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Intercomparisons, Error Assessments, and Technical Information on Historical Upper-Air Measurements

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Abstract. Upper-air data form the backbone of weather analysis and reanalysis products, particularly in the pre-satellite era. However, they are particularly prone to errors and uncertainties, especially data from the early days of aerology. Information that allows to better characterize the errors of radiosonde data is important. This paper reports on an attempt to collect data from historical upper-air intercomparisons and from historical error assessments reaching back to the 1930s. The digitised numerical data will be made available through Copernicus Climate Change Services; here we publish the full information that includes images, literature, and other metadata that may be relevant and can be used to inform homogenization approaches or reanalysis production. The data collection described in this paper is available on PANGAEA https://www.pangaea.de/tok/9e5b464ba828e931103d3794d9ae1d4576f7a03d (Imfeld et al, in review).

1. Introduction

Despite the advanced use of satellite data in analysis systems, upper-air data from weather balloons still form the backbone of weather analysis and reanalysis products. This is particularly the case in the pre-satellite era. Although surface-only reanalyses have become highly successful (Compo et al., 2011; Laloyaux et al., 2018; Slivinski et al., 2019), better results could be gained by assimilating the available upper-air data (Hersbach et al., 2017), which on a large scale reach back to the 1910s (Stickler et al., 2015; Ramella et al. 2014; Durre et al. 2018). However, the quality and homogeneity of radiosonde data is a serious issue and could hamper the proper use of these data in reanalyses. Statistical methods have been used to generate more consistent radiosonde products (e.g., Lanzante et al., 2003; Sherwood et al., 2008). Some homogenization methods successfully make use of the background departures from reanalysis data sets (RAOBCORE, Haimberger 2007; RICH, Haimberger et al., 2012). However, most homogenization approaches rely entirely on statistics.

An alternative would be to use information on the measurement system and corresponding errors. Such information is sometimes available from direct comparisons, from other systematic trials or analyses or even laboratory tests. Compiling such information might support future homogenization efforts and might inform future reanalysis projects. Grant et al. (2009) used a physics-based correction approach to obtain consistent

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corrections; error classes were diagnosed based on the shape of the error profile. Today, assimilation systems could possibly make use of such additional information, e.g., to better define online bias correction schemes.

Within Copernicus Climate Change Services (C3S) contract C311c, a data base of error characterizations of radiosonde was compiled. In particular, the data base contains data from radiosonde intercomparison campaigns. These data will be incorporated into the global radiosonde data set, such that reanalyses and other applications can make use of it. However, only the numerical data such as the ascents from intercomparisons can be made available via C3S. Here we present and publish the complete documentation which includes the data itself, and also additional metadata such as imaged graphical data, handbooks, technical literature translated from Russian and an expert interview.

The paper is organised as follows. Sect. 2 gives an overview of the history of radiosonde intercomparisons and error assessments. This is important to understand the material at hand. Sect. 3 describes the compilation and structure of the database. In Sect. 4 we discuss findings and present examples. Conclusions are drawn in Sect. 5.

2. Historical background

2.1. Intercomparison campaigns

Upper-air measurements, particularly in the early decades, were extremely demanding in terms of instrumentation posing a challenge for their first designers (e.g., Diamond et al. 1937; Lange, 1937). Measurement devices need to be lightweight, operate under an extremely large range of conditions (e.g., they need to cover a temperature range from 30 °C to -80 °C within an hour or a pressure range from 1040 to 10 hPa), and each instrument only operates for a short time. The instruments are exposed to radiation, freezing clouds, and strong winds. Both systematic and random errors in these situations are large. Furthermore, the transmission of the data and their processing introduces uncertainties.

Scientists such as Gustave Hermite were aware of the overheating of sensors due to radiation at high altitudes already in the very beginning of unmanned balloon flights. His observations, in 1893, of high temperature at 16 km were therefore considered erroneous (Hermite, 1893). To overcome this problem, several strategies were selected including statistical approaches (comparing day and night ascents), intercomparisons (parallel measurements with manned and unmanned balloons, Labitzke 1999), and laboratory studies (better characterization of instruments). The same strategies are used until present.

Already in the early years it was considered important to coordinate and compare results (Assmann et al., 1898). In 1896, the program of „International Days" was established: One day per month on which participating countries performed their ascents. Later one „International Week" per year was added. These coordinated ascents were interrupted during the First World War and resumed in the 1920s. In 1927, two French scientists managed to transmit the measurements through a radio transmitter to the ground. This was the start of the development of a worldwide radiosonde network and the need for further intercomparisons was stated (Jeannet et al., 2016). For instance, in 1935, in the context of an „International Week", Norway and Sweden agreed to launch additional ascents at two locations, Nesbyen and Filipstad, 296 km apart (Nyberg et al., 1942) with the same radiosonde types in order to compare the instrument errors. These data are part of our collection.

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The first World Meteorological Organization (WMO) intercomparison of radiosondes took place in Payerne (Switzerland) in 1950 (Painter, 1950) as many countries started operational upper-air networks after the Second World War and the WMO had been a newly founded body to coordinate such activities. Intercomparisons then increased in anticipation of the International Geophysical Year (IGY) in 1957/58. A regional intercomparison was performed in Brussels in 1954 (Malet, 1955) and a second global intercomparison of radiosondes was organised in Payerne in 1956 in preparation of the IGY (Beelitz, 1958). Further global intercomparisons took place in 1968 (in several countries, see Kuzenkov and Shlyakhov., 1976), 1984/85 (UK/USA), 1993 (Japan) and 1995/7 (USA/Russia). In addition, important regional intercomparisons were carried out in Payerne (1981; Richner and Phillips, 1982) and Crawley, UK (1987 and 1992; Bond et al., 1988) as well as in the Former Soviet Union (FSU) in 1984 and 1985 (Kazakova, 1998; Karhunen et al., 1987; Zaitseva et al., 1989). For some campaigns however, precise information on the radiosondes were missing (e.g. Goltsova et al. 1974) or the comparison has been made against other thermometers, but not radiosondes (e.g. Krechmer et al. 1969), which are thus not be added to the database.

The raw data from past intercomparisons are often not available electronically (for some campaigns not even on paper) and distribution is limited. For some campaigns, however, assessments and statistics have survived, and perhaps these are the more important products.

Today, radiosonde intercomparisons have become a standard procedure within the WMO to assure the quality of the global radiosonde network, the most recent intercomparisons took place in 2001 (Brazil), 2005 (Mauritius), and 2010 (China) (Nash et al., 2006; da Silveira et al., 2006; Nash et al., 2011). Within GCOS (Global Climate Observing System), the GRUAN (GCOS Reference upper-air network) was established as a reference, and with this the quality is further enhanced (Seidel et al., 2009).

2.2. Characterisation of errors and instruments

There are other ways to characterise the error of a radiosonde than intercomparisons with other radiosondes. For instance, statistics of day versus night ascents can be used to estimate the radiation error. Radiosondes and sensors can be analysed in the lab, and well understood influences (e.g., the lag) can be modelled. It is therefore important also to compile information from such sources. Brönnimann (2003) has compiled some of the early information. Reports are available, for instance, for the Finnish (Väisälä, 1941, 1949; Raunio, 1950), German (Scherhag, 1948), and UK Met Office (Scrase, 1954) radiosondes.

In the FSU, a considerable amount of studies on radiosondes has been conducted (e.g., Balagurov and Fridzon, 1983; Balagurov et al., 1984; Shlyakhov and Kuzenkov, 1973; Zaichikov 1957 and 1962; Zaitseva et al., 1989), whereof reports and correction values are available at the WDC/RIHMI in Obninsk, Russia. A selection of these error assessments has been added as well to our database.

In the early days, measurements were not fully operational, procedures and instruments were changing and not always well documented. Although several error sources were known (e.g., the lag error) and understood, it is sometimes unclear whether a correction (e.g., of the radiation error) was performed or not. It is therefore important to also compile hand books from early times. Our compilation contains the hand book for the Lang radiosonde that gives insights into lag corrections that have been applied to the Lang radiosondes in 1940 (Reichsamt für Wetterdienst, 1940). A set of hand books has also been collected by the "Museum of Radiosondes of North America". Its content can however only be accessed on request and is not available online

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(see http://radiosondemuseum.org/, last accessed 2020-09-17). Detailed technical descriptions of the very early radiosonde systems up to the year 1950s can as well be found in Dubois et al. (2002) and for example for the British Radiosonde in Lander (1946) and Lange (1937).

In the context of the IGY, Beelitz (1958) compiled the information on current and planned operational corrections, which is useful to determine, were corrections have been applied. Many countries started operational corrections of the soundings only after the IGY of 1957/58.

2.3. History of station networks

In order to relate error estimates derived from intercomparisons or error assessments to the operationally used radiosondes by weather services, it is important to know the changes a station network underwent and to be able to identify radiosondes properly. This is especially relevant regarding the missing international standards of early radio soundings. A range of radiosonde manufacturers has existed since the early 1930s that used different sensor types, radiation shielding or applied different corrections to the data, which often led to difficulties when comparing soundings that have been conducted in different countries (Painter, 1950).

A station history of a network needs to include instrumentation changes, applied corrections, launching procedures, or also information on transmission systems. An attempt to provide a comprehensive summary of radiosondes and station histories from different countries has been made by Gaffen et al. (1993). By contacting a vast amount of weather services, they established a document of historical changes of radiosonde instruments and practices for 49 countries covering the period between the 1930 and 1990. The summary reports on the used radiosondes in the 1990s as well as previously used radiosondes. Further, it lists a large amount of radiosondes including their sensor types of temperature, pressure and humidity measurements and applied corrections.

WMO established a table of common-codes for radiosondes, but prior to the 1960s radiosonde descriptions are equivocal and its coverage is by no means exhaustive (WMO, 2019). A comprehensive list including radiosondes from the very early days of aerology (e.g., the Britain Biram's anemometer suspended from a kite in 1883) up to 2014 has been compiled by S. Schröder from the Texas A&M University (personal communication). This inventory covers even small instrumentation changes or changes in transmission frequencies. It relates each radiosonde to a unique reference identifications and where possible to the codes established by WMO. For example, for the Väisälä radiosondes, more than 200 different radiosonde types are found in the collection including the earliest radiosonde developed in 1931. Fig. 1 shows three different Väisälä radiosondes from 1937, 1971 and 1981, that are part of Schröder's list, as well as our database. It is also worth mentioning the radiosonde collection from an association devoted to finding radiosondes in Europe. Their website offers a detailed though not very systematic description of sensors of very old to more recent radiosondes including pictures of the radiosondes (http://radiosonde.eu/RS03/RS03A01.html last accessed 2020-09-17).

A large collection of radiosondes has also been compiled by the aforementioned "Museum of radiosondes from North America", that includes worldwide used radiosondes, as well as artefacts, such as balloons and batteries.

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Figure 1: Left: Three types of Väisälä radiosondes: The Väisälä RS-11 was introduced in 1937 and won a gold medal in the world fair at Paris (vaisala.com). Middle: Väisälä RS-21 from 1971 (radiosondemuseum.org). Right: Väisälä RS-80-N from 1981 with its original packaging (radiosondemuseum.org). All three radiosondes have been used in the intercomparison campaigns in our collection. They correspond to comp002fin (left), comp009van (middle) comp009v80 (right). Note, that the introduction dates may vary because of slight modification of the instruments.

3. The Database

3.1. Compilation of the database

For the compilation of the database (Imfeld et al., in review), we started by creating a list of intercomparison campaigns, comprising global (WMO organised), regional and national campaigns based on existing documents (e.g. Jeannet et al., 2016). This list of regional and national intercomparisons is however not exhaustive. Not all intercomparisons are equally important with the prospect of building a global data set. National intercomparisons were less important, and those focusing on specific parts such as the boundary layer (e.g. Kaimal et al. 1980) also were not of high priority. Rather, we set priority to historical campaigns (i.e. the first intercomparison campaigns that were conducted), assuming that these data are more error-prone and hence corrections more important.

We searched the archives of the MeteoSwiss aerological station of Payerne (Switzerland, e.g. Fig. 2) and WDC/RIHMI Obninsk (Russia) to obtain raw data from early intercomparisons, and obtained further data via interlibrary loan. Furthermore, we also searched for other literature (including laboratory, statistical etc.). We consulted WMO with regards to data from more recent intercomparison campaigns and had meetings with scientists who performed radiosonde intercomparisons in the 1970s and 1980s (Hans Richner, ETH Zürich, and Pierre Jeannet, MeteoSwiss, Payerne). The interview with Hans Richner was recorded and can be found in the database (in German).

Digitization of raw data as well as aggregated data was performed based on this list of intercomparisons (Tab. 1). Raw data allow own analyses, but the analyses performed in the aftermath of the campaigns had all the expert information, which might be relevant, and usually the results are preferable (e.g., for determining corrections). However, all intercomparisons have the problem of a missing standard. There is no agreed standard, so only pairwise comparisons can be made.

We made quality checks of the digitised data (mainly the ascent data) to find digitizing errors. These checks included simple consistency checks, e.g., whether the data is within a reasonable range, whether pressure is

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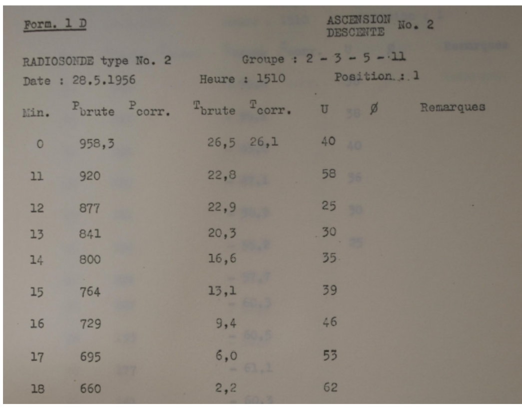
decreasing and cross-checks of geopotential altitude with the hydrostatic balance. No additional quality control has been performed on the data; suspicious values have not been corrected if they corresponded to the values on the original image.

With respect to error assessments, we digitised relevant information from tabular data and even graphical data (e.g. Fig. 3). The scope of the digitised error assessment is however much smaller compared to the intercomparison campaigns. In addition, studies on errors and intercomparisons from the Soviet radiosondes found at the WDC/RIHMI Obninsk were translated into English and are incorporated into the database. The full collection of translated literature is publicly available under https://github.com/MBlaschek/CEUAS/tree/master/CEUAS/public/intercomparisons



Form. 1 D

ASCENSION DESCENTE No. 2

RADIOSONDE type No. 2 Groupe : 2 - 3 - 5 - 11

Date : 28.5.1956 Heure : 1510 Position : 1

Min.	P_{brute}	$P_{corr.}$	T_{brute}	$T_{corr.}$	U	Ø	Remarques
0	958,3		26,5	26,1	40		
11	920		22,8		58		
12	877		22,9		25		
13	841		20,3		30		
14	800		16,6		35		
15	764		13,1		39		
16	729		9,4		46		
17	695		6,0		53		
18	660		2,2		62		

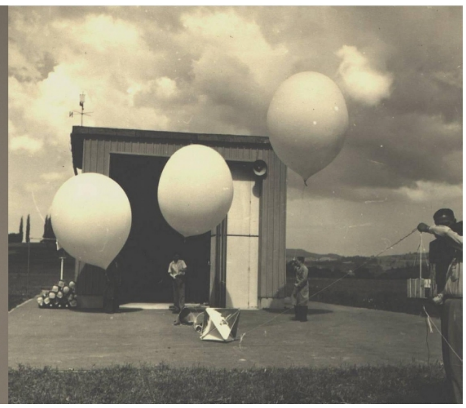


Figure 2: Left: Sounding data from the 1956 campaign held in Payerne, Switzerland, from the archive of MeteoSwiss in Payerne (own image). Right: At the beginning of the campaign, soundings were performed with four radiosondes on a train of balloons (archive of MeteoSwiss). Within the course of the campaign this procedure changed to 13 radiosondes on a train of several balloons.

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Table 1: Digitised intercomparison campaigns between 1935 and 1995 containing raw ascent data and statistics. For full table of intercomparison campaigns, refer to link provided in Sect. 5.

ID	Name	Year	Country code	Location	Participating county or sonde	Data digitised	Literature
COMP001	International Ascents	1935	NOR, SWE	Norway and Sweden	Jaumotte meteorographs	ascent data	Nyberg et al. 1942.
COMP002	Global Intercomparison	1950	CHE	Payerne	Finland, Swiss, USA (2 types of sondes), France, UK, US Zone Germany	ascent data in minutes, statistics	OMM, 1951; OMM, 1952; Nyberg, 1952; Painter, 1950.
COMP003	Regional Intercomparison	1954	BEL	Brussels	Western Germany (GRAW H50), Netherland (KNMI-Philips) UK (KEW MK 2), USA (AN/AMT 4, Bendix 403 Mc/s)	ascent data in minutes	Malet, 1955.
COMP004	Global Intercomparison	1956	CHE	Payerne	Belgium JRM, West Germany (Graw H50), East Germany (Lang, improved version), USA (AN/AMT4), Finland (Väisälä), France (Metox), Japan (CMO- S 56), India C (chronometric), UK (Kew Mk IIB), Netherlands (Philips)	ascent data in minutes, statistics	OMM 1956, Väisälä 1957, Beelitz 1958.
COMP005	Global Intercomparison	1968	JPN, DEU, RUS, GBR	Tateno, Stuttgart, Saint Petersburg, Bracknell	Finland, Federal Republic of Germany, Japan, FSU, UK, France	statistics	Kuzenkov and Shlyakho, 1976; Shlyakhov and Kuzenkov, 1973.
COMP007	ASOND-78	1978	CHE	Payerne	Väisälä RS18, VIZ 1292, Swiss BASORA	ascent data at standard pressure level	Richner and Philips, 1981.
COMP009	SONDEX-81	1981	CHE	Payerne	AIRSONDE Univ Bonn, ASA Swiss Army Weather Service, Graw RSG78 DWD, Sprenger E076 Sprenger, Swiss SMI, Thommen Swiss Artillery Weather Service, Väisälä RS18 Univ. Zurich, Väisälä RS21 Väisälä, Helsinki, Väisälä RS80 Väisälä, Helsinki, VIZ 1392 ETH Zurich	statistics	Richner and Philips, 1982.
COMP010	Regional Intercomparison	1984	RUS	Northern Atlantic	Meteorit-RKZ, RS-21 (CORA)	statistics	Kazakova, N.N., 1998
COMP011	Global Intercomparison (WMO)	1984	GBR	Beaufort Park	Finland (RS80-15N), UK (RS3), USA (VIZ 1392-510), OCAN (1524-511), Federal Republic of Germany (G78C)	ascent data in minutes and at standard pressure levels	Hooper, 1986.
COMP012	Regional Intercomparison	1984	BLR	Minsk (Former Soviet Union)	USSR (RKZ-2), Finland (RS80-15N)	statistics	Karhunen, Trifonov and Yurmanov, 1987.
COMP013	Global Intercomparison (WMO)	1985	USA	Wallops Island	Australia (Philips RS4 MK3), Finland (Vaisala RS80-15N) India (Mk-III), United States (VIZ Model 1392), Graw M60	ascent data in minutes and at standard pressure levels	Schmidlin, 1988.

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COMP014	Regional Intercomparison	1985	RUS	Northern Atlantic	USSR (RKZ-2) Finland (RS80-15N)	statistics	Zaitseva, Akhmetyanov and Karhunen, 1989.
COMP015	Regional Intercomparison	1987	GBR	Crawley	UK-RS3, AIR (pre-operational), Väisälä RS80-15, Väisälä RS80-15L, Väisälä RS80-15N	statistics	Bond et al., 1988.
COMP016	Global Intercomparison (WMO)	1989	KAZ	Dzhambul (Former Sovier Union)	USSR (MARS-2), China (SMA-TC-1/SMA-GZZ), Finland (RS80-15N), USA (VIZ 1392), UK (AIR IS-4A)	ascent data in minutes and at standard pressure levels	Ivanov et al. 1991.
COMP018	Global Intercomparison (WMO)	1993	JPN	Tsukuba	Japan (RS80 and RS2-91), Finland (RS80-15N, RS80-15LH and RS80-15U), USA (AIR IS-4A-1680HS and AIR IS-4A-403L), USA (VIZ Mark II)	ascent data in minutes and at standard pressure levels	Yagi et al. 1996

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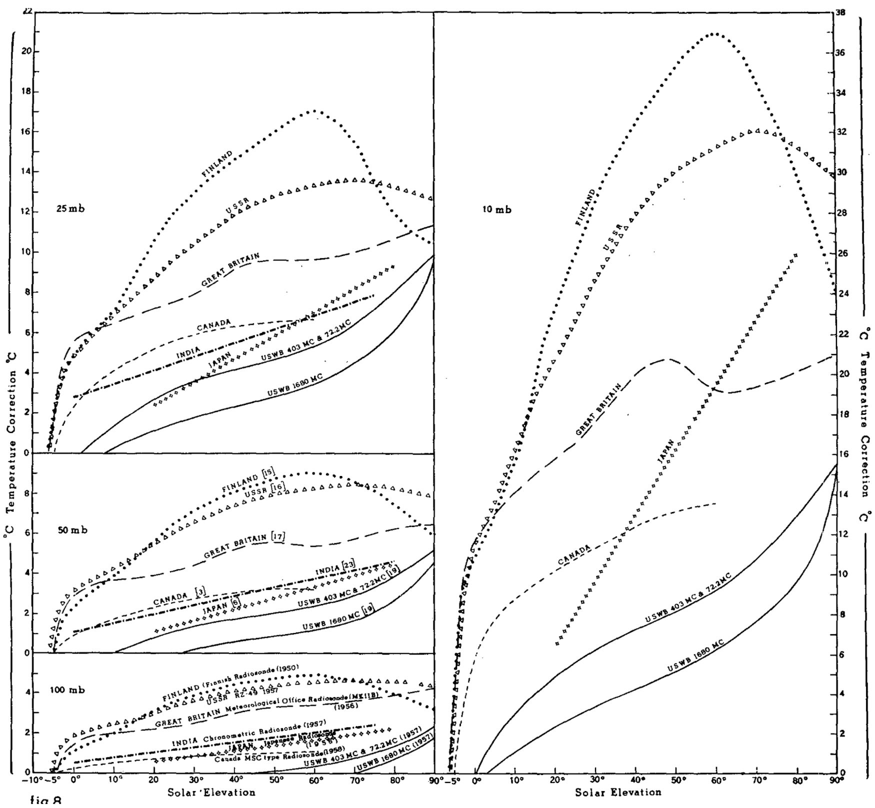

Figure 3: Radiosonde temperature biases due to radiation for different radiosonde types, pressure levels, and solar elevation angles (from Tweles and Finger, 1960).

3.2. Database structure

Intercomparisons can have different set-ups: Different radiosondes can be flown on the same balloons, on different balloons at the same time, different balloons at different times, or even different balloons at different times and different places. The comparison of pressure is for example only possible if instruments are flown on the same balloon; then time can be used as the common axis in the data format. Also, the intercomparison campaigns are sometimes accompanied by statistical evaluations that present relative errors per radiosonde type, pressure level, etc. This information is also important as it embodies the expert knowledge of the authors, such as applied corrections. An organization of the data must thus be found that retains all the original information while also making use of the evaluated data and that allows easy access to metadata and original images.

We structured the database therefore along two main threads of information: a table of intercomparison campaigns and a table of error assessments (see Fig. 4 for structure of database). Both types are linked to a third thread of information, a list of radiosondes, which reports information on the sonde type and relates them to operationally used radiosondes. To relate all types of information, we introduced a specific nomenclature for the campaigns, error assessments and radiosondes. Intercomparison campaigns are named with COMPXXX, where

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XXX relates to one campaign. All information related to one campaign is named correspondingly. Error assessments are named as CORRXXX.

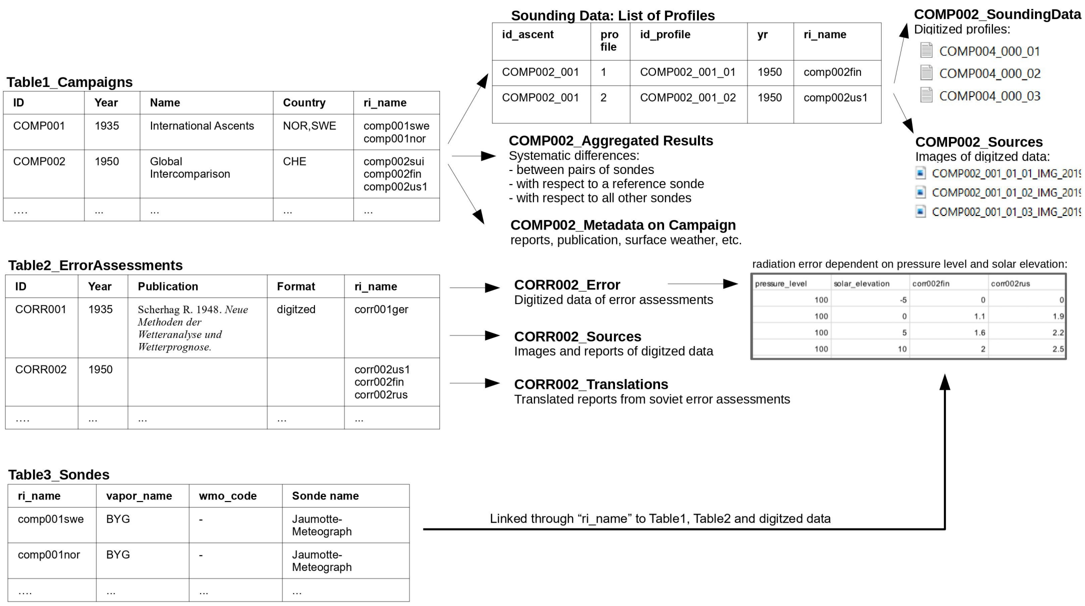

Figure 4: Schematic view of database structure based on the three tables for intercomparison campaigns, error assessments and radiosondes. A common nomenclature links the different elements of the database, i.e. the digitised data files, the metadata, the source files and the respective radiosondes.

3.2.1 Intercomparisons

A summary of each intercomparison campaign for which digitised data is available in our database can be found in Tab. 1. Note that a more comprehensive summary on intercomparison campaigns can be found in the database itself, that also includes intercomparison campaigns for which we were not able to find raw or even aggregated data. The information on each intercomparison is structured uniformly: All performed soundings and all profiles of the different radiosondes from these soundings are listed in two separate lists, a list of soundings and a list of profiles. Every sounding is assigned an identification (COMPXXX_XXX) chronologically. Every profile is then assigned this sounding identification, including in addition two digits that identify the radiosonde (or profile) (COMPXXX_XXX_XX). Profiles may correspond to the same sounding, but they have been launched on different balloons. Thus, start times of profiles from the same sounding can deviate. The profile identification links to the digitised ascent data and to the images that have been digitised. Ascent data can be available in minute or standard level pressure data, though minute data is preferred as it allows for the comparison of pressure sensors. The prefix “m” or “s” indicate whether the data is available as minute data, resp. on standard pressure levels. An example of the digitised ascent data is shown in Fig. 5 (left). For some campaigns, sounding lists are available, but we could not find the raw data. We still consider these lists important, as they report on the sounding schedule during the campaign and they allow to estimate the number of performed ascents.

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For some campaigns, aggregated results (statistics) that stem from analyses performed in the aftermath of the campaign, are available (for some, only the aggregated results are available, see Tab. 1). These aggregated results are either comparisons between pairs of radiosondes, comparisons to a reference radiosonde or comparisons to the mean of all other radiosondes. The available information includes mean differences, standard deviations, standard errors, significance levels and the number of profiles used for the calculation of the statistics. Abbreviations thereof are mean_diff, sd, se, siglev and n. For the aggregated results however, the amount of information differs. For example it is not known for every campaign, how many pairs of comparisons have been used for the calculation of the statistics. The standardised files for statistics are named additionally to the campaign number with the variable they contain (e.g. temperature, pressure, etc.), the aforementioned abbreviation ("m"/"s") for minute and pressure data, and whether it contains day or night comparisons. An example of the file structure is seen in Fig. 5 (right).

All digitised data (the profile data and the statistics) are linked to a radiosonde type, which is further described in a radiosonde table (see Sect. 3.2.3). The metadata of each campaign is available in a sub-folder of the respective campaign, and mostly describes the set-up of the intercomparisons, specifies the participating radiosondes or reports on the methods used to calculate aggregated results.

```
group           comp004bel-comp004ddr-comp004inf-comp004ukk
ri_name         comp004ddr
date            1956-05-27
hour_utc        08:27
Min PPP PPPcorr TTT TTTcorr UU H
0 966.4 966.4 NA 15 65 NA
28 892 892 NA 13.5 47 NA
29 854 854 NA 14 34 NA
30 818 818 NA 11.7 36 NA
31 778 780 NA 8.5 41 NA
32 743 748 NA 5 45 NA
33 710 715 NA 1.7 50 NA
34 679 683 NA -1.2 58 NA
35 645 650 NA -4.3 63 NA
```

```
project     C3S_311c_Lot2
campaign    COMP004
type        systematic_differences_pressure_levels
source      COMP004_A03_Beelitz1958.zip
location    payerne
lon         6.942472
lat         46.811578
year        1956
var         geopotential
unit        gpm
pl     time   ri_name      ri_name_ref   mean_diff   sd    se    siglev  n
850    day    comp004bel   comp004usa    3           NA    NA    NA      12
850    day    comp004dbr   comp004usa    -1          NA    NA    NA      17
850    day    comp004ddr   comp004usa    0           NA    NA    NA      15
```

Figure 5: Left: Example of data format for a radiosonde profile based on minute data. Right: Example of data format for aggregated results. Both data files can be linked to the lists of profiles and the lists of soundings of the respective campaign.

3.2.2 Error Assessments

Error assessments are either in digitised form as aggregated results, in graphical form or refer to publications (and the tables therein). A summary of error assessments that are part of the database can be found in Tab. 2. Error assessments can report overall errors, estimations of lag or radiation errors of a radiosonde, or also results from laboratory measurements or calibration information. Error assessments of temperature include further information, such as the solar elevation related to the temperature error and for temperature they are mostly made on standard pressure levels. Not for all radiation errors the solar elevation angle is known, nor can it be derived, because the time when the soundings were performed is not available. The digitised error assessments is stored in a folder CORRXXX, where XXX corresponds to the identification as seen in Tab. 2 or the table error assessments in the database.

The list of error assessments contains the links to the digitised data, as well as metadata (e.g. methods of calculations) and images (CORRXXX_Sources). For error assessments from the WDC/RIHMI the original literature in Cyrillic and the translations thereof are made available.

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3.2.3 Radiosondes table

The list of radiosondes includes specifications of the instruments that are mainly based on metadata from the individual campaign. Each radiosonde type has a unique identifier that refers to the WMO-Code for radiosondes (if available) and more importantly to the UID from the compilation of S. Schröder described in Sect. 2.3. Despite the comprehensiveness of Schröders's list, we were not able to relate all radiosondes used in our comparison to the list by Schröder and extended his list with additional instruments. In the database, the radiosondes have their own nomenclature, the ri_name (compXXXzzz), whereof XXX refers to the campaign the radiosonde has been used and zzz to the radiosonde itself. For the complete list of radiosondes, please refer to the database with the link provided in Sect. 5.

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Table 2: Digitised error assessment in our database for different radiosonde types. For full table of error assessments, refer to link provided in Sect. 5.

ID	Literature	Countries or sondes	Format in database	Digitised data
CORR001	Väisälä, 1941	Finland	Not included - article under copyright	
CORR002	Scherhag, 1948	Different radiosondes used in Germany	digitised	Radiation error for geopotential for pressure levels and solar elevations
CORR003	OMM, 1952	Finland, Swiss, USA (2 types of radiosondes), France, UK, US Zone Germany		Pressure differences from laboratory measurements Radiation errors for temperature Time lag errors for temperature
CORR004	Scrase, F.J. 1954	Great Britain	Not included - article under copyright	
CORR005	Marfenko, 1957	FSU	Translated literature and tables	
CORR006	Väisälä, 1957	Belgium JRM, West Germany (Graw H50), East Germany (Lang, improved version), USA (AN/AMT4), Finland (Väisälä), France (Metox), Japan (CMO- S 56), India C (chronometric), UK (Kew Mk IIB), Netherlands (Philips)	Literature	
CORR007	Teweles and Finger, 1960	Japan, Finland, United Kingdom, USA, Canada, FSU	digitised	Radiation error for different pressure levels and solar elevations for temperature
CORR008	Zaichikov, 1962	FSU/RZ-049, A-22, RKZ-1	Translated literature and tables	
CORR009	Zaichikov, 1964	FSU/RZ-049 and A-22-III	Translated literature and tables	
CORR010	Marfenko and Markelova, 1965	FSU/RKZ	Translated literature and tables	
CORR011	Marfenko, 1969	FSU/A-22-IV and RKZ-2	digitised	Radiation errors, lag errors, statistics of intercomparison of the two sondes
CORR012	Balagurov and Fridzon, 1983	FSU/RKZ	Translated literature and tables	
CORR013	Marfenko, 1983	FSU/Meteorit-RKZ	Translated literature and tables	
CORR014	Balagurov, Fridzon and Dozortsev, 1984	FSU/RKZ and MARZ	Translated literature and tables	
CORR015	Fridzon, 1989	FSU/Titan Meteorit-2	Translated literature and tables	
CORR016	Fridzon, 1990	FSU/RKZ and MARZ	Translated literature and tables	
CORR017	Luers and Eskridge, 1995	USA/VIZ and Vaisala RS-80	Translated literature and tables	
CORR018	Kazakova and Fridzon, 2011	RUS/RZ-049 and A22-III	Translated literature and tables	

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4. Discussion

In the course of the three early regional and international campaigns held in Payerne 1950/1956 and Brussels 1954, the magnitude of discrepancies between radiosondes types was recognized. As a result of these intercomparisons, it was emphasized that further intercomparisons are highly needed and that efforts should be put into correcting these errors and harmonizing instruments (Beelitz, 1958; Nyberg, 1952; Painter, 1950). Nyberg (1952) concluded in their report on the first international intercomparison (COMP002) that the systematic differences between the six compared radiosondes are considerable and primarily relate to radiation and lag errors. For Europe, upper-air weather maps were drawn at that time based on at least seven different radiosonde types (Painter, 1950). Until then, however only for the Finnish radiosonde radiation correction have been applied, which likely made the European network even less homogeneous (Nyberg, 1952). As a result of the second international comparison in 1956 (COMP004), technical recommendations were formulated to harmonize radiosonde construction. Correction values with respect to the US radiosondes were reported that could be applied to the present radiosonde network for increasing homogeneity (Beelitz, 1958). Such corrections are however different from corrections of lag or radiation errors, as their goal is not to correct for physical errors.

When interpreting the data from earlier intercomparison campaigns, some considerations have to be addressed: Regarding the operational networks at times, it is not entirely clear what kind of procedures were followed by the different weather services (e.g., which radiosondes were corrected for radiation and lag errors). Also, the soundings performed during the intercomparison campaigns may not be fully comparable to operational soundings (Nyberg, 1952). The intercomparisons were conducted by experts, taking more precautionary measures that may not have been taken in operational soundings. Nevertheless, estimated biases are useful. Fortunately, for most of the campaigns minute data was found. This has the advantage that pressure sensors can be compared. For campaigns, for which profile data is only available at standard pressure levels (e.g. COMP007), comparisons of temperature (or other) data may also contain differences that stem from the pressure sensors and not the temperature measurements.

More than ten years after the second international intercomparison, in 1968-69, different temperature reference radiosondes were compared in Japan, FSU, Germany, and the UK (Kuzenkov and Shlyakhov, 1976). For these comparisons, summary statistics but no raw ascent data have been found at the WDC/RIHMI.

Despite improved radiosonde technologies, after the intercomparisons held in Payerne in 1978 and 1981, the main conclusions still pointed out the importance of radiation correction and the need for laboratory tests (Philips et al., 1981; Richner and Philips, 1982). Systematic differences between radiosondes changed from the early campaigns in 1956 (COMP004) to 1982 (COMP009) however, they still remain evident, though systematic differences in upper-levels decreased (Fig. 6). Regarding these statistics, metadata is important, because often different calculation methods were applied which also resulted in considerably different results (see e.g. a comparison of calculation methods in Beelitz, 1958). Statistics have the advantage that they contain all relevant information, such as for which radiosondes lag or radiation corrections have been applied. In this context, it should be noted that some results may only be of limited practical value, as modifications have been made on the radiosonde or software after the experiment took place. This was the case for Airsonde, Graw RSG 78, Vaisala RS80 used in COMP009, and might also be true for earlier campaigns.

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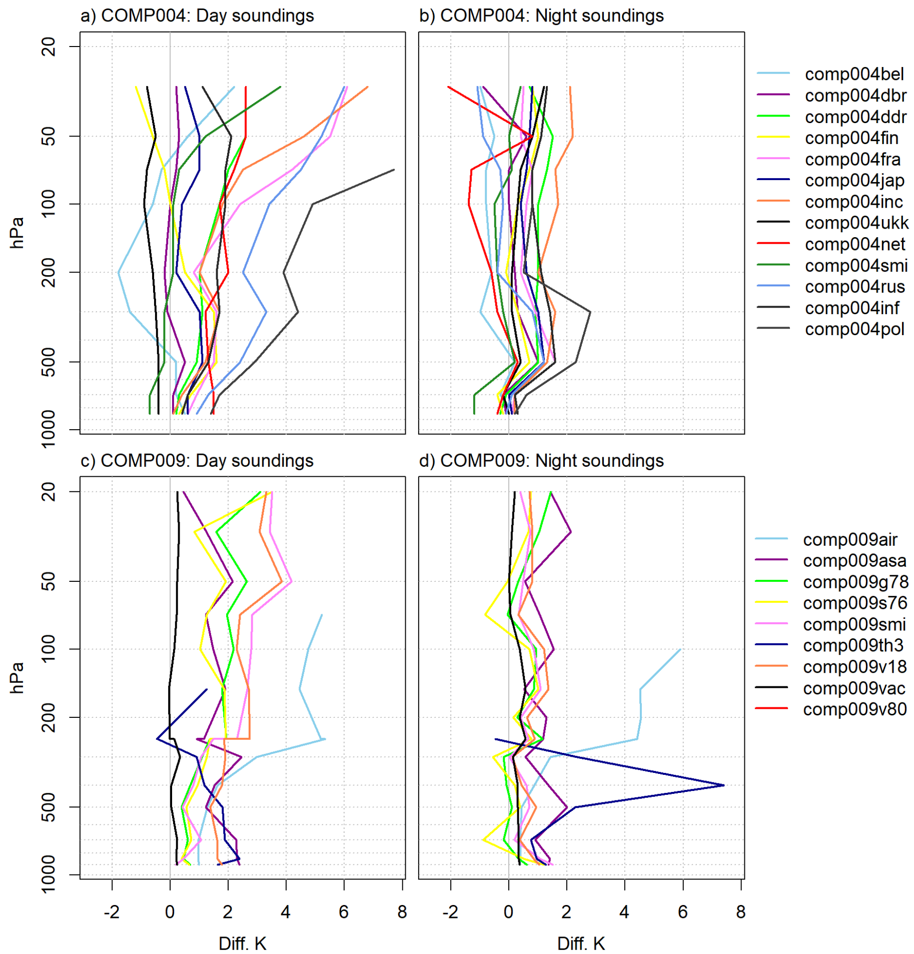

Figure 6: Example of the mean differences between pairs of sondes for day and night soundings with respect to the US sonde AN/AMT-4 for COMP004 (a and b) and to the Vaisala sonde RS21-12CN (Navaid) for COMP009 (c and d). Both comparison campaigns were conducted in Payerne in 1956 and 25 years later in 1981.

Data from more recent campaigns is easier to interpret, as more metadata is available and station histories are more carefully documented. As of 1984, the first of four phases of the WMO-organised intercomparison campaigns was held in Beaufort Park, UK (Hooper, 1984). These intercomparison campaigns followed standard procedures in the set-up of experiments, the calculation methods, the software, and for all instruments relevant information on sensors and applied corrections were carefully documented. Link radiosondes were used (i.e. radiosondes without instrument changes) that allow relating results between the different campaigns (Hooper, 1984; Bond et al., 1988). The same practices were adopted in the regional campaign held at Crawley in 1987. Comparisons showed a marked increase in the consistency of radiosondes due to technological advances (Hooper, 1984; Bond et al., 1988). Fig. 7 shows three daytime and three nighttime soundings from COMP002 (1950), COMP004 (1956), and COMP011 (1984). Despite it being exemplary, the discrepancy between temperature measurements in radiosondes is much smaller in upper-levels, and soundings reached much higher

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levels for COMP011. The technological improvements that made the soundings less labour intensive also allowed research teams to focus on other aspects. More soundings were conducted per day to evaluate the effects of different solar angles and systematic differences of night-time soundings could be evaluated (Bond et al., 1988). At the same time, intercomparison took place comparing FSU radiosondes, and Finnish and FSU radiosondes. They also represent an important contribution to the database, because in only one of the four WMO intercomparison a Soviet radiosonde was participating (Zaitseva et al., 1989; Ivanov et al., 1991).

Despite the successful search of early radiosonde intercomparison, it should also be noted that for very recent campaigns, such as Mauritius 2005 (Nash et al., 2006), the original ascent data has not be found. This stresses the need for proper archiving and data retrieval systems.

On a large scale, radiosonde data reaches back to the 1910s (e.g. Stickler et al., 2015). For this period, no sources report on intercomparison campaigns. However, on "International Days", radiosondes ascents have been conducted in different countries synchronously. This data, which remains undigitised, could provide further information on biases of these very early soundings.

Notwithstanding the more challenging interpretation of the early radiosondes intercomparisons, for the purpose of estimating biases in early radiosonde data, the now digitally available data from the early campaigns (e.g 1950, 1953, 1956, 1968) is very important. With this database, this data is now publicly available without restrictions.

5. Data availability

The full database is made available through PANGAEA (https://www.pangaea.de/tok/9e5b464ba828e931103d3794d9ae1d4576f7a03d) (Imfeld et al., in review). In addition, the digitised ascent data is also available at Copernicus Climate Data Store (Link will be provided).

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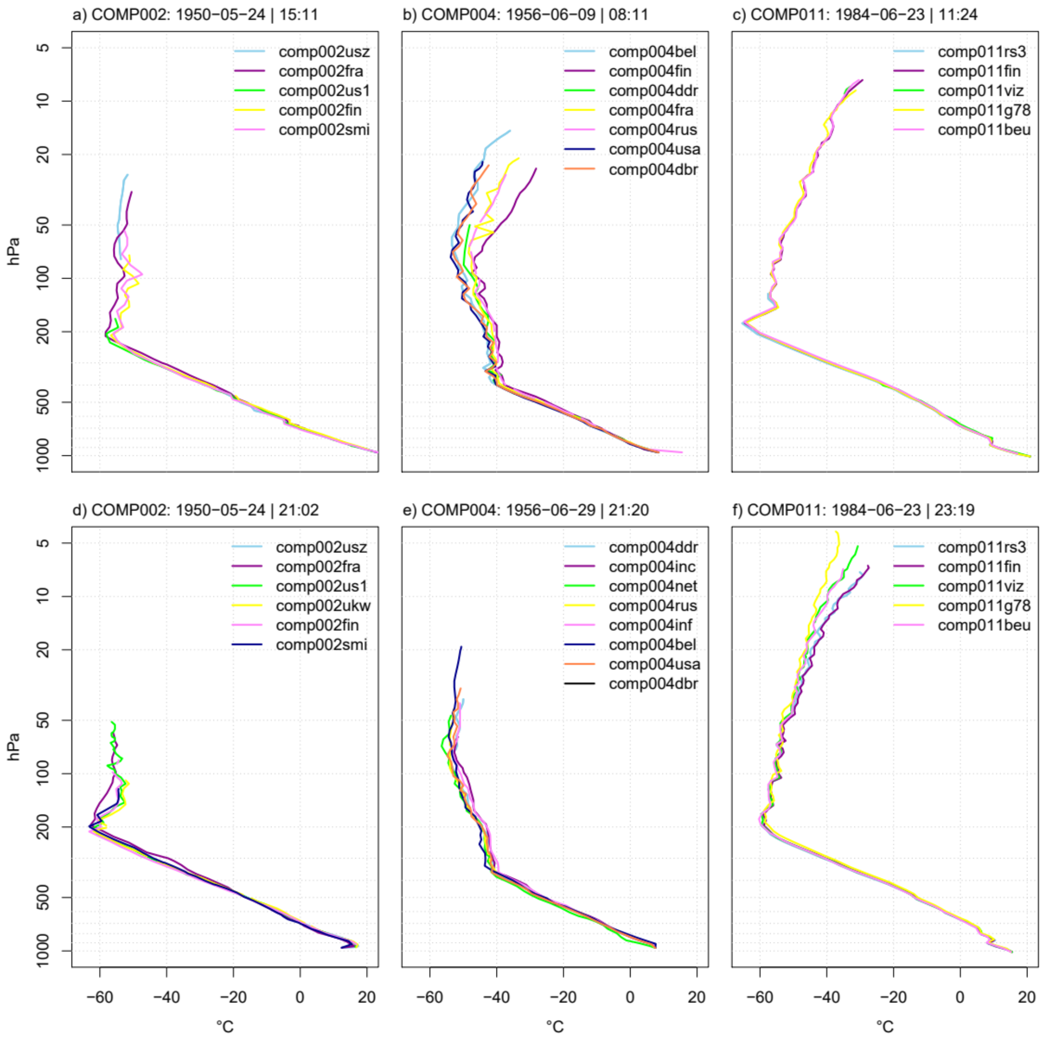

Figure 7: Example of the raw digitised temperature data for Payerne 1950 (COMP002, a and d), Payerne 1956 (COMP004, b and e), and Beaufort Park 1984 (COMP011, c and f). Upper row shows soundings during different day times, the lower row shows soundings during different night times. Note, that the different day times lead to considerable different solar angles. Nevertheless, the development of radiosondes is nicely visualized, in particular the increased consistency between radiosondes in 1984.

6. Conclusions

For the early intercomparison campaigns of radiosondes, so far no data has been digitally available. Especially for this time, however, quantitative estimates for errors of radiosondes are available, and thus making use of this newly digitised data can prove very useful for example for future reanalysis products assimilating upper-air data. This paper presents a database of upper-air sounding intercomparisons and error assessments mainly focusing on data from historic radiosondes intercomparison and error assessments as these are more error-prone. The structure of the database allows combining digitised soundings, graphical sources as well as metadata. This should serve to better correct for errors in historical upper-air data, which contributes to future reanalysis efforts.

Author contribution. NI and SB wrote the manuscript and set up the database. NI organised the digitisation, converted the data and completed the database. YB contributed to the digitization, database structure and writing of the manuscript. AS carried out the archive work and translation from WDC/RIHMI. SB and LH led the project, contributed to the database organisation and the writing of the manuscript.

Competing interests. The authors declare that they have no competing interests.

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References

Assmann, R., Moedebeck, H. and Hergesell, H.: Zur Geschichte der internationalen Ballonfahrten, Illustrierte Aeronautische Mitteilungen 1898, 49-51, 1898.

Balagurov, A. M., and Fridzon, M. B.: Investigation of the temperature impact on humidity sensors of radiosonde RKZ and capabilities of its rationing, CAO Proceedings, 151, 28-33, 1983.

Balagurov, A.M., Fridzon, M.B., and Dozortsev, A.P.: Estimating the time constant of radiosondes' sorption humidity sensors, Meteor. Gidrol., 4, 114-117, 1984.

Beelitz, P.: Bearbeitung der Ergebnisse der Radiosonden-Aufstiege anläßlich des 2. Weltvergleichs von Radiosonden in Payerne (Schweiz) 1956, Meteorologische Abhandlungen, Band VII, Heft 4. Berlin, Dietrich Reimer, 1958.

Brönnimann, S.: A historical upper air data set for the 1939-1944 period. International Journal of Climatology, Vol. 23, 7, 769-791, 2003.

Bond, F., Edge, P., and Nash, J.: Final report on the advanced radiosonde intercomparison held at Crawley 1987. Met Office Bracknell, 1988.

Compo, G.P., Whitaker, J.S., Sardeshmukh, P.D., Matsui, N. , Allan, R.J., Yin, X., Gleason, B.E., Vose, R.S., Rutledge, G. , Bessemoulin, P., Brönnimann, S., Brunet, M., Crouthamel, R.I., Grant, A.N., Groisman, P.Y. , Jones, P.D., Kruk, M., Kruger, A.C., Marshall, G.J., Maugeri, M., Mok, H.Y., Nordli, Ø., Ross, T.F., Trigo, R.M., Wang, X., Woodruff, S.D., Worley, S.J.: The Twentieth Century Reanalysis Project. Q. J. R. Meteorol. Soc., 137, 1-28, 2011.

da Silveira, R.B, Fisch, G.F, Machado, L.A.T, Dall'Antonia, A.M., Sapucci, L.F, Fernandes, D. Marque, R., Nash, J.: WMO Intercomparison of GPS Radiosondes. Alcãntra, Brazil, 20 May – 10 June 2001. WMO Instruments and Observing Methods Report 90, 2011.

Diamond, H., Hinman, Jr. W.S., and Dunmore, F.W.: The development of a radio-meteorograph system for the Navy Department. B. Am. Meteorol. Soc. 18, 73-99, 1937.

Dubois, J.L., Multhauf, R.P, Ziegler, C.A.: The invention and development of the radiosondes, with a catalog of upper-atmospheric telemetering probes in the National museum of American History, Smithsonian Institution. Smithsonian Institution Press, Washington D.C., 2002.

Durre, I., Yin X., Vose, R.S., Applequist, S., Arnfield, J.: Enhancing the Data Coverage in the Integrated Global Radiosonde Archive. J. Atmos. Oceanic Technol., 35, 1753–1770, 2018.

Fridzon, M.B.: Estimation of temperature and humidity measurement errors at radiosondes on the USSR aerological network. "Meteorologia and Gydrologia", 5, 114-118, 1989.

Fridzon, M.B.: On research of metrological characteristics of radiosondes' humidity sensors. CAO Proceedings, 168, 48-56, 1990.

Gaffen, D.J.: Historical changes in radiosonde instruments and practices. WMO Instruments and observing methods Report No. 50. WMO/TD-No. 541, 1993.

Goltsova, K.l., Marfenko, O.V., Petrosyants, M.A., Reshetov, V.D.: Intercomparison of the Soviet and the American systems for ship radiosounding. Meteor. Gidrol., 12, 92-97, 1974.

Grant, A.N, Brönnimann, S., Ewen, T., Nagurny, A.,: A New Look at Radiosonde Data Prior to 1958. J. Climate, **22,** 3232–3247, 2009.

Haimberger, L.: Homogenization of radiosonde temperature time series using innovation statistics. J. Climate 20, 1377-1403, 2007.

Haimberger, L., Tavolato, C. and Sperka, S.: Homogenization of the global radiosonde dataset through combined comparison with reanalysis background series and neighboring stations. J. Climate 25, 8108–8131, 2012.

Hooper, A.H.: WMO International radiosonde comparison Phase 1 Beaufort Park, U.K. 1984. WMO Instruments and observing methods, Report No. 28, 1986.

Hermite G.: L'exploration de la haute atmosphère. Ascension du ballon l'Aérophile. L'Aérophile,1, 45-55, 1893.

Hersbach, H., Brönnimann, S., Haimberger, L., Mayer, M., Villiger, L., Comeaux, J., Simmons, A., Dee, D., Jourdain, S., Peubey, C., Poli, P., Rayner, N., Sterin, A. M., Stickler, A., Valente, M. A. and Worley, S. J.: The potential value of early (1939–1967) upper-air data in atmospheric climate reanalysis. Q. J. R. Meteorol. Soc., **143,** 1197–1210, 2017.

Imfeld, N., Haimberger, L., Sterin, A., Brugnara, Y., Brönnimann S.: Intercomparisons, Error Assessments, and Technical Information on Historical Upper-Air Measurements. *PANGAEA*, https://www.pangaea.de/tok/9e5b464ba828e931103d3794d9ae1d4576f7a03d *(dataset in review)*

Ivanov, A., Kats, A., Kurnosenko, S., Nash, J. Zaitseva, N.: WMO International Radiosonde Comparison, Phase III, Dzhambul, USSR, 1989. WMO Instruments and observing methods, Report No. 40, 1991.

Jeannet, P., Philipona, R. Richner, H.: Swiss upper-air balloon soundings since 1902. In: Willemse S. and Furger M. (Eds). From weather observations to atmospheric and climate sciences in Switzerland. Celebrating 100 years of the Swiss Society for Meteorology: A book of the Swiss Society for Meteorology, Vdf Hochschulverlag AG ETH Zürich, 141-167, 2016.

Kaimal, J. C., Baynton, H. W., Gaynor, J. E.: The Boulder low-level intercomparison experiment. NOAA/NCAR Boulder Atmospheric Observatory, 189, 1980.

Karhunen, P., Trifonov, G.P. and Yurmanov, V.A.: The intercomparison of the Soviet radiosonde system "Meteorit-2-MARS-2-0KA-3" with the Finnish system MicroCORA. Meteor. Gidrol., 11, 1987.

Kazakova, N.N.: On the comparison of temperature and wind sounding data obtained by different systems. AARI Proceedings, 409, 93-111, 1998.

Kazakova, N. N. and Fridzon, M.B.: Assessment of uniformity (homogeneity) of the data series of temperature-wind sounding of the atmosphere at the Russian Antarctic stations. Problemi Arktiki I Antarktiki, 1(87), 41-55, 2011.

Krechmer, M.V., Shlyakhov, V.I., Glagolev, Yu.A., et al.,: Individual results of comparison between upper-air radio-thermometers. Meteor. Gidrol., 10, 98-102, 1969.

Kuzenkov, A.F., and Shlyakhov, V.I.: Implementing the programme of international comparisons of upper-air radiosondes. CAO Proceedings, 118, 33-39, 1976.

Labitzke, K.: Die Stratospäre: Phänamene, Geschichte, Relevanz. 177 S., Springer Verlag Berlin Heidelberg New York, 1999.

Laloyaux, P., de Boisseson, E., Balmaseda, M., Bidlot, J.-R., Broennimann, S., Buizza, R., et al..: CERA-20C: A coupled reanalysis of the twentieth century. Journal of Advances in Modeling Earth Systems, 10, 1172–1195. https://doi.org/10.1029/2018MS001273, 2018.

https://doi.org/10.5194/essd-2020-395
Preprint. Discussion started: 15 January 2021

Lander, AJ.: The British Radiosonde. Weather, 1, 21-24, 1946.

Lange, K.O.: The 1936 radio-meteographs of Blue Hill Observatory. B. Am. Meteorol. Soc. 18, 107-126, 1937.

Lanzante, J. R., S. A. Klein, and D. J. Seidel: Temporal homogenization of monthly radiosonde temperature data. Part I: Methodology. J. Climate, 16, 224–240, 2003

Luers, J.K., Eskridge, R.E. Temperature correction for the VIZ and Vaisala Radiosondes. J. Appl. Meteorol. 34, 1241-1253, 1995.

Malet, L. M.: Comparaison régionale de radiosondes - Bruxelles 4.11.54-19.11.54. Inst. Roy. Mét., Publ. Série A 3, Uccle, 1955.

Marfenko, O.V.: Random (Accidental) errors of radiosonde RZ-049, CAO Proceedings, 22, 35-39, 1957.

Marfenko, O.V.,: Estimating the accuracy of radiosounding results in the upper-air network of the Soviet Union. Meteor. Gidrol., 3, 14-21, 1969.

Marfenko, O.V.: Metrological investigation of the method for pressure measurement in atmospheric radiosounding. CAO Proceedings, 147, 3-9, 1983.

Marfenko, O.V., and Markelova, K.I.: Findings of radiation errors of thermistor radiosonde RKZ in flying conditions. CAO Proceedings, 67, 24-30, 1965.

Nash, J., Smout, R., Oakley, T., Pathack, B., Kurnosenko, S.: The WMO Intercomparison of Radiosonde Systems – Final Report, Vacoas, Mauritius, 2 – 25 February 2005. WMO/TD No. 1303, OM Report No. 83, WMO, Geneva, 21–27, 2006.

Nash, J., Oakley, T. , Vömel, H., Wei, L.I.: WMO Intercomparison of high quality radiosonde systems. Yangjiang, China,12 July – 3 August 2010. WMO Instruments and Observing Methods Report 107, 238, 2011-

Nyberg, A., Bergeron, T., Palmén, E.: Synoptisch-aerologische Bearbeitung der Internationalen Registrierballonaufstiege in Europa in der Zeit 17.-19. Oktober 1935, Geografiska Annaler, 24 51-93, 1942.

Nyberg A.: On the comparison of radiosonde data in Payerne, May 1950. Sveriges Meteorologiska Och Hydrologiska Institut. Stockholm, 1952.

OMI (Organisation Météorologique Internationale): Comparaison Mondiale des Radiosondes. Acte Final. Vol. I. Station Centrale Suisse de Météorologie, 1951.

OMM (Organisation Météorologique Mondiale): Comparaison Mondiale des Radiosondes. World Comparison of Radiosondes. Acte Final. Vol. III. Station Centrale Suisse de Météorologie, 1952.

OMM (Organisation Météorologique Mondiale): Comparaison Mondiale des Radiosondes. World Comparison of Radiosondes. Recueil des Radiosondages. Complet Results of Radiosoundings. Vol. I. Technical Informations, 1956.

Painter EE.: International radiosonde trials, Weather, 307-310, 1950.

Ramella P., L., Haimberger, L., Stickler, A. and Brönnimann, S.: A global radiosonde and tracked balloon archive on 16 pressure levels (GRASP) back to 1905 – Part 1: Merging and interpolation to 00:00 and 12:00 GMT, Earth Syst. Sci. Data, 6, 185-200, 2014.

Raunio N.: Amendments to the computation of the radiation error of the Finnish (Väisälä) radiosonde. *Geophysica* **4:** 14-20, 1950.

https://doi.org/10.5194/essd-2020-395
Preprint. Discussion started: 15 January 2021

Reichsamt für Wetterdienst, Juli 1940. Technische Vorschrift für die Radiosonde, Reichsamt für Wetterdienst (Modell Lang) (Vorläufige Form)

Richner, H., and Phillips, P. D.: Reproducibility of VIZ Radiosonde Data and Some Sources of Error. Journal of Applied Meteorology 20, 954-962, 1981.

Richner, H., and Phillips, P. D.: The Radiosonde Intercomparison SONDEX Spring 1981, Payerne. PAGEOPH, 120, 852–907, 1982.

Seidel, D. J.; Berger, F. H.; Diamond, H. J.; Dykema, J.; Goodrich, D.; Immler, F.; Murray, W.; Peterson, T.; Sisterson, D.; Sommer, M.; Thorne, P.; Vömel, H. & Wang, J., Reference Upper-Air Observations for Climate: Rationale, Progress, and Plans. Bulletin of the American Meteorological Society, 90, 361–369, doi:10.1175/2008BAMS2540.1, 2009.

Scherhag R.: *Neue Methoden der Wetteranalyse und Wetterprognose.* Springer, Berlin, 1948.

Schmidlin, F.J.: WMO International Radiosonde Comparison, Phase II, 1985. WMO Instruments and observing methods, Report No. 29, 1988.

Scrase FJ.: Radiation and lag errors of the Meteorological Office radiosonde and the diurnal variation of upper-air temperature. *Q. J. Roy. Meteor. Soc.* **80,** 565-578, 1954.

Sherwood, S.C., Meyer, C.L., Allen, R.J. and Titchner, H.A.: Robust Tropospheric Warming Revealed by Iteratively Homogenized Radiosonde Data. J. Climate, 21, 5336–5352, https://doi.org/10.1175/2008JCLI2320.1, 2008.

Shlyakhov, V.I., and Kuzenkov, A.F.: The results of international comparison of the reference radiosondes, Meteor. Gidrol., 4 94-98, 1973.

Slivinski, L.C., Compo, G.P., Whitaker, J.S., et al.: Towards a more reliable historical reanalysis: Improvements for version 3 of the Twentieth Century Reanalysis system. *Q J R Meteorol Soc*.; 145: 2876– 2908. https://doi.org/10.1002/qj.3598, 2019.

Stickler, A., Brönnimann, S., Valente, M. A., Bethke, J., Sterin, A., Jourdain, S., Roucaute, E. , Vasquez, M. V. , Reyes, D. A., Allan, R., Dee, D. ERA-CLIM: Historical Surface and Upper-Air Data for Future Reanalyses. *B. Amer. Meteorol. Soc.,* **95,** 1419–1430, 2014.

Teweles, S., Finger, F.G.: Reduction of diurnal variation in the reported temperatures and heights of stratospheric constant-pressure surfaces. *J. Meteorol.* **17,** 177-194, 1960.

Väisälä, V.: *Der Strahlungsfehler der finnischen Radiosonde*. Mitteilungen des Meteorologischen Instituts der Universität Helsinki No. 47, 1941.

Väisälä, V.: Solar radiation intensity at the ascending radiosonde. *Geophysica* **3,** 37-55, 1949.

Väisälä, V.: Radiation error of different radiosondes at Payerene, 1956. *Geophysica* **6,** 1, 1957.

WMO (World Meteorological Organization). Common code table and alphanumeric codes. https://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/WMO306_vI2_CommonTable_en.pdf, 2019.

Yagi, S., Mita, A. and Inoue, N.: WMO International Radiosonde Comparison, Phase IV, 1993, Tsukuba, Japan, 15. February – 12 March 1993. WMO Instruments and observing methods, Report No. 29, 1988.

Zaichikov, P.F. The preliminary results of processing the observational materials of the 2nd International Radiosonde Comparison. CAO Proceedings, 22, 51-59, 1957.

https://doi.org/10.5194/essd-2020-395
Preprint. Discussion started: 15 January 2021

Zaichikov, P.F.: Procedure to determine radiation corrections to temperature readings of radiosondes A-22, RKZ-1 and RZ-049 from differential data "daytime minus night". CAO Proceedings, 43, 10-21, 1962.

Zaichikov, P.F.: Some additions for "the triple check" method. On the precision of independent determining the altitude of the system that is raised up. CAO Proceedings, 60, 43-53, 1964.

Zaitseva, NA.: Historical developments in radiosonde systems in the former Soviet Union. *B. Am. Meteorol. Soc.* **74:** 1893-1900, 1993.

Zaitseva, N.A., Ahmetyanov, R.K. and Karhunen, P.: On the results of the intercomparison between the Soviet and Finnish radiosondes. Meteor. Gidrol., 1, 105-110(108), 1989.