finds indications of the "UTMREF", standing for "UTM Reference". E.g., Orthophoto Map Sheet 0292 Memel bears UTMREF34UEG0578.

Since all sheets are located at or close to the coast, there are good reasons for the assumption that this is due to the fact that the Germans tried to unify the different grid-locating methods of army, air force and navy (using the so-called "Marinequadrate", [Navy quadrangles]).

In order to prove the originality of the discovered map sheets, analyses of these photographic reproductions by means of magnifying glass (factors 15–20) and microscope (factors up to 100) were carried out by the first author. It could be clearly seen that the various collateral information outside the map frame has been drawn on the orthophoto with template and ink. Discussions with experts on historical drawing inks at the University of Heidelberg/Germany (Research Group Prof. Ernst Pernicka) pointed toward the provenance from WW II times. This proved that these map products and their marginal information was labeled by manual work. The authenticity of the three features framed red in Figure 2 demonstrates that the discovered maps have in fact been produced by the Deutsche Wehrmacht during the years 1943 and 1944.

Due to the fact that to the authors′ knowledge no clarifying archival materials from the "Abteilung Luftbildwesen" (Department for Aerial Photography) stood the test of the turmoil of war, it seems so far not clear what happened with DHB, IWK, and which organizations developed each system. If, however, the statement by Boog (1982), that with effect from 30 April 1943 the Department for Aerial Photography was dissolved, is correct, this fits well in with the fact that (later in 1943 and) in 1944/45 the Marine Survey Unit of the OKM, the Supreme Command of the German Navy, produced – and, hence, also used – the UTM-referenced orthophoto maps (cf. Figure 2–8).

Be that as it may, model for the 100-km grid squares might have been the "British Modified System". It consists of country-specific 500-km "Großquadrate "(large squares) labeled with letters which are, again, subdivided into 25 100-km "Kleinquadrate" (small squares) and numbered from upper left to lower right using the letters A to Z (without I). A location reference within a 100-km square consists of the two letters of the respective large and small squares in combination with orthogonal coordinates (Kneißl 1943a, 1943b).

Development of UTM projection in the United States

Practically all Internet sources draw upon "a whimsical, yet serious look" back into what he calls the "Dawn of a New Era 1940–1950" by Joseph F. Dracup (2006). He devotes a short "section" or rather paragraph in his historical account "Geodetic Surveying 1940–1950" to these activities. It was "last updated on 8 June 2006":

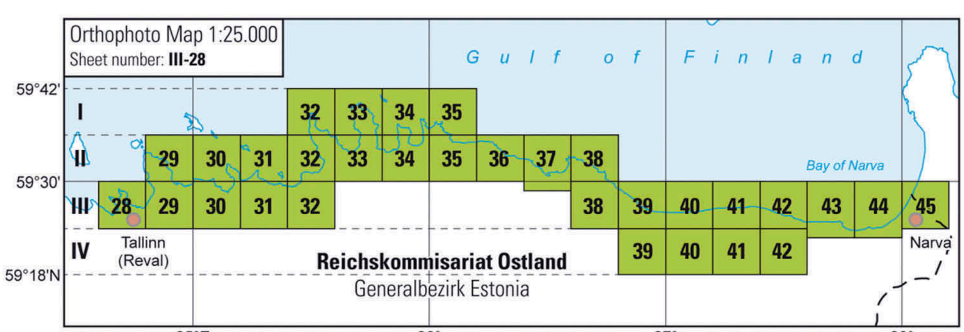

Figure 2. Sheet index of the archived 1:25,000 Orthophoto Maps (green) of Estonia (design René Pfahlbusch).

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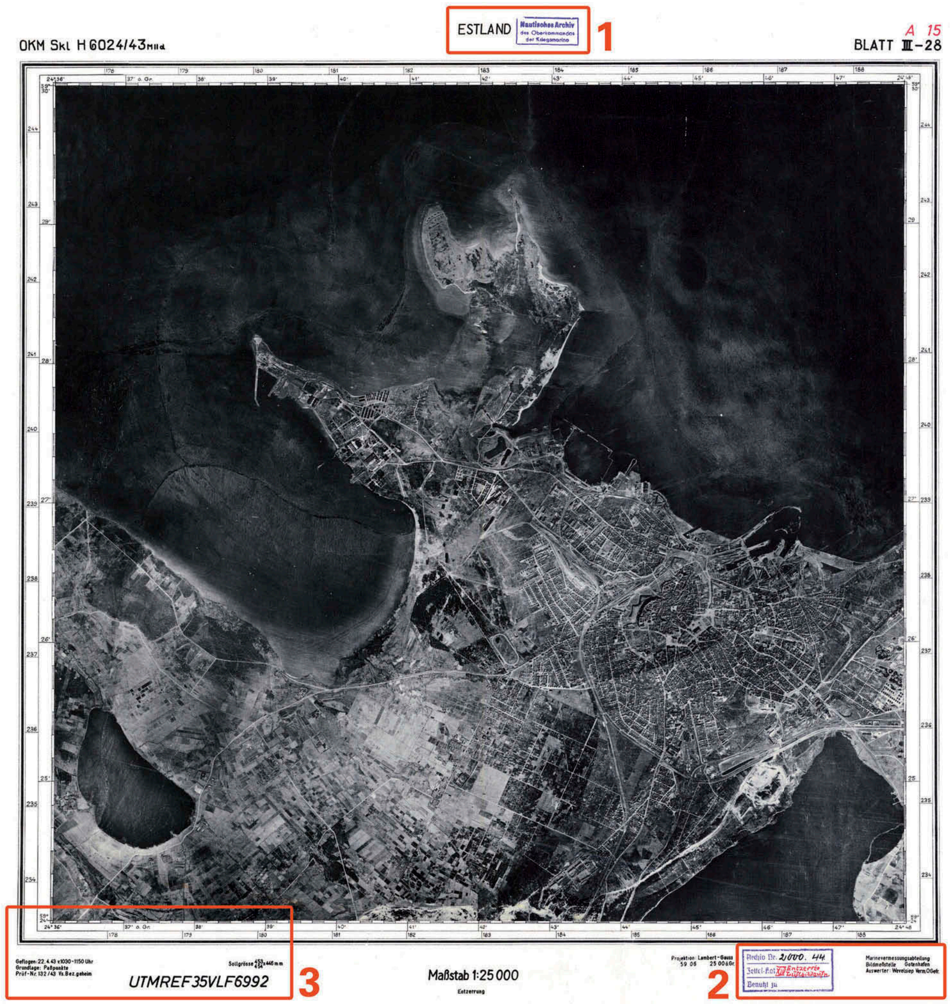

Figure 3. 1:25,000 Orthophoto Map, "Reichskommissariat Ostland – Generalbezirk Estland" (Reich Commissariat Eastland – General District Estonia), Sheet III-28 (figure downscaled), based on aerial photos taken in April 1943. Red frames and numerals indicate details displayed in the following figures.

Figure 4. Template-written title of map sheet and property stamp of the archive of the supreme command of the "Deutsche Kriegsmarine" (German Navy). Cf. Figure 3.

UTM Grid Developed

The Universal Transverse Mercator (UTM) grid, a worldwide plane coordinate system was developed in the 1940's by the Corps of Engineers, U.S. Army, following the recommendations of Oscar S. Adams of the C&GS Geodesy Division. The grid consists of bands, 6 of longitude wide, and a maximum scale reduction of 1:2,500. Original tables (for the Clarke spheroid of 1866) were computed by a Civil Works project, in NYC, sponsored by the U.S. Lake Survey (USLS) during the early 40's. The USLS unit evolved into the Geodetic Division of the Army Map Service (AMS) about 1943. Later, tables were computed for other ellipsoids then in use. Floyd W. Hough, David Mills, Homer Fuller and Frank L. Culley were directly associated with the grid's development. (Dracup 2006)

The AMS was reorganized at the end of the World War II, with many staff returning to peacetime occupations. However, the General Staff and the Corps of Engineers realized that the need for mapping meant that the AMS needed a program to match the U.S. global role. A program was instituted that would provide adequate maps for all areas of vital interest to the U.S. Army Forces, replacing map substitute products where necessary and providing map coverage where none existed. There was also an expansion of the program to collect existing map coverage of foreign areas and intelligence data. A new uniform military grid system, the Universal Transverse Mercator (UTM), was adopted to replace more than 100 grids used during World War II. The design of maps was overhauled to meet user requirements, and interservice map standardization was adopted (United States,

Figure 5. Archive shelf-mark and indication of map producer (right). Cf. Figure 3. The German term "Zettel-Kat." stands for index-card catalogue, indicating that it concerns rectified aerial photos ("Enzerrte Luftbildaufn."). The three template-written text lines to the right refer to the producer, the Marine Survey Unit of the OKM (cf. "Development until the beginning of World War II", top) with its "Bildmeßstelle" (Photogrammetric Plotting Office) in Gotenhafen, today Gdynia. Even the name of the "Auswerter" (respective photogrammetric operator: Surveying Private First Class Wevelsiep) is given.

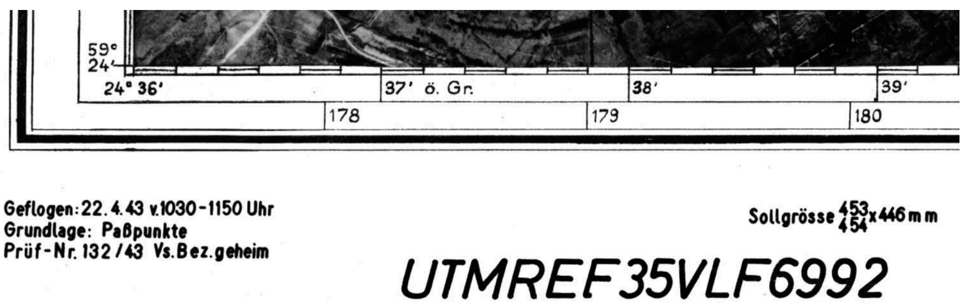

Figure 6. Aerial photo-acquisition date and template-written UTMREF inscription. Cf. Figure 3.

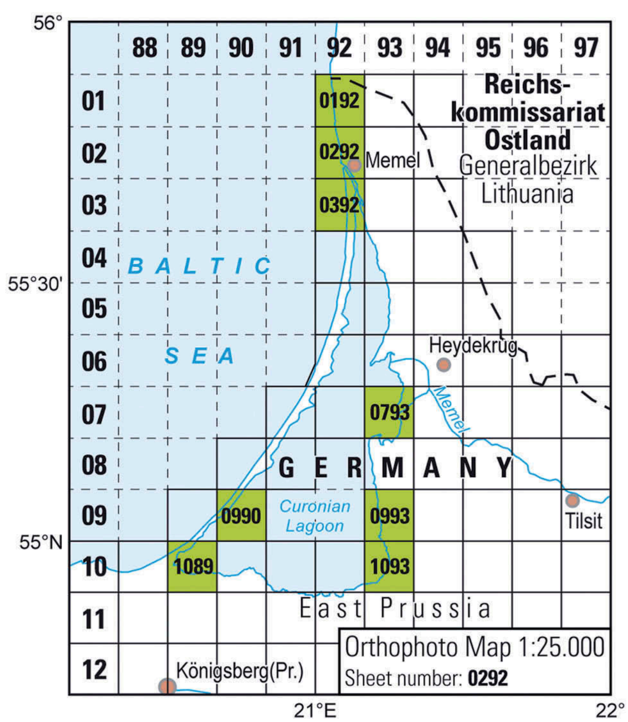

Figure 7. Sheet index of the archived 1:25,000 orthophoto maps (green) of East Prussia. They correspond to the sheet lines of the German Topographic Map 1:25,000. Cf. also the sheet index of today´s NATO map series M852 and N851 (Section "Post-war period"). (Design René Pfahlbusch).

Army Map Service 1960). These changes did not take in isolation, as cooperation with the British continued into the postwar era. With the formation of the North Atlantic Treaty Organization (NATO), the changes in map design and the adoption of the UTM grid took on a wider international role. (Withington 2015a, 888)

So, the cited sources in the three above paragraphs contain no concrete chronological information, other than stating "in the 1940`s" or – in the case of the mentioned "Civil Works" project – "in the early 1940`s" UTM was developed by Americans. A look into various Internet sources gives the impression that all other authors drew upon Dracup's statement.

[For the respected reader who is not so familiar with U.S. history: From its establishment in 1802, the U.S. Army Corps of Engineers has had a dual role to support both military activities and the development of the United States. The latter activities by the Corps, still on-going, are "civil works" programs (to distinguish them from military works) (US Army Corps of Engineers Headquarters without publication year). The "Civil Works Administration", however, was only a short-lived "work relief program that gave jobs to many unemployed people.... It was created in November 1933, and was abandoned only a few months later in the spring of 1934." (Hardmann 1999).]

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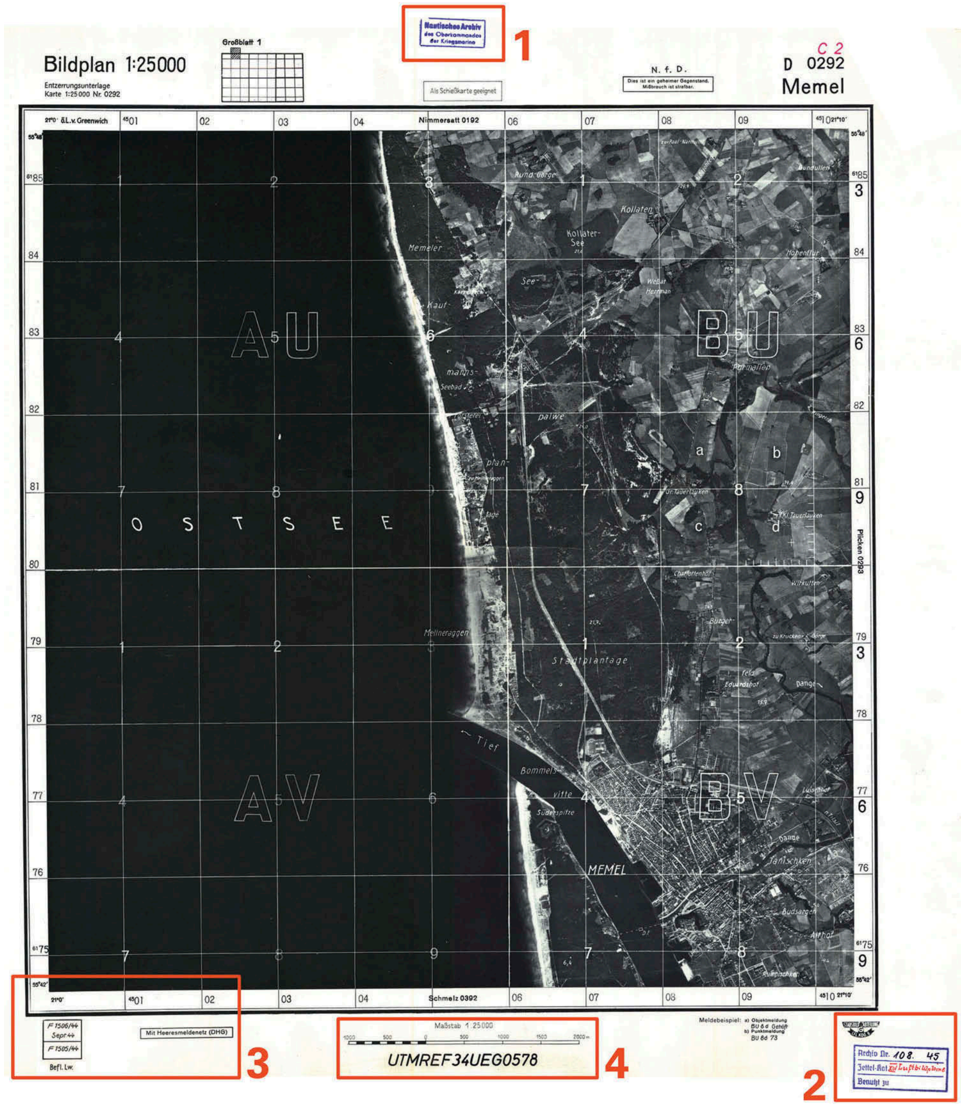

Figure 8. 1:25,000 orthophoto map, Deutsches Reich, Sheet 0292 Memel (figure downscaled) with "Deutsches Heeresgitter" (German Army Grid) with "Deutsches Heeresmeldenetz" (German Military Reference Grid: AU, BU, AV, BV etc.), based on aerial photos taken in September 1944. Red frames refer to essential features mentioned in this article. 1: Property stamp of the Archive of the Supreme Command of the "Deutsche Kriegsmarine" (German Navy). 2: Archive shelf-mark. 3: Aerial photo numbering with date of data acquisition. 4: Template-written UTMREF inscription with numerical scale and scale bar.

The renowned U.S. American map historian John W. Hessler also seems to draw upon Dracup`s above mentioned statement in his article about confirmality in the seminal book about the "Cartography in the Twentieth Century" (Monmonier 2015a). Practically all Internet sources draw upon Dracup (2006) when writing that the "development and adoption of the UTM coordinate system by the U.S. military [took place] in the 1940s." (Hessler 2015, 273).

Hence, either the assignment to the Civil Works project(s) or the UTM development time declaration is wrong. Also the official "Civil Works History" site of the Office of the Assistant Secretary of the Army for Civil Works does not shed light upon this question, other than stating "… and in 1943 the Bureau of the Budget became the chief monitor of the nation's Civil Works program." (Assistant Secretary of the Army for Civil Works Without publication year). The document of Adams (1937) appears to clarify the issue about the Civil Works Administration. It seems that the work done at the Geodetic Survey was indeed catalyzed by that short-lived organization.

Now, where is the truth? Is there "only one truth"? We believe that our investigations can at least prove that already in 1942/43 the Germans had developed the theoretical basis for UTM and then made extensive field trials in 1944 latest. Whatever the case may be, let us have a look at the development after WW II. This might shed some additional light onto the historical reality.

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Post-war period

Various U.S. American as well as German sources state that shortly after WW II, as from 1947 on, the UTM system has been used by the U.S. Armed Forces in U.S. Military map series (cf. e.g. Heriszt 2001).

> In the West, the political strength of the United States and the creation of the North Atlantic Treaty Organization (NATO) and other military alliances prompted a need for compatible topographic maps and coordinate systems (as well as standardized formats and symbols). Reflecting this priority, the U.S. Army Map Service in 1947 utilized the Gauss–Krüger platform to produce the Universal Transverse Mercator (UTM) system, which divides the globe into sixty north–south zones, each six degrees wide. This extensive system, an alliance of projection and reference grid, produced much discussion and some dissension, particularly over excessive fragmentation at high latitudes. After the UTM framework was modified to cover polar areas with the polar stereographic projection, another conformal framework, it became the dominant projection for worldwide topographic coverage (Steward 2015a, 1186).

With the complete military occupation of Germany through the Allied Forces in spring 1945 the largest part of the German geodetic documents and records stored in the Thuringian temporary evasion quarters of the "Reichsamt für Landesaufnahme" (RfL, Reich Office for Surveying) and the "Kriegskartenhauptamt" (Main Office for Military Maps) fell into the hands of the American troops. The U.S. Army Map Service (AMS) immediately examined these "German Materials, as they came to be called" (Cloud 2002, 264, cum lit.) and recognized its value. Since Thuringia was by negotiation provided as part of the Soviet Occupation Zone, all the material and the expert staff was evacuated to Bamberg in the American Occupation Zone. Directly after the war (Bamberg Conference in June 1945), with cooperation of staff members of the former RfL, a new geodetic "armaments program" for Europe began. Leading members of the mapping activities of the Deutsches Reich, last not least of the Reconnaissance Unit "Dora" and the "Forschungsstaffel zur besonderen Verwendung" (Research Squadron for Special Deployment) were, during the first months and years after the war, interrogated by the Americans.

In his memoirs, Wolfgang Pillewizer (1911–1999), first member of the Reconnaissance Unit "Dora" and then of the "Forschungsstaffel zur besonderen Verwendung" (cf. Stams 2012) and as chair holder of cartography predecessor of the first author of this article, describes in considerable detail the interrogations of himself and also other members of the Reconnaissance Unit "Dora" and the "Research Squadron for Special Deployment" by OSS, the Office of Strategic Services, the then military secret service (Pillewizer 1986). In his book and later during oral communications with the prime author in the 1990s, he also mentioned that one task of the "Forschungsstaffel" was the mapping of possible "extension areas" of the Deutsches Reich, and that immediately after the war OSS chased him and subsequently kept him detained in Kransberg Castle, Germany, over 16 months for interrogations about his cartographic activities in Eastern Europe and outside Europe (cf. also Häusler 2007b; Buchroithner, Koch, and Stams 2012). There, not only thematic but also geometric questions of the cartographic work were subject of the questioning.

Due to the fact that by the end of the war an anything else but insignificant part of the cartographic material generated by Forschungsstaffel "Dora" has been destroyed, it is practically impossible today to prove that the mapping activities of the Deutsche Wehrmacht were actually motivated by German intentions of expansion (cf. Häusler 2007a, 2007b as well as oral communication by Wolfgang Pillewizer with the prime author few years prior to his death). Also, the U. S. troops eagerly took possession of all the original cartographic material of the renowned Swedish explorer of Central Asia Sven Hedin (1865–1952) which was archived at Justus Perthes Publishers in Gotha/Thuringia (Buchroithner 2007, also oral communication of Dr. Manfred Reckziegel (1951–2012) late Chief Cartographer at Perthes, with the prime author in 2005).

Based on the German work-results (Reich Triangulation Network, DRG, DHG, and UTM-REF) the European 1st order triangulation networks were adjusted using new methods. In 1950, the development activities for this "European Triangulation Network", which could be connected with the adjacent networks of Northern Africa and the Middle East, were completed. Consequently, a new geodetic datum for Europe and its periphery, the European Datum 1950 (ED50), was, as a standardized geodetic framework, available for military purposes.

The present article does not claim to indisputably clarify how UTM came to be so widely used. It seems, however, – in the light of the statements made in the above paragraphs – to be a matter of fact that on the basis of the "Deutsche Heereskarten" (German Military Maps) the AMS initiated a new map projection. In distinction from the tangential cylinder of the German/Soviet Gauss–Krüger Projection a secant cylinder was introduced for the individual median strips which now shortens the central meridian to a factor of 0.9996 (i.e. 1 km in nature is shortened by 40 cm), and hence the distortions occurring in every strip are more equally distributed. The numbering and labeling of the meridian strips was borrowed from the German UTM-REF, and this referencing method was completely integrated. That is most probably why this projection, also in the USA, received its name "UTM Projection" (Universal Transverse Mercator Projection). The geodetic basis was now provided by ED50 referring to the earth dimensions published in 1909 by John Fillmore Hayford (1868–1925). In 1924 his "Hayford Ellipsoid" was recommended by the International Union of Geodesy and Geophysics (IUGG) as the International Ellipsoid. The planar orthogonal coordinates of this map projection were now called "UTM Coordinates", the reference grid "UTM Grid". The difference to "Gauss–Krüger Coordinates" is that, corresponding to the "British Modified System" the *x*-coordinate number is called "Easting" and the *y*-coordinate value "Northing". For the reference grid also the bold representation of the 10-km grid-lines and the labeling of the grid-lines with shortened coordinates were adopted for the habitus of the large-scale map sheets. "Beginning in 1949, the North Atlantic Treaty Organization (NATO) standardized the scales of maps and charts and adopted the use of a single coordinate system, the Universal Transverse Mercator (UTM), [...]" (Boulanger 2015, 908).

Through a "Standardisierungsübereinkommen" (Standardization Agreement – STANAG) this new geodetic system und the corresponding "Meldeverfahren" (location reporting method) became the military coordinate system of the European NATO countries in 1951, and this grid was also printed into the 1:25,000 German topographic map sheets, which were in part up-dated by the means of aerial photos. Until 1953 all map sheets published by the United States Army Map Service (AMS) were then used by NATO (Clough 1952). They displayed the series labeling M841 (Germany 1:25,000), M851 (Poland 1:25, 000), M852 (East Prussia 1:25,000), N851 (Lithuania 1:25,000) (cf. Figure 6) and M873 (Czechoslovakia 1:25,000) with reference to the borders of 31 December 1937. For the USA and Canada the system was introduced on the basis of the North American Datum of 1927 (NAD27).

After the war, in the civilian domain the surveying and mapping administrations of Bundesrepublik Deutschland (Federal Republic of Germany), then consisting of the three western (American, French, British) occupation zones, continued working with the reference system enacted in 1923. After the accession of Western Germany to the NATO in 1955 this led to problems. While on the civilian side, due to the considerable reorganization effort and the insufficient accuracy regarding cadastral survey, a new orientation in favor of this international system was declined, the newly established Deutsche Bundeswehr (German Federal Armed Forces) were required to publish the military maps according to NATO standards. Thus, for the production of authoritative map series the duplication of work caused by the war, which began in 1942, continued over 40 more years. The new German Topographische Karte 1:50,000 received for its civilian edition a 3° Gauss–Krüger Grid in Gauss–Krüger Projection based on the Bessel Ellipsoid, whereas the military edition (Series M745) got a 6° wide UTM Grid based on the Hayford Ellipsoid. The same is true for the new German Topographische Karte 1:100,000 (Series M645 and M648). Only the Federal State of Schleswig-Holstein constituted an exception, using the military editions for civilian purposes, too.

In the 1980s, steps were taken into the direction of a reorientation of the geodetic basis used within NATO. With the meanwhile established World Geodetic System of 1984 (WGS84), which is supported by the operational application of the Global Positioning System (GPS), for the first time NATO disposed of a uniform geodetic reference system. With definite effect of 1 January 1994 the German Federal Armed Forces introduced it.

> A notable achievement of NATO Geographic Policy was the early resolution of the plethora of British Military Grids in use over Europe at the end of World War II by the introduction of the Universal Transverse Mercator (UTM) grid on NATO maps and aeronautical charts. GEOREF (World Geographic Referencing System) was also introduced, but its use was mainly limited to aeronautical charts, and it had fallen out of use by the end of the [20th] century. (Withington 2015b, 894)

At this time the general geopolitical " [...] trends led to a commonly repeated observation in the latter decades of the century that non-Universal Transverse Mercator/Universal Polar Stereographic (UTM/UPS) grids were being phased out." (Steward 2015b, 1188).

Subject to the increasing use of the declassified GPS data the need for GPS-conform coordinates kept growing. During their 96th Meeting the AdV ("Arbeitsgemeinschaft der Vermessungsverwaltungen", Consortium of the Surveying and Mapping Authorities of the Federal Republic of Germany; see Section "Indroduction") decided in May 1995 to introduce the European Terrestrial Reference System (ETRS89), i.e.

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the European variant of WGS84, as geodetic reference system. For cartographic applications both systems can be considered identical. Within their 101st Meeting in June 1997 AdV passed the resolution to enter, beside the already previously used Gauss–Krüger Grid (in black), also the UTM Grid (with blue lines) into the civilian topographic map series. At this very meeting the Head of the German Military Geo Office of the Bundeswehr suggested to publish joint civilian-military map series and, hence, to introduce the UTM coordinate system, previously only used by the military, to all German authoritative map series in a universally valid way. It was at the 106th AdV Meeting in Potsdam in the year 2000 that eventually the resolution was adopted to produce the joint civilian-military Topographische Karte 1:50,000. In 2005 the German Federal States and the Bundeswehr concluded an administrative agreement about the publishing of a joint civilian-military Topographische Karte 1:100,000. With that, today uniform topographic map series with a globally valid coordinate system are freely available for use, and the dualism between civilian and military map editions in Germany came to an end.

Conclusion

With the AdV Board decisions in 1997 and 2000 the internationally common UTM coordinate system was introduced for all German authoritative topographic map series. Its roots, however, virtually reach back to the year 1917. The history of its origins is characterized by the distresses of two world wars and the subsequent Cold War between the two super-powers USA and Soviet Union. Early German research and development results were adopted by the Soviet Union in the 1930s and later by the USA and gained worldwide recognition – last not least through the introduction of the UTM system by the NATO member states in 1951. The end of the Cold War and the release of the military satellite navigation system of NATO for civilian purposes led to its final breakthrough. This implies that today almost all industrialized countries use for their authoritative map series a geodetic coordinate system which has its origin, for the most essential part, in Germany. In the twenty-first century, in a world of ubiquitous application of GPS at a global scale, UTM Projection became simply a *conditio sine qua non* for everyday life.

Notes

1. Concerning a concurrent statement about today's nature of "authoritative cartography" and its present transitive nature the authors kindly want to refer to the deliberations of Éric Loubier during his keynote address at ICC 2013 (Loubier 2013). In the present article, a conservative, "historical" annotation of this term is implied.
2. German: IWK – Internationale Weltkarte 1:1,000,000; English: IMW – International Map of the World.

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Appendix. Citations from original German literature

(1) Für die Erdmessung ist das Besselsche Ellipsoid auch weiterhin beizubehalten. [. . .] Als gemeinsame Koordinatensysteme sind rechtwinkelige, konforme, ebene Koordinaten nach Gauß in Meridianstreifen nach den von Geheimrat Prof. Dr. Krüger ausgearbeiteten Formeln einzuführen. Und zwar Meridianstreifen mit einer Ausdehnung von 3° in der Länge, d.h. mit 1,5° Abstand beiderseits der Abszissenachse (Mittelmeridian), und ist ausserdem zwecks Übergreifung die Koordinatenberechnung beiderseits noch um 0,5° (über den Grenzmeridian) auszudehnen. [. . .] Die Streifen, welche alle beteiligten Staaten gemeinsam zu durchlaufen haben, sind in Länge nach Ferro zu zählen (Krüger 1912).

(2) Es muss angestrebt werden, diese Bezifferung mit den tatsächlichen Koordinatenwerten in Übereinstimmung zu bringen. Die Zählweise darf nicht nach der Lage der Quadranten steigen und fallen, sondern muss in ein- und derselben Richtung fortlaufend durch das ganze Kartenwerk erfolgen (Baumgart 1919).

(3) [. . .] eine Kommandoberechtigung über OKH, OKL und OKM besaß das OKW allerdings nicht. Häufig verhinderten Kompetenzstreitigkeiten eine geordnete Koordination aller drei Wehrmachtsteile, und vor allem mit dem OKH trat das OKW bei Fragen der taktischen und operativen Kriegführung wiederholt in heftigen Widerstreit (Scriba 2015).

(4) Die bisher in die Karte eingetragenen Gitternetze einschl. des deutschen Heeresgitters sind für Meldezwecke zwar brauchbar, aber nicht praktisch voll zweckmäßig. Eine große Zahl von Truppenversuchen suchte auf verschiedenartige Weise hierin Besserung herbeizuführen. Allen Versuchen gemeinsam ist der Gedanke, das koordinatenmäßige Festlegen von zwei getrennten Dimensionen (Rechts- und Hochwert) durch eine flächenhafte Bezeichnung mit Benennung von Quadraten oder Trapezen zu ersetzen. Das Luftwaffenmeldenetz stellt wohl den größten bisher durchgeführten Versuch dar, doch zeigt allein schon der Umstand, dass es sich beim Heer nicht [. . .] behaupten kann, dass es den Heereszwecken nicht voll entspricht. Die Bezifferung muss Ziffern und Buchstaben in ständigem Wechsel aufweisen und für Schießzwecke muss das System unbedingt rechtwinkelig sein. Das deutsche Heeresgitter, verbunden mit einer flächenhaften Bezeichnung der Quadrate wird wohl die Endlösung darstellen (Junker 1942).

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