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A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901–present

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Abstract

The availability of highly accessible and reliable monthly gridded data sets of the global land-surface precipitation is a need that has already been identified in the mid-80s when there was a complete lack of a globally homogeneous gauge based precipitation analysis. Since 1989 the Global Precipitation Climatology Centre (GPCC) has built up a unique capacity to assemble, quality assure, and analyse rain gauge data gathered from all over the world. The resulting data base has exceeded 200 yr in temporal coverage and has acquired data from more than 85 000 stations world-wide. This paper provides the reference publication for the four globally gridded monthly precipitation products of the GPCC covering a 111-yr analysis period from 1901–present, processed from this data base. As required for a reference publication, the content of the product portfolio, as well as the underlying methodologies to process and interpolate are detailed. Moreover, we provide information on the systematic and statistical errors associated with the data products. Finally, sample applications provide potential users of GPCC data products with suitable advice on capabilities and constraints of the gridded data sets. In doing so, the capabilities to access ENSO and NAO sensitive precipitation regions and to perform trend analysis across the past 110 yr are demonstrated. The four gridded products, i.e. the Climatology V2011 (CLIM), the Full Data Reanalysis (FD) V6, the Monitoring Product (MP) V4, and the First Guess Product (FG) are public available on easy accessible latitude longitude grids encoded in zipped clear text ASCII files for subsequent visualization and download through the GPCC download gate hosted on ftp://ftp.dwd.de/pub/data/gpcc/html/download_gate.html by the Deutscher Wetterdienst (DWD), Offenbach, Germany. Depending on the product four (0.25°, 0.5°, 1.0°, 2.5° for CLIM), three (0.5°, 1.0°, 2.5°, for FD), two (1.0°, 2.5° for MP) or one (1.0° for FG) resolutions are provided, and for each product a DOI reference is provided allowing for public user access to the products. A preliminary description of the scope of a fifth product – the Homogenized Precipitation Analysis (HOMPRA) – is also provided. Its comprehensive description will be handed later in

an extra paper upon completion of this data product. DOIs of the gridded datasets examined:

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doi:10.5676/DWD_GPCC/CLIM_M_V2011_050,
doi:10.5676/DWD_GPCC/CLIM_M_V2011_100,
doi:10.5676/DWD_GPCC/CLIM_M_V2011_250,
doi:10.5676/DWD_GPCC/FD_M_V6_050,
doi:10.5676/DWD_GPCC/FD_M_V6_100,
doi:10.5676/DWD_GPCC/FD_M_V6_250,
doi:10.5676/DWD_GPCC/MP_M_V4_100,
doi:10.5676/DWD_GPCC/MP_M_V4_250,
doi:10.5676/DWD_GPCC/FG_M_100

1 Introduction

Precipitation is probably the most important of the essential climate variables (ECV) identified for the Global Climate Observing System (GCOS; Table 1 in GCOS, 2010). This is due to its crucial role to sustain any form of life on earth as major source of fresh water, its major impact on weather, climate, climate change and related issues of society's adaptation to the latter. The occurrence of precipitation is highly variable in space and time thus bearing the potential to trigger major flood and drought related disasters. Finally, high-quality monthly precipitation data sets across a long-term period are key information for an improved understanding of the global water cycle. This need has already been identified in the late 80s by the Commissions for Hydrology and Climatology consulting the World Meteorological Organization (WMO).

In addressing this need, the Global Precipitation Climatology Project (GPCP; WMO, 1990; Adler et al., 2003; Huffman et al., 2009) has been charged with the development of long-term global gridded records of precipitation for the scientific community in

support of the WMO World Climate Research Programme (WCRP) and the Global Energy and Water Cycle Experiment (GEWEX). Naturally a global data set encompasses both, the land-surface and the ocean areas of the globe. Noting the limited quality of solely satellite-based quantitative ground-reaching precipitation monitoring across land-surfaces due to large biases and stochastic errors (Barret et al., 1994; Rubel and Rudolf, 2001) and the potential benefit of gauge based in-situ precipitation measurements across these areas, it was straightforward to design satellite-gauge based data sets. In doing so the strengths of satellites across oceans are combined with the strength of direct measurements across the land-surfaces. Supplementary to this approach, regular inter-comparison of satellite based precipitation products are made to enhance their reliability. This is coordinated through the International Precipitation Working Group (IPWG; Ebert, et al., 2007; Kidd et al., 2010) including the Pilot Evaluation of High Resolution Precipitation Products (PEHRPP; Arkin et al., 2005) Project in preparation for the Global Precipitation Measurement (GPM; Hou et al., 2008, Chapter 6.4) mission.

From a conceptual point of view two approaches are possible to construct a high-quality global precipitation satellite-gauge reanalysis data set

i. Calibration of satellite data against the in-situ data as done for the GPCP project (Huffman et al., 2009), the Climate Prediction Centre (CPC) Merged Analysis of Precipitation (CMAP; Xie and Arkin, 1997) or the Precipitation Reconstruction over Land (PREC/L; Chen et al., 2002)

ii. Concatenation of data sets according to a resolution-dependent land-sea mask while nudging both data sets along the border (Andersson et al., 2010)

Approach (i) yields an optimum spatial homogeneity of the data set without jumps along the coastlines. The coastlines separate the oceanic regime with satellite only data from the land-surface area where both kinds of data are available. For approach (ii) a nudging scheme is required to make up for potential jumps along the coastline. On the other hand it utilizes only one data source per regime, which allows for a more reliable diagnosis of the systematic (measurement device specific) error for the oceanic (satellite-based) and the land-surface (gauge-based) precipitation analysis.

Regardless of the approach ultimately chosen, there is a strong demand on high quality rain gauge based precipitation reanalysis data sets to serve the in-situ based reference component for the period covered also by satellite data (Kidd et al., 2012; Kidd and Huffman, 2011). In 1988 the Deutscher Wetterdienst volunteered to provide such a data set, and was mandated to do so by the WMO World Climate Research Programme (WCRP). The Global Precipitation Climatology Centre was inaugurated in 1989 but it took several more years to provide the first land-surface precipitation analysis product, a decadal data set (1986–1995) as contribution to the Global Energy and Water Cycle Experiment (GEWEX) of WCRP (Rudolf, 1995). The series has been complemented backwards to 1979 by another preliminary gauge product using the same analysis method but a reduced input data set (Xie et al., 1996).

The GPCC effort was initially set up as a scientific project in support of the GPCP effort. In view of the high quality of its first delivery for GEWEX the GPCC was institutionalized at the Deutscher Wetterdienst upon a WMO request for long-term operation of GPCC. Subsequently, GPCC has been integrated into new permanent instruments such as the WMO GCOS. Since 1999, GPCC is one of the two global GCOS Surface Network Monitoring Centres (GSNMCs) with special emphasis on precipitation. The other GSNMC being responsible for air temperature monitoring is operated by the Japan Meteorological Agency (JMA).

In parallel with these settlements, GPCC has successively extended the temporal coverage of its analysis products backward from present to originally 1986 to 1951 and 1901 in years 2004 and 2008 (see also Fig. 1). There are also earlier periods available in the data archive, but so far GPCC has decided to renounce on analysis prior to 1901. In these early years the number of available stations is too small to support a reliable data product with an acceptable sampling error. As we will discuss in detail in Sect.5 the sampling error of the GPCC products is strongly related to the number and density of available stations.

Of course, the GPCC portfolio of gridded global datasets of monthly terrestrial precipitation based on gauge data was and is not unique as such. There have been similar data archives and products compiled and published by the Climate Research Unit (CRU) of the University of East Anglia (New et al., 1999, 2000, 2001, 2002); by Peterson et al. (1997, 1998) based on the Global Historical Climatology Network (GHCN) data set, by Hijmans et al. (2005), and by Mitchell and Jones (2005), all for a number of atmospheric ECVs including precipitation. For precipitation only there are also the datasets published by Dai et al. (1997) and Matsuura and Willmott (2012). A strength of some of these data sets lies in the public availability of both, the gridded products and the underlying original station observations. This is in distinct contrast to the GPCC data products where the latter cannot be provided for many stations as GPCC does not claim copyrights on acquired data, which is also true for the non-global APHRODITE data sets published by Yatagai et al. (2009, 2012). Therefore, GPCC applies a general policy not to parse any original station data but to pass according requests to the original suppliers, if possible. On the other hand the GPCC data archive is by far the largest world-wide for monthly precipitation, outperforming the global precipitation data coverage of all aforementioned data sets by at least a factor of two and partly much more. The non-claiming of copyrights on the original data is certainly a key to this success.

In line with the scope of the ESSD journal, this paper serves as a reference publication to describe the multi-decadal and partly centennial data products published by the GPCC under product specific digital object identifiers (DOI). The five products are:

a. **GPCC – Climatology (CLIM) Version 2011** (Meyer-Christoffer et al., 2011a–d)

Target period 1951–2000, with the grid resolution specific DOIs
doi:10.5676/DWD_GPCC/CLIM_M_V2011_025 (for 0.25°),
doi:10.5676/DWD_GPCC/CLIM_M_V2011_050 (for 0.5°),
doi:10.5676/DWD_GPCC/CLIM_M_V2011_100 (for 1.0°), and
doi:10.5676/DWD_GPCC/CLIM_M_V2011_250 (for 2.5°) jointly referring to

ftp://ftp.dwd.de/pub/data/gpcc/html/gpcc_normals_v2011_doi_download.html

b. **GPCC – Full Data Reanalysis (FD) Version 6.0** (Schneider et al., 2011c–e)

Period 1901–2010 with the grid resolution specific DOIs

doi:10.5676/DWD_GPCC/FD_M_V6_050 (for 0.5°),
doi:10.5676/DWD_GPCC/FD_M_V6_100 (for 1.0°),
doi:10.5676/DWD_GPCC/FD_M_V6_250 (for 2.5°), jointly referring to

ftp://ftp.dwd.de/pub/data/gpcc/html/fulldata_v6_doi_download.html

c. **GPCC – Monitoring Product (MP) Version 4.0** (Schneider et al., 2011a, b)

Period 2007–present in Version 4, (in Version 1 since 1986) with the resolution specific DOIs

doi:10.5676/DWD_GPCC/MP_M_V4_100 (for 1.0°), and

doi:10.5676/DWD_GPCC/MP_M_V4_250 (for 2.5°) jointly referring to

ftp://ftp.dwd.de/pub/data/gpcc/html/gpcc_monitoring_v4_doi_download.html

d. **GPCC – First Guess Product (FG)** (Ziese et al., 2011)

Period August 2004–present (temporally inhomogeneous due to Version changes)

doi:10.5676/DWD_GPCC/FG_M_100 (for 1.0°) referring to ftp://ftp.dwd.de/pub/data/gpcc/html/gpcc_firstguess_doi_download.html

e. **GPCC – Homogenized Precipitation Analysis (HOMPRA) Version 1.0**

Period 1951–2005 (fully homogeneous, replaces VASClimO V1.1)

Tentative DOIs 10.5676/DWD_GPCC/HOM_M_V1_<xxx>with xxx=050, 100 and 250 depending on the resolution, similar to the Full Data (FD) Product.

The fifth product, the Homogenized Precipitation Analysis Product (HOMPRA), being the follower of the VASClimO Product published by Beck et al. (2005) and still available from ftp://ftp.dwd.de/pub/data/gpcc/vasclimo/ could not be completed before submission of this paper. Therefore, only basic features will be described here (Sect. 7.4), while a thorough description will be published in a follow up paper corresponding to the issuance of HOMPRA.

The issuance of the DOI references implies that ISO 19115 compliant metadata is provided under URLs constructed from the DOI proceeded by http://data.datacite.org. For example the metadata for the "GPCC Climatology Version 2011" at 0.25° resolution is available from http://data.datacite.org/10.5676/DWD_GPCC/CLIM_M_V2011_025.

Moreover the DOI referenced GPCC products are included in the dataset catalogue of the Climate Data Centre (CDC) of Deutscher Wetterdienst. This catalogue disseminates ISO19139 compliant metadata on its data sets through the Geo-Network software application. For example the GPCC Climatology Version 2011 products are documented under http://cdc.dwd.de/catalogue/srv/de/main.home?uuid=de.dwd.gpcc.climatology.v2011.

In this GPCC reference paper the underlying data base and provenance is described thoroughly in Sect. 2, followed by brief descriptions of the data quality control (QC) applied to the station data in Sect. 3. The QC issues shall be elaborated in a companion paper of Schneider et al. (2012). Here, we will focus on the description of the gridded GPCC products in terms of the specific methodology applied for the gridding of the station data in Sect. 4, the additional information available with regard to the uncertainty of the products, a comparison of the three interpolation methods (arithmetic mean, modified SPHEREMAP, and ordinary Kriging) and their related sampling error (Sect. 5), followed by a brief description, how the GPCC climatology is constructed (Sect. 6). This climatology serves as a background field for the other GPCC analysis products that shall be described in Sect. 7 together with sample applications to resolve ENSO and NAO related precipitation patterns and to reveal trends in precipitation across the past century. Finally Sect. 8 informs on access methods to the data sets and provides basic user advice.

2 GPCC's rain gauge data base

The accuracy of rain gauge based precipitation analyses mainly depends on the spatial density of stations being used. For example in order to calculate monthly area-mean precipitation on a 2.5° × 2.5° grid with a sampling error of less than 10 %, it takes 8 to 16 stations per grid cell depending on the variability of the precipitation in the region analysed (Jenne and Joseph, 1985; Rudolf et al., 1994). On the other hand, 10 % sampling error has been the accuracy requirement of the GPCP (WMO, 1990) which corresponds to a global requirement of 40 000 homogeneously distributed stations worldwide.

The rain gauge data received so far by GPCC can be divided into the part received in near-real time (Sect. 2.1) through the Global Telecommunication System (GTS) and the much bigger part collected offline (Sect. 2.2). In total, data of more than 85 000 stations have been integrated at least once throughout the centennial reanalysis period starting in year 1901. This is a good success rate of 57 % or 34 % depending on which estimate on the total number of gauges operated world-wide in national meteorological or hydrological observation networks is taken: 150 000 according to New et al. (2001) or 250 000 according to Strangeways (2007). However, depending on the duration of the longest uninterrupted time series of each station fetched by the GPCC analysis these figures differ. Applying a 10 yr minimum constraint, as applied as a screening criterion for the cadre data set of the background climatology GPCC-CLIM, the number of eligible stations drops already down to slightly more than 67 000 stations. Requiring coverage of fixed 30-yr reference periods, the number drops further to approximately 35 000 for the WMO standard period 1961–1990. As will be discussed in further detail within Sect. 6 this situation has driven decisions on the length of the reference period chosen for the GPCC Climatology.

2.1 Near real-time GTS data base

If a real-time access to the station data is required, for example to issue monitoring products suitable for a watch function, the number of actually available stations drops dramatically to a subset of about 8000 stations, out of the 12 000 stations listed in WMO Volume A (WMO, 2011a), that are currently internationally exchanged between the National Hydro Meteorological Services (NHMSs) on a regular basis. These data are disseminated near real-time by the NHMSs via the (World Weather Watch) GTS. Monthly precipitation data from the following three sources are routinely obtained at GPCC within about one month after observation, and can thus be used for the early analyses.

2.1.1 Meteorological synoptic data (SYNOP) received at DWD, Offenbach

The SYNOP data received at DWD forms the primary GTS source. Its primary purpose is the analysis of global current weather charts and initialization of numerical weather prediction models. For GPCC purposes only the precipitation-related components of the SYNOP code are evaluated as follows:

- The precipitation group: t_RRRR with
  t_R = time interval (t_R can be 1, 2, 3, 6, 9, 12, 15, 18 or 24) and RRR = precipitation total for the interval t_R in mm, respectively in tenths of mm for precipitation amounts less than 1 mm (RRR ≥ 990)

- The weather group wwW1W2
  ww and W1,W2 describe the observed current weather (e.g. ww = 65: heavy rainfall) and the past weather.

- The climatological precipitation group RRRR with
  RRRR = precipitation total for the last 24 h

The limited number of GTS stations makes their data particularly precious and it is always aspired to make maximum use of the SYNOP data. In doing so the GPCC data processing routine includes some automatic quality checks and corrections to rescue damaged SYNOP messages:

- Correction of obvious coding errors
- Consistency check of RRR for messages overlapping in time
- Plausibility check of RR with respect to typical maximum values
- Consistency check of RR versus ww and W1,W2
- Completion of missing RRR messages by t_R000 in case of available weather groups messages indicating no precipitation for the corresponding time interval t_R.

For months featuring 100 % SYNOP data availability, the monthly precipitation totals can be easily calculated. However, this is on average only the case for just 2000 of 6800 SYNOP stations. The other stations feature incomplete monthly data availabilities with smaller or larger data gaps. Based on statistical inter-comparison studies (Schneider et al., 1992) application of a 70 % minimum availability (Pct) constraint yields a still acceptable reliability of the monthly total P_M calculated by

$$P_M = R_{Sum} \cdot \frac{100\,\%}{Pct} \tag{1}$$

with R_{Sum} = Sum of the observed precipitation intervals with Pct > = 70 % during the month regarded, keeping the mean difference between the monthly totals calculated as under Eq. (1) and reference data (CLIMAT, see next section) at about 15 % of the reference. With further decreasing data availability this deviation would increase. All SYNOP-based monthly totals calculated by the GPCC are accompanied by quality indices representing the availability and corrections of individual SYNOPs.

2.1.2 Monthly CLIMAT reports received at DWD, JMA and UK Met Office

In the framework of the regulated global data exchange, monthly climatic data for more than 2000 stations are disseminated by the countries via GTS as CLIMAT bulletins. The CLIMAT bulletins include monthly means or totals for a number of variables compiled from reprocessed SYNOP observations collected by the publisher. The data are known to be of high quality because some control of quality and completeness was performed on it. However, some errors still occur partly caused by the manual coding process. Therefore, the data is checked by GPCC upon arrival for typical coding errors, completeness and consistency. The plausibility of monthly precipitation is examined using additional information being also part of the CLIMAT bulletin, e.g. number of days with precipitation above 1 mm and the quintile of the monthly data with regard to the frequency distribution, yielding the possibility to recognize and flag questionable data. The resulting quality-controlled CLIMAT precipitation data serves as reference data during GPCCs QC procedures explained in much more detail by Schneider et al. (2012).

2.1.3 Monthly precipitation derived from SYNOP data collected by NOAA/CPC

As third source, GPCC utilizes the monthly precipitation data of the Climate Prediction Center (CPC), Washington DC, hosted by the National Oceanic and Atmospheric Administration (NOAA) being mainly based on SYNOP data. The global SYNOP data collective received by CPC through the GTS is not fully overlapping the collective received at Offenbach, thus featuring unique data contributions. While the CPC receives more data for the Americas, Eastern Russia and some African regions, the DWD reaches a much higher data density over Europe. The CPC procedure to estimate monthly precipitation totals and especially to fill gaps in the SYNOP precipitation series is different from the GPCC method described before. In addition to GPCC's method, CPC includes precipitation data being statistically estimated from the qualitative weather observations ww and W1,W2, and extrapolates to the full month even if only relatively few observations are available. Therefore GPCC ranks redundant CPC-SYNOPS below the DWD ones but still applies cross-checking of both data to detect trivial data transmission or encoding/decoding errors.

In order to obtain the best possible spatial data coverage at the earliest time as required by the GPCP and other users, the GPCC merges for its Monitoring Product the monthly totals from all three GTS data sources CLIMAT, DWD-SYNOP and CPC (Fig. 2) after each of them has been loaded into GPCC's relational data base management system (RDBMS) from where it is subsequently available for the monthly near-real-time GPCC Monitoring Product and other analyses.

The near real time data base provides in some regions a sufficient data base for quantitative precipitation estimates, if the grid resolution is not too high. Therefore, the GTS based GPCC products are only offered on a 2.5° and 1.0° resolving latitude longitude grid but not at 0.5° in contrast to the reanalysis products utilizing also non-GTS data. Moreover the number of stations per grid is provided as additional information to every GPCC product, to allow for an easy assessment of its potential reliability.

Within the data pool, the CLIMAT data – after a quality check – is assigned a higher quality and provide therefore a reference for quality assessment of the SYNOP-based data. The earliest GPCC (First Guess) product is public available for all months since August 2004 and utilizes just the DWD SYNOP-based monthly precipitation totals from approximately 6000 stations (Fig. 2). Most recently this number has increased to more than 6800 stations. For the GPCC Monitoring Product, issued two months later than the corresponding First Guess Product almost 8000 stations are utilized nowadays starting from approximately 6000 GTS stations in 1986.

2.2 GPCC full data base

All other data not exchanged through the GTS has been originally raised by WMO NHMSs for the specific purposes of the host countries and its exchange is subdued to particular national rules. It is still only a few NHMSs that publish their national data without restrictions or with copyrights through the Web. Therefore GPCC needs to

perform data acquisition in order to access the many more stations that are not reporting through the GTS. Major sources are:

i. National data contributions by WMO Members (158 countries and 31 regional suppliers so far totalling the number of national sources to 189, see Appendix A)

ii. Data collections of some international regional projects (e.g. SE Asia, Africa, Former Soviet Union)

iii. Global data collection of the Climate Research Unit (CRU, Norwich, UK; New et al., 2002)

iv. Global data collection of the UN Food and Agricultural Organisation (FAO, Rome, Italy)

v. Collection of the Global Historical Climatology Network (GHCN, NCDC Asheville, USA; Peterson et al., 1997, 1998)

National data contributions are normally acquired through bilateral correspondence of GPCC with the responsible national agencies. Moreover all WMO Members are informed by circular letters of WMO about the international task of the GPCC and the corresponding data requirements. The GPCC has no funds for data purchasing and even not for covering any shipping costs. The data delivered are contributions of the countries to the international task of the GPCC and are restricted to the defined purpose. In doing so GPCC globally applies a policy to respect the copyrights of every data supplier and to publish only gridded products from the data but not the original data itself. While this data policy can be criticized as contradicting open access data policies it has yielded a data base of double and triple size (Fig. 3), respectively, with regard to the most popular data sets of the Global Historical Climatology network (GHCN; Peterson et al., 1997, 1998) and the Climate Research Unit (CRU) of the University of East Anglia (New et al., 2002) that supply also the original data to the community. In order to warrant transparency on our methods without parsing data to third parties any scientist is invited to inspect the GPCC archive and its methods on site at the Headquarters of the Deutscher Wetterdienst.

Original data is provided from a national source (i) and origins directly from the institution (e.g. a WMO NMHS) that has actually carried out the measurement. It constitutes the core part of the GPCC data base (Fig. 3). To be comprehensive in its approach, the GPCC integrates also other global precipitation data collections from sources (iii) to (v) as well as several regional data sets. For example a data set from Nicholson (1979) comprising unique precipitation data across Africa has been integrated in year 2010, as well as an update of the data set of Pavel ("Pasha") Groisman (NCDC, 2005) for the countries of the Former Soviet Union. As a result of these efforts the GPCC holds the worldwide largest and most comprehensive collection of monthly precipitation data, which is continuously updated and extended.

All precipitation data received are stored in source specific slots within the RDBMS and the corresponding meta information and quality indices are assigned to the data. The eight aforementioned major sources (CLIMAT, DWD-SYNOP, CPC-SYNOP, National, Regional, CRU, FAO and GHCN) are considered.

Figure 3 displays the temporal evolution of the number of monthly precipitation station data in the GPCC data base from the different sources during the time period 1901–2011. The volume and timeliness of the individual data provisions largely differ, with the time delay resulting in an increase of the number of stations being available for the analyses looking back from year 2011 where basically the GTS coverage determines the total number of available stations until the month of best data coverage, i.e. June 1986 with monthly precipitation data being available for just 47 400 stations. Looking further into the past, there is a drop from 47 228 stations in January 1986 to 41 285 in December 1985 with an increase further backward until another local maximum of 45 869 stations for June 1970. This drop is a remainder on the initial project phase where only months since January 1986 where regarded. GPCC will ultimately fill this gap with future data acquisition. The data coverage for all months older than June 1970 shows the typical behaviour of almost monotonically decreasing data availability

due to loss or not yet performed data rescue with regard to digitization of historic data records. Only World Wars I and II shortly interrupt this monotonous decrease with age of the data records.

Despite the number of stations successfully recruited, the homogeneity of its global distribution is another quality criterion for a climate data set. Therefore, Fig. 4 demonstrates how the coverage of the GPCC data base is composited (as of July 2012) with regard to the six regions defined by the WMO Regional Associations (RAs). Interestingly the total numbers are quite similar for the periods before World War II across all RA's despite RA1 (Africa), whereas a spread occurs for the periods post 1950 with RA4 (North America) and RA6 (Europe) showing the highest numbers up to 10 603 and 11 961 stations, respectively, followed by RA5 (Oceania including Australia) with up to 7706 stations, RA3 (South America) with up to 6657, RA2 (Asia) with up to 5742 stations. For all months from 1901 until 1942 the GPCC data base features the least number of stations for RA3, since 1950 the least number of stations is available from RA1 (Africa) with up to 5028 stations. Only in early 1971 the GPCC data base features slightly less stations for several months in RA2. Moreover the most recent months being controlled by the availability of GTS connected stations have the lowest number of stations from RA3. Finally Fig. 4 demonstrates that the time elapsing until the arrival of historic data is much shorter for RA4 and RA6, respectively, where it takes 5–7 yr in distinct contrast to RA1-3 where the increase through historic data is much lesser and it can take easily 20 yr before data arrives at the GPCC. This situation challenges all efforts to achieve a geo-temporal homogeneous station coverage which is a prerequisite for highly reliable gridded trend analysis products solely based on in-situ data.

As listed in Appendix A, GPCC holds also records from the 19th century, but the overall coverage is currently too low to justify reanalysis of these early periods. Further successes in data acquisition and rescue might change this situation in the mid-term future.

All in all acquisition and integration of the additional non-GTS data from sources (i) to (v) takes much longer than through the GTS, but even delays of some years are to be accepted for the sake of a high quality and reliable quantitative gridded reanalysis, being crucial for global climate variability and hydrological studies. Therefore, the processing of the individual data collectives is a continuous GPCC activity and requires a number of steps:

a. Identification of the file content (variables, period), general structure and specific format

b. Conversion of the file into a uniform GPCC format

c. Visualization of the reformatted file in maps and diagrams for a quick overall quality check

d. Clear identification of the stations and meta data control by a semi-automatic comparison of the delivered meta data and the existing GPCC stations master catalogue

e. Loading of the data into the Relational Data Base Management System (RDBMS)

f. Semi-automatic quality-control of the monthly precipitation data based on a comparison of the data from the different sources with respect to the spatial and statistical data structure.

Apparently redundant data from different sources for the same stations and time allows for cross-comparison, quality-control and assessment of the accuracy of the data to be selected for analysis. This quality controlled merging of data from all eight sources leads to the best possible and comprehensive data base. The semi-automated QC system applied is detailed in Schneider et al. (2012).

All products are generated out of this data base by selection of data with respect to the data quality and product specifications. The spatial distribution of 6325 stations for the GTS data basis and of all 46 711 stations available for a well-covered month (July 1987) is shown in the left column of Fig. 5. So for this month the global 40 000 stations criterion is met but not the homogeneity requirement because the station density varies

substantially with large data-sparse regions, in particular across parts of Africa, Central and South America, East and Central Asia. The spatial distribution of 7964 stations for the GTS data basis forming the August 2011 monitoring product versus the more than 67 200 stations available for the GPCC climatology of the month August is shown on the right hand side of Fig. 5. The row by row comparison in Fig. 5 demonstrates how the time constraint affects the data availability and station density; the column by column comparison in the top row reveals the limited temporal homogeneity of the GTS data coverage and in the bottom row the improved data coverage for the longer integration period of a climatology versus a monthly reanalysis which serves an argument for the anomaly interpolation method introduced in Sect. 4.

So the data coverage is very different depending on whether the data collection takes place with a time constraint (in online mode) or if time is a less important criterion. As will be shown in Sect. 7, both modes have their applications. In all cases the availability of a reliable background climatology is crucial for the quality of the analysed product.

During the last two decades the set of GPCC data and products has continuously grown both in temporal coverage, as well as in extent and quality of the underlying data base. Until the end of 2003, the period covered by the GPCC reanalysis products reached back from present to just 1986, when the GPCP project was started. Later, in years 2004 and 2008 GPCC extended this period back to 1951 and 1901 respectively, as shown in Fig. 1 where the evolution of the GPCC Monthly Precipitation Database throughout the dates of issuance of the latest five Versions of its Full Data Reanalysis Product (GPCC FD) is depicted. This product is only updated after substantial growths of the data base. It can be seen, that the starting period of GPCC, 1986–2001, is still the period with the highest number of station data. However a larger increase of the number of stations available for the period before 1986 and after 2001 is visible in particular for the updates from Version 3 to 5. So the gap from 1986 to the years before is almost closed with issuance of the most recent Version 6 issued in December 2011 and discussed in this paper. Moreover the number of 30k, 35k, and 40k stations is exceeded for the 56, 45 and 31 yr periods from 1950–2005, 1959–2003 and 1962–1992, respectively, making those periods in particular reliable for analyses of means, anomalies, variability and even trends of global land-surface precipitation.

Figure 6 shows the evolution of the number of station months in the GPCC Monthly Precipitation Database (decades with data from 1901 onwards) during the period August until December 2011. It indicates that the extension of the GPCC data base concerning historical data (data before year 1951) started in 2007. The historical extension of the GPCC data base during the last 8 yr is very visible by looking at the decades with data before year 1981. Altogether the number of station months tripled from 13 to just 40 million making GPCC the host of the worldwide largest and most comprehensive collection of monthly precipitation data, which is continuously extended.

Figure 7a–h shows the temporal evolution of the spatial coverage of the GPCC database (indicated by the number of stations available for analyses in each 2.5° × 2.5° grid) used for GPCC Full Data Reanalysis Version 6 issued in December 2011. Green, blue and magenta colours indicate grids with a nominal sampling error of less than 10 % of the precipitation total on the grid according to Jenne and Joseph (1985). This criterion is missed across vast areas in particular during the first two decades (Fig. 7a, b), but later the world-wide best data coverage of the GPCC is good enough for a fair spatial homogeneity of the station density. Figure 7h shows the consequences of the rather limited number of available GTS stations, leading to a wide-spread exceedance of the 10 % sampling error criterion. Comparison of Fig. 7h representing basically the GTS station coverage with the other Fig. 7a–g shows the added value of GPCCs successes in historic data acquisition.

Finally Fig. 8 and the Appendix A give a country specific account on GPCCs efforts towards universalization of the data contributions and coverage. Obviously data acquisition remains an on-going challenge for the GPCC. It is backed by WMO through support letters of the WMO Secretary-General and by endorsements made by the WMO GCOS Atmospheric Observation Panel for Climate (AOPC; GCOS, 2011).

3 Data processing and quality control

The collected data are imported into a relational data base, where they are kept in eight separate source specific slots. This methodology allows for a source specific cross-comparison of the data. As none of the sources is error free, each source is allowed to provide for the reference information on a case-by-case basis. This is realized by a comparative analysis of data entries from different sources relevant for the same or neighbouring stations, the latter only in cases staying ambiguous if only the station itself is regarded. Typical errors identified during data import are factor-10 (caused by a format shift or coding errors), factor 2.54 or also factor 25.4 errors due to wrong inch to mm conversions, shifts of the reference time, or geo-reference errors that had affected the data already before arrival at the GPCC. Any time new data is imported to the data base, an elaborated procedure is applied to compare the accompanying metadata of the pertinent stations to the metadata already available for this station from the data base. In case of discrepancies (e.g. deviating coordinates), external geographical sources of information are utilized to decide whether a correction of the metadata information in the data base is required or not. Moreover the precipitation data to be imported is compared against a background statistic. Exceptional values are checked and either confirmed, corrected if possible, or flagged as erroneous and thereby excluded from the analyses. This approach requires a high level of human interaction, due to the complexity of the error analysis, which varies strongly from case to case in the absence of general valid screening criteria. Nevertheless, despite all corrections applied by the GPCC, a set of the original data is also kept, allowing backtracking of all corrections. A detailed account on GPCCs data processing and quality control is presented by Schneider et al. (2012).

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4 Calculation of gridded precipitation data sets (interpolation method)

The calculation of area means on the grid cells from gauge observations consists of three major steps, the interpolation from stations to regular latitude longitude grid points staggered at 0.25° resolution, the calculation of area-mean precipitation for grid cells sized 0.25° (GPCC-CLIM) or 0.5° (GPCC-FD, MP), and the assessment of area-mean precipitation for larger grid cells (0.5°, 1° or 2.5°) or other areas (e.g. river basins).

4.1 Interpolation of gauge data onto regular grid points

For the GPCC (background) climatology and the full data reanalysis products on a 0.25° latitude longitude grid, GPCC still prefers the very robust empirical interpolation method SPHEREMAP. The method constitutes a spherical adaptation (Willmott et al., 1985) of Shepard's empirical weighting scheme (Shepard, 1968), which is taking into account:

a. the distances of the stations to the grid point (for limited number of nearest stations),

b. the directional distribution of stations in relation to the grid point (in order to avoid an overweight of clustered stations), and

c. the gradients of the data field in the grid point environment.

This choice was made in 1991 following external studies (Legates, 1987; Bussieres and Hogg, 1989) and internal inter-comparison studies (Rudolf et al., 1992, 1994) indicating the SPHEREMAP method of being particularly suitable in analysis of a global precipitation climatology. In an inter-comparison study of four different interpolation schemes (Bussieres and Hogg, 1989) it was the best of the empirical schemes and did a job almost as well as Optimum Interpolation.

Willmot et al. (1985) apply a weighting method for all stations beyond a minimum distance to the grid point (ε_1, circles filled blue in Fig. 9). However, if stations closer are

found their method only relies on those stations and applies a simple arithmetic mean for them, while neglecting all station outside this environment. This leads to neglecting many potentially useful stations and information in areas of high station density. Therefore GPCC has introduced the following modifications to interpolate data of stations surrounding each point of the stereographic GPCC product grids, as follows:

- Vicinities are defined by concentric circles of different radii (see Fig. 9) defining threshold distances to the grid point regarded
- A second distance (ε_2, circles filled green in Fig. 9) is introduced defined by 50 % of the grid cell size (depicted by grid lines in Fig. 9). This approach still leaves up to 21.5 % stations unprocessed, but any larger circle would lead to a double use of stations, as the green circles in Fig. 9 would start to overlap each other.
- ε_1 is defined by 10 % of the grid size instead of Eq. (14) in Willmot et al. (1985)
- The simple arithmetic mean method is now only applied, if stations are found within the vicinity defined by radius ε_1 but not within the wider (green) circle of ε_2
- In all other cases, stations are interpolated with the original weighting method, even those located closer than ε_1
- For the normalization in the weighting method, we keep Shepard's method for the calculation of the combined weighting (Term w in Eq. (7) of Wilmot et al., 1985 and t in the 1st equation of page 520 in Shepard, 1968, respectively)
- The determination of the radius to the grid point beyond which the weighting of a station reaches zero is used as published by Shepard (1968)

In view of the potentially high number of stations involved in the interpolation process (> 10 000), it is feasible to introduce an intelligent search algorithm to identify for each grid cell the closest stations to be utilized for the interpolation. Instead of ranking the distances across all stations, we apply in advance a clustering of stations on 2° × 2°

sized grid cells and limit the search algorithm to a search window being sized as 1.75 times the cluster size (here 3.5°) at the equator. Towards higher latitudes the size of the search window is conserved in the canonical manner by scaling with the cosine of the latitude. The 175 % oversizing of the search window warrants that it does not miss stations just outside the closest cluster. Target number of stations to be ranked is 16. If the original search window finds fewer stations than this target number, the window is doubled in size and the search is repeated until the target number is reached. For latitudes higher than 87.5 degrees the whole area is regarded as one cluster giving one for each pole region.

4.2 The GPCC anomaly gridding method

Since year 2008, when Version 4 of the precipitation reanalysis was issued, the GPCC has enhanced its gridding method to a climate anomaly method. This became possible because the GPCC data base allowed the first time for the calculation of the GPCC climatology product (Version 2008) to be utilized as background field for the anomaly method. Now the anomalies can be interpolated with the methods described in Sect. 4.1 instead of the absolute precipitation totals yielding product specific gridded deviations from the climatology being subsequently superimposed to the gridded global background. For earlier versions this methodology was not applicable, as there were too few stations with sufficiently long data series to calculate climatological normals for a reliable gridded global background. The method is most beneficial in data scarce (under sampled) regions as we will demonstrate in the sampling error Sect. 5.2.

4.3 SPHEREMAP vs. Kriging interpolation

A statistical interpolation method according to Rubel and Hantel (2001) that basically constitutes ordinary block kriging (Krige, 1951) is also implemented at GPCC as an alternate method. Figure 10 shows the difference of the SPHEREMAP and Kriging method for the particular challenging real-time monitoring product analysis at 1° spatial

resolution. It should be noted that for this comparison the absolute values but not the anomalies have been interpolated. Besides the difference field plotted in the upper right part and the monitoring product from both interpolations (lower row) the number of stations included into the analysis is also shown in the upper left graph. The example demonstrates that deviations occur only in data scarce areas where the minimum constraint of 4 stations per grid cell is not fulfilled. However, the deviations are only substantial in regions where station scarcity and high precipitation variability come together, i.e. the Equatorial region of South-America and Central Africa plus the southern rim of the Himalaya. Moreover singular stations with no neighbour stations across long distance naturally produce differences (see Greenland or patches across northern Siberia). In these areas the Kriging method features somewhat smoother patterns and is thus a considerable alternative to SPHEREMAP.

Therefore, the GPCC kriging method, being an adaptation of the ordinary block kriging introduced by Rubel and Hantel (2001), is the method currently tested for the daily products currently under development at GPCC, where the issue of under sampling and intermittency is more severe. Daily GPCC products are not part of this paper but will be discussed in a separate paper upon their first issuance. On the other hand, many also station scarce areas exhibit very little deviations, which gives confidence in the quality of the SPHEREMAP interpolation applied in particular for the non-real time GPCC full data reanalysis and the GPCC climatology which can utilize a data coverage that is overall five and eight times better, respectively (Fig. 11). Comparison of Fig. 11b with Fig. 10b demonstrates the diminishing effect of the interpolation method with increasing data density and sampling.

4.4 Calculation of area-mean precipitation for the high resolution mother grid (0.25° or 0.5° lat./long.)

For the GPCC products based also on historic data, the first area-average precipitation is calculated as arithmetic mean from the interpolated data from (up to) four grid points representing the corners of a 0.25° × 0.25° grid cell. In doing so, only those corners located across land are used, so the mean represents the land-surface precipitation. The 0.25° grid cell means only represent the land-surface proportion of the total grid cell area as derived from USGS GTOPO-30 (USGS, 2012) data projected on the same evaluation grid. For the real-time products the mother grid has 0.5 degrees resolution instead of 0.25 reflecting the weaker data coverage.

4.5 Reduction of the gridded precipitation for coarser grids

To allow utilization of the precipitation totals for multiple purposes, area-average precipitation are calculated by the GPCC onto coarser grids (1.0° or 2.5°) from the 0.5° mother grid means and also published. In doing so it is important, to take into account the high latitude convergence of the meridians but also the relative land-surface proportion of the grid cells used. The following formula applies

$$\mathrm{PAM}=\frac{\sum < \mathrm{SP}_{ij} > \cdot\cos(\varphi_j)\cdot \mathrm{LP}_{ij}}{\sum \cos(\varphi_j)\cdot \mathrm{LP}_{ij}} \qquad (2)$$

with PAM: Precipitation area mean
<SP>: Mean scaled (gridded) precipitation
LP: relative land-surface proportion
φ: Latitude
i, j: Horizontal indices counting positive eastward and northward, respectively

Figure 12 illustrates the grid topology applied for the GPCC procedure. Any user, utilizing the GPCC products for calculation of a global mean land-surface precipitation based on the gridded data product (e.g. GPCC FD) needs to apply the same land-surface percentage correction in order to avoid partly severe deviations (easily 20 mm) when applying standard tools alike the "fldmean" command of the climate data operators (CDO, Schulzweida et al., 2011) to reproduce a global land-surface mean precipitation, for example.

5 Uncertainty information

5.1 The three basic error types

As already indicated by the SPHEREMAP vs. Kriging comparison the GPCC gridded products are subdued to uncertainties. Typical sources of uncertainty are:

i. Systematic errors yielding biases of gauge measurements, such as wind-induced gauge under-catch (when droplets and particularly snowflakes are drifted by the wind across the gauge funnel), wetting and evaporation losses, and underestimation of trace precipitation amounts (Ye et al., 2004; Goodison et al., 1998).

ii. Stochastic sampling errors due to a sparse network density and/or uneven distribution of measurement sites (spatially heterogeneous data density). It mainly depends on the density of the gauge locations and the variability of the precipitation field according to the climatic/orographic conditions (WMO, 1985; Rudolf and Schneider, 2005; Rudolf et al., 1994).

iii. Residual errors, e.g. resulting from spatial and temporal discontinuities of precipitation measurements associated with changes of observational methods and differences of observational techniques used in different countries (homogeneity).

To address these problems the GPCC provides a gridded quantification for the following errors:

i. The systematic gauge-measuring error as (a) climatic or (b) SYNOP derived under-catch factors:

   a. Error correction on climatic time scale: parameters affecting the efficiency of measurement are features of the instrument used (size, shape, exposition etc.) and the meteorological conditions (wind, precipitation type, air temperature, humidity, radiation) during the precipitation event. This information is not available for most of the precipitation stations. The global distribution of the error has been estimated for long-term mean precipitation (Legates and Willmott, 1990) and is provided as climatic mean correction factor for each calendar month. The error and thus the required correction is large in snow regions respectively in cold seasons.

b. SYNOP derived correction: with the GPCC MP available for all months since January 2007, an on-event correction method for systematic gauge measuring errors is also available at GPCC (Fuchs et al., 2001). This correction is usually smaller than the climatological correction, however it is still a rough bias estimate based only on wind, weather, temperature and humidity data retrieved from synoptic observations of ca. 6000 stations available worldwide. These corrections have been calculated for the GTS based Monitoring Product (Schneider et al., 2011a, b) public available for all months since January 2007.

ii. The sampling error of gridded monthly precipitation data has been quantified by GPCC for various regions of the world. Based on statistical experiments using data from very dense networks, the relative sampling error of gridded monthly precipitation is between ± 7 to 40 % of the true area-mean, if 5 rain gauges are used, and with 10 stations the error can be expected within the range of ± 5 % and 20 % (Rudolf et al., 1994). The error range for a given number of stations represents the spatial variability of precipitation in the considered region. In the next Sect. 5.2 we provide a systematic assessment of the sampling error.

iii. The residual errors mainly related to the data homogeneity issue are addressed by construction of a special homogenized precipitation analysis (HOMPRA) data set that relies on a carefully chosen sub-set of stations featuring time series of particular length, completeness and temporal homogeneity. The method has been introduced by Beck et al. (2005) for the construction of the VASClimO data set (based on a sub-set of some 9300 stations) to be replaced soon by HOMPRA that will build on more than 16 350 stations. For the Full Data Reanalysis the

homogeneity is less controlled, although a check on the stations collective was also performed (H. Österle, personal communication, 2008, 2010) to remove stations with obvious jumps.

5.2 A systematic assessment of the sampling error

In order to perform a quantitative assessment of the sampling error of the GPCC products in dependence of station density and gridding (interpolation) method applied, we introduce here two standard sampling error metrics, the mean square error (MSE) and the mean absolute error (MAE), as follows

$$\mathrm{MSE} = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k)^2; \tag{3}$$

$$\mathrm{MAE} = \frac{1}{n}\sum_{k=1}^{n}|y_k - o_k| \tag{4}$$

with o, y denoting the observed, interpolated value at station k of the in total n stations.

In the following these metrics have been utilized to calculate the sampling error of arbitrarily resampled data sets according to the Jackknife error approach (Miller, 1974). In doing so the following steps have been taken:

a. Reducing the data density across Germany by dropping almost all of the 4000 stations available, to keep just 219 of them, yielding a horizontal homogenized station density across Europe

b. Define 300 bins to distribute the 45 000 stations utilized into

c. Pick up randomly 16 bins to form the reference data set (of 4800 stations)

d. Utilize remaining stations to interpolate to the locations of the reference stations

e. Calculate the absolute deviations (Jackknife errors) at the reference station locations

f. Repeat (c)–(e) 50 times with a different choice of reference stations according to (c)

g. Calculate MSE and MAE from the 50 Jackknife errors yielded.

h. The steps (c)–(g) are then repeated assuming station networks of increasing number starting from 1500, and increasing in steps of 1500 up to 39 000 stations

i. The steps (c)–(h) are repeated for the three interpolation methods "arithmetic mean", "modified SPHEREMAP" and ordinary block "KRIGING" utilized at GPCC

j. The steps (a)–(i) are performed on the "absolute" precipitation totals and on the "anomalies", utilizing the Climatology Version 2011 (GPCC-Clim) as background field.

The results, compiled in Fig. 13, are qualitatively similar for both metrics as follows:

– The error metrics are much more sensitive against the decision whether the anomalies or the absolute values are interpolated in comparison to the choice of the interpolation method (arithmetic mean, modified SPHEREMAP or Kriging)

– The sampling error can still exceed 25 mm per month for gauge networks of low density

– If a sufficient number of stations is available for the interpolation, the choice of the interpolation method has only a marginal impact

6 Construction of the 50-yr background climatology

Since introduction of the anomaly based interpolation method in 2008, the monthly GPCC climatology product serves as a background field for the analysis, and is thus of central importance for all products.

Anytime the GPCC data base has grown substantially due to successful acquisition and pre-processing of further historic data, including the quality assurance and control performed on the data as described in Sect. 3 and by Schneider et al. (2012), a new climatology product is built as follows:

– Selection of monthly precipitation data from the GPCC data base for the period 1811–2010 comprising all stations with data of minimum 10 yr (120 months) data availability out of the total record length of the up to 200 yr from 1811–2010. More than 67 200 stations were selected for the most recent Climatology (Version 2011) by this screening.

– For each of these stations a time series is constructed from the up to eight source specific time series available.

– Depending on the lengths of the time series yielded, climatic normals are constructed for the reference periods 1951–2000, 1931–1960, 1951–1980, 1961–1990 and 1971–2000. It should be noted, however, that we still accept for each month missing data of up to 10 yr in total.

– If none of these periods is covered by the series examined, a climatic normal is still calculated for arbitrary periods still divided into a long and an arbitrary category.

– Subsequently the 12 monthly minima and maxima of each station's time series for the period 1901–2010 are calculated to be available for interactive sanity checks.

– These 24 station specific (located) extreme values are than transcoded into KML files to perform a visual interactive sanity check of the stations time series while making use of the "Google Earth" software application.

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- In doing so, necessary corrections (e.g. relocation of a station) are fed back into the data base and the associated stations are reprocessed again (which means re-examination from the first bullet of this list)
- Based on the corrected data station specific climatic normals are calculated for the reference periods possible (preferably 1951–2000)
- Subsequently these normals are loaded to the DB to make them available for gridding with SPHEREMAP yielding the climatology product at 0.25° spatial resolution
- Finally reduction of the high-resolution gridded product to 0.5°, 1.0° and 2.5° grids is performed with the same methods as described in Sect. 4.5

6.1 The most recent GPCC Climatology Version 2011 product

The most recent climatology product (Meyer-Christoffer et al., 2011a–d) consists of data from over 67 200 stations. It comprises normals collected by WMO (CLINOs), delivered by the countries to GPCC, or calculated from time-series of monthly data (with at least 10 complete years of data) available in our data base. The Version 2011 climatology for all 12 months and the entire year are published by Meyer-Christoffer et al. (2011a–d).

Note: GPCC's monthly precipitation analysis products described in the following section are based on anomalies from climatological normals. For the FD product only anomalies at the stations were utilized. The MP and FG product uses also anomalies based on the corresponding climatological grid value including the station, if the station has no station based climatological normal. The anomalies are spatially interpolated by using the analysis method SPHEREMAP and the gridded anomaly analyses are then superimposed on GPCC's corresponding background climatology.

7 The GPCC products and their major sample applications and capabilities

Plenty of applications of the GPCC data products have been documented and published (Oldenborgh et al., 2012; Parker et al., 2012, Hennon et al., 2011; Rubel and Kottek, 2010; Yatagai et al., 2009, 2012; Dinku et al., 2008; Gruber and Levizzani, 2008; Kaspar and Cubasch, 2008; Wild et al., 2008; Kottek and Rubel, 2007; Rajeevan et al., 2005; Rudolf and Rubel, 2005). In order to address the wide spectrum of users the GPCC has designed four different gridded monthly precipitation products optimized for partly competing requirements related to the purpose of product use. We categorize the product requirements as follows

- Timeliness to support watch functions alike drought monitoring
- Quality and high availability at reasonable timeliness to serve as reference in-situ data set for regularly issued satellite-based products
- Accuracy via high station density to provide for a minimized sampling error for water resources assessment and case studies
- Homogeneity of stations time series to construct a product suitable for trend analysis

7.1 The GPCC first guess product (addressing timeliness)

This global gridded product of the monthly precipitation provided on one lat-long grid of 1.0° resolution (Ziese et al., 2011) is based on interpolated precipitation anomalies from more than 6000 stations worldwide. Data sources are synoptic weather observation reports (SYNOP) received at DWD via the WMO GTS, and climatic mean (mainly 1951–2000, or other reference periods as described before) monthly precipitation totals extracted from GPCC's global normals collection. An automatic-only QC is applied to these data. Since August 2004, GPCC First Guess monthly precipitation analyses are available within 3 to 5 days after end of an observation month.

7.1.1 Major sample application: drought watch and water stress monitoring

Main application purpose is to serve as input for near real-time drought monitoring applications, as has been demonstrated by the Food and Agriculture Organisation FAO (2011) and is still active at the Hazard Research Centre of the University College of London (UCL, 2011). Figure 14 illustrates a typical drought monitoring application of the First Guess Product in accumulating monthly totals for a certain period prior to the assessed date for a region chosen to be Portugal here.

7.2 The GPCC monitoring product (addressing quality and timeliness)

This global gridded product of the monthly precipitation (Schneider et al., 20011a, b) is based on SYNOP and monthly CLIMAT reports received near real-time via GTS from ca. 7000–8000 stations (after high level QC) and is available within two months after observation month on two lat-long grids of 2.5° and 1.0° resolution. This is the GPCC product with the longest history: operational monthly analysis started in 1986 and has continuously been updated every month since then. The analyses are based on automatic and intensive manual quality control of the input data. In general the GPCC MP is known as the best regularly issued in-situ and GTS based monthly land-surface precipitation reference product, public available.

7.2.1 Major sample application: calibration of satellite based data products

The GPCC Monitoring Product is the in situ component to the satellite-gauge combined precipitation analyses of GPCP (Huffman et al., 1995; Adler et al., 2003) and of CMAP (Xie and Arkin, 1997). Figure 15 shows an example visualization of the GPCP satellite-gauge product in terms of the anomaly against a GPCP 1961–1990 climatology for the El Niño (top plot) and La Niña (bottom plot) controlled southern hemispheric years ending in June 1998 and 2000, respectively. Across the land-surfaces each product relied on the twelve GPCC monthly monitoring products.

7.2.2 Auxiliary sample application: early annual reporting and monitoring

The gridded product is also utilized for the annual WMO statement on the status of the global climate (WMO, 2011b) and the BAMS Annual State of Climate (Parker et al., 2012; Hennon et al., 2011). Early assessments on larger scale extreme events like the Pakistan flooding in 2010 or the Thailand flooding in 2011 (Oldenborgh et al., 2012) also rely on this high availability and quality product.

7.3 The GPCC full data reanalysis (addressing accuracy)

This global gridded product of monthly precipitation (Schneider et al., 2011c–e) is based on near-real-time and non-real-time data. These are data from NMHS, regional and global data collections, CLIMAT bulletins and values calculated from SYNOP reports. It uses the same stations applied to calculate the GPCC Climatology product, i.e. more than 67 200 stations for Version 6. Grid resolutions are 0.5°, 1.0° and 2.5°. The QC is extended by an additional manual control. Upon substantial improvements of the data base a new version of this product is released, which happens approximately every 1–2 yr.

7.3.1 Sample application: verification of reanalysis products

Global reanalysis products like the ERA-interim reanalysis (Dee et al., 2011) become more and more popular to hindcast the most recent decades of the global climate and to serve geo-temporal homogeneous and contingent reference data sets for the validation of climate prediction models. However, the quality of the precipitation data in these model reanalysis's requires particular attention as precipitation is not a diagnostic but a prognostic parameter in the underlying global numerical weather prediction models utilized. Hence there is a need for purely observational analysis products of precipitation. It is the GPCC FD that proves to have a particular strength here (Simmons et al., 2010; Simmons, 2011). Its 110-yr coverage will also allow provision of reference information for the currently running ERA-CLIM effort (http://www.era-clim.eu/) to reanalyse the entire 20th century.

7.3.2 Sample application: analysis of historic global precipitation and the global hydrological cycle

The GPCC FD is well suited to provide reference information on the precipitation for certain periods and regions of interests due to its optimization for station density yielding a minimized sampling error of the interpolation. This makes it also most suitable to study the global water cycle, arctic precipitation (Mächel et al., 2012) and to derive mean precipitation across regional and global river catchments.

7.3.3 Sample application: identification of ENSO or NAO sensitive regions

An excellent sanity check for the centennial GPCC FD product is to diagnose regions being sensitive to indices of natural large scale variabilities of pressure patterns, known to govern precipitation patterns like the North Atlantic Oscillation (NAO) and the El Niño Southern Oscillation (ENSO) index (SOI). In doing so we have correlated the monthly resolved temporal evolution of precipitation for every 0.5° sized grid cell of the GPCC FD product against the negative SOI (Fig. 16) and NAO (Fig. 17). The sensitive regions, identified by areas of positive or negative correlation of the annual totals (left plots in top panels of Figs. 16/17) are congruent with the areas of significant correlation (right plots of top panels of Figs. 16/17). For the negative SOI (positively correlating with the typical SST indices, e.g. the Niño 3.4 region 5° N–5° S, 120–170° W; Trenberth, 1997) the well-known ENSO sensitive regions across eastern Australia, Indonesia, the Rio Plata Delta, Argentina, and the South-West of the US are clearly indicated. Looking into the seasonal behaviour (bottom panel of Fig. 16) the well-known ENSO sensitive areas across Southern Africa and South-East China during northern hemispheric (NH) winter; the fall and wintertime sensitive areas across the Amazonas basin, Venezuela and Guyana; and the South-West US being sensitive in fall, winter and spring are well

exposed. Even the narrow area along the pacific coastline of Ecuador is well resolved. For the NAO sensitive areas (Fig. 17) the typical north-south gradient from positive to negative correlation across Europe is well visible for the annual average and in particular during wintertime. Interestingly this analysis exposes also other regions world-wide where the attribution to NAO is less straightforward. The strength of both analyses lies in the fact that it is based on a purely observational data set and along a 110-yr period, making the result accordingly reliable. GPCC will publish a thorough discussion of these regional sensitivities of precipitation in a separate paper.

7.3.4 Sample application: trend analysis despite limited data homogeneity

Due to the GPCC success in data acquisition the data coverage (Figs. 1, 3, and 4) of the GPCC FD product does not feature anymore a strong inhomogeneity at the end of 1986, in contrast to predecessor versions (e.g. Version 4, see Fig. 1). Notwithstanding the fact that a robust trend analysis requires the scrutiny of a comprehensive station data homogenization, as currently carried out for the HOMPRA data set, the GPCC FD product can also be applied for trend analysis if the method of Sen (1968), according to the interpretation of Huxol (2007) being rather robust against inhomogeneities is utilized. This is done while bearing in mind the inhomogeneity issue during interpretation of the results. A thorough trend analysis shall be provided in a separate paper; here we only show the 110- and 55-yr trends across the globe at 0.5° resolution (Fig. 18) in terms of total sums of deviations from the median across the period. Only trends above 95-percent significance level according to a Mann-Kendall test are considered. Apparently the trend patterns shrink substantially if only the most recent 55 yr are considered, but certain regions with positive trends across Eastern North America, Northern Europe, the Rio de la Plata Delta, and the western part of Siberia are clearly highlighted. Negative trends are strongest across the tropical western equatorial Africa. Despite the non-existence of a positive trend across north-western Australia, these results identify the same regions for the annual trends as the VASClimO data set published by Beck et al. (2005).

7.4 The GPCC Homogenized Precipitation Analysis (HOMPRA; addressing homogeneity)

While the GPCC FD product involves all available stations with time-series longer than 10 yr, this constraint is still not strong enough to warrant a data coverage that is stable across all times of multi-decadal or centennial studies of variability and trends of precipitation. And even if a longer time constraint is applied, the lack of homogeneity of long-term series of in-situ precipitation observations remains a challenge to be met by appropriate detection and – if possible – correction to ultimately allow for a robust trend analysis. Currently the GPCC develops its new Homogenized Precipitation Analysis (HOMPRA) product that is based on a limited data collective of little more than 16 350 stations that feature an above 90 % availability of data across a 55 yr period from 1951–2005. For these stations an automated version of the homogenization tool PRODIGE (Caussinus and Mestre, 2004; Mestre, 2004) developed by Rustemeier et al. (2012) is applied. Unfortunately the evaluation could not be finalized until the submission of this paper made in due course to still be eligible for assessment by the authors to Chapter 2 of the WG-I part of the 5th assessment report of IPCC. Therefore, the station based trend analysis shown in Fig. 19 did not undergo the scrutiny and correction of Auto-PRODIGE. Notably areas of positive trends match to a good extend those identified by the evaluation of the non-homogenized GPCC FD product already. In addition the positive trends across Northern and Western Australia also identified by the VASClimO analysis appear again on the subset of the HOMPRA stations. Moreover the cluster of stations with positive total trends for periods within 1951–2005 across the US (Fig. 19) covers a much bigger area compared to the GPCC FD based trend analysis (Fig. 18) for periods 1901–2011 and 1951–2011, respectively. However, zooming into this area, as well as into Europe (not shown) reveals that besides the large scale patterns (alike the north-south gradient of trends across Europe) there is a high variability of trends among stations though located close to each other. This is a typical feature in particular across the mid-latitudes where the natural variability is high in both, wind

and precipitation, leading to very local effects in dependence of elevation, surrounding orography and exposition of each station. This can also induce inhomogeneities when stations are relocated. Only with completion of the HOMPRA data set a robust gridded trend analysis updating the VASClimO data set can be provided. For the time being the user is referred to the VASClimO data set also provided through the GPCC products download gate. The access to all GPCC products is specified in the following Sect. 8.

8 Access to GPCC products and plots and user advice

8.1 Access methods

The different gridded monthly precipitation data sets of GPCC, as well as the GPCP Version 2.1 satellite-gauge data set being available at 2.5° resolution for the period January 1979 until June 2009, are published. They can be visualized in maps like Figs. 10 or 11 or downloaded in ASCII format using the GPCC-Visualizer (Fig. 20) integrated into the public GPCC website http://gpcc.dwd.de. Moreover the download pointers and DOIs listed in Sect. 1 apply. On ftp://ftp.dwd.de/pub/data/gpcc/html/download_gate.html, GPCC has also implemented an ftp download gate pointing to all aforementioned products, the "GPCC Visualizer" and current documentation of each product, for the users' convenience.

8.2 User advice

Whenever considering usage of GPCC gridded land-surface precipitation products:

- Check which product is most suitable for the application purpose with regard to the priority of timeliness, regional accuracy, or homogeneity.
- Pay attention to the accuracy-related information provided by the GPCC (number of stations per grid, systematic error). Check the error range by consideration of the systematic error estimates and the regional number of stations used.

- Do not compare regional area-means which are calculated from data sets on different grid resolutions. The rough approximation of coastlines may cause relevant deviations between 2.5° and 1.0° based area means. If you use standard software tools, please note that they have their own approaches to consider the land-surface percentage thus yielding means that are potentially tool specific.
- When analysing long–term climate variability and changes do not combine different GPCC products available for different periods, which may cause discontinuities in time. Only a homogenized product like the HOMPRA product under development is fully adjusted to support long-term precipitation trend analyses.
- For periods where both, the FD V6 and the MP V4 product are available, rather refer to the FD product which is always based on more stations than the MP product. Only if you need to reproduce a GPCP product, reference to the MP product is meaningful.
- Reference to the GPCC through citations of this publication is requested from the users, and feedback about the application of the products to http://gpcc@dwd.de is very welcome.

9 Conclusions

Reference information on the most recent versions of the four gridded monthly observational data sets on the global gauge-based land-surface precipitation constructed and published by the Global Precipitation Climatology Centre (GPCC) is provided. Each of the four data set products is optimized for a specific purpose where either best stability and representativeness, (Climatology Version 2011), high accuracy (Full Data Reanalysis Version 6.0), high availability and reasonable timeliness (Monitoring Product Version 4.0), or high timeliness (First Guess Product) are the major requirements. For all products GPCC claims to serve the best possible observational gridded monthly land-surface precipitation data set world-wide, as they all are fed by the world-wide largest

data base of quality controlled rain gauge data collected from eight different sources allowing also for cross-checking of redundant data gathered from multiple sources.

With the Digital Object Identifiers (DOIs) issued for each product and spatial resolution of the gridded data sets we hope to have provided a repository of high quality gridded precipitation analysis across the past 110 yr from present back to year 1901, for the general public as well as for the scientific user community including the authors of the 5th assessment report of the IPCC. The data sets are accompanied by all essential information on their genesis and the corresponding ISO compliant metadata. All gridded products of the GPCC are provided through a download gateway under ftp://ftp.dwd.de/pub/data/gpcc/html/download_gate.html hosted permanently by the Deutscher Wetterdienst

Utilization examples of the GPCC products encompass case studies of specific events in the near or long term past, identification of ENSO and NAO sensitive precipitation regions and trend analysis across periods that can be chosen to up to 110 yr length starting from year 1901. Moreover the GPCC suite of documented gridded products establishes a homogeneous reference data base for model validation and cross-comparison and calibration with non in-situ based data sets.

10 Outlook

A fifth product optimized for homogeneity is in preparation, thus its predecessor VASClimO V1.1, thoroughly utilized for the 4th assessment report remains a recommended reference and is also available through the aforementioned GPCC download gateway. The replacement product HOMPRA (Homogenized Precipitation Analysis) will be superior in terms of the number of supporting stations that is effectively doubled (given the too high density of stations across central Europe for VASClimO) and the homogenization methodology utilized. The publication of HOMPRA is scheduled for year 2013.

Since 2011 GPCC has also commenced analysis of daily precipitation within an effort to combine a daily version of the HOAPS-3 product (HOAPS-4) with a daily GPCC precipitation analysis. First prototype results are expected to become available in year 2013, but providing a purely observational gridded daily data product at a reasonable quality and reliability remains a challenge. A major prerequisite for future enhancements on daily products lies in the success in data acquisition, as the demand on the station number and density is much higher for daily data.

Appendix A

List of contributions to GPCC from national and regional suppliers

Below, the 230 potential and actual contributors of original data from suppliers running gauge networks are listed. The list comprises the 158 WMO NHMSs and 31 regional suppliers that actually have supplied data to the GPCC at least once. The total data period covered is indicated (T) for each contributor followed by an ad hoc indicator rating the network density (S = superior, G = good, H = half sufficient, M = minor number of stations). The first and last year of data available at the indicated network density is also provided for every record. Finally a "*" indicates if the data has arrived GPCC through a scientific project instead of an official bilateral contact to the country or region regarded. Countries and regions without any time entry have not yet supplied data to GPCC, hence GPCC would particularly welcome there initial supplies, as well as updates from the other contributors. It should be noted that GTS connected stations are not considered in this list but their screened data is also processed for all GPCC products. Therefore the universalization of the GPCC data coverage is even higher than listed below and permanently growing.

Afghanistan	H: 1976–1980 TM: 1958–1984
Alaska (USA)	TH: 1986–2000
Albania	S: 1986–2000 TG: 1951–2008
Algeria	TM: 1936–2005
American Samoa (USA)	TS: 1986–2000
Andorra	
Angola	TM: 1901–2006
Anguilla	
Antarctica	
Antigua and Barbuda	
Argentina	TM: 1861–2008
Armenia	G: 1986–2000 TH: 1931–2005
Atlantic Ocean Islands	
Australia	TS: 1850–2008
Austria	S: 1936–2011 TH: 1900–2011
Azerbaijan	TH: 1989–1993
Azores (Port.)	TS: 1986–1996
Bahamas	TS: 1971–2000
Bahrain	TS: 1948–2009
Bangladesh	TH: 1948–2008
Barbados	TS: 1968–2004
Belarus	TG: 1961–2008
Belau (USA)	TS: 1986–2000
Belgium	S: 1986–2008 TH: 1951–2008
Belize	TS: 1960–2004
Benin	TS: 1951–2005
Bermuda's	
Bhutan	TS: 1990–2009
Bolivia	TM: 1942–2009

Bosnia Herzegovina	S: 1951–1991 TM: 1888–2001
Botswana	TM: 1981–2009
Brazil	H: 1986–1999 TM: 1950–2004
Brunei	TH: 1986–1996
Bulgaria	G: 1986–2006 TM: 1931–2006
Burkina Faso*	TS: 1902–2000
Burundi	TG: 1986–1993
Cambodia*	TM: 1907–2001
Cameroon	TM: 1960–1997
Canada	TG: 1840–2009
Canary Islands (Spain)	TG: 1986–1998
Cape Verde	TH: 1950–2003
Cayman Islands	
Central African Republic	
Chad	
Chile	TS: 1970–2007
China	TM: 1951–2010
Colombia	S: 2001–2005 TM: 1910–2009
Comoros	TG: 1987–1993
Congo	
Cook Islands (New Zealand)	TS: 1986–1996
Costa Rica	TM: 1888–2011
Croatia	TM: 1862–2005
Cuba	TG: 1986–1993
Cyprus	S: 1986–1990 TG: 1925–2011
Czech Republic	TS: 1961–2011
Dem. Congo (former Zaire)	
Denmark	S: 1961–2012 TH: 1860–2012
Djibouti	TM: 1986–1998

Dominica	
Dominican Republic	TS: 1931–2010
Ecuador	S: 1976–2003 TM: 1901–2008
Egypt	H: 1986–1996 TM: 1968–2008
El Salvador	G: 1986–1993 TM: 1971–2008
Equatorial Guinea	
Eritrea	TM: 1986–2000
Estonia	TH: 1986–2001
Ethiopia	TM: 1951–2008
Falacep Island (USA)	TG: 1989–2000
Falkland Islands	
Faroe Islands	
Fiji	TS: 1986–1998
Finland	TS: 1961–2005
France	TS: 1819–2010
French Guyana	
French Polynesia (N. Zeal.)	TS: 1989
Gabon	TM: 1950–2000
Gambia	
Georgia	S: 1936–1990 TM: 1844–2010
Germany	TS: 1840–2012
Ghana*	TM: 1944–2010
Gibraltar	
Greece	TH: 1911–2010
Greenland	TM: 1860–2004
Grenada	
Guadeloupe	
Guam (USA)	TS: 1986–2000
Guatemala	TH: 1980–1992

Guinea	TM: 1903–2003
Guinea-Bissau	S: 1950–2005 TG: 1924–2011
Guyana	S: 1995–2006 TM: 1950–2006
Haiti	
Hawaii (USA)	TS: 1986–2000
Honduras	TM: 1944–1993
Hong Kong	TS: 1884–2011
Hungary	TS: 1951–2010
Iceland	TS: 1924–2007
India	TM: 1961–2000
Indian Ocean Islands	
Indonesia	TM: 1979–1999
Iran	S: 1986–2005 TM: 1951–2008
Iraq	H: 1939–1958 TM: 1887–1958
Ireland	TS: 1986–1995
Israel	TG: 1986–2007
Italy	S: 1986–1991 TG: 1951–2011
Ivory Coast	TS: 1905–2000
Jamaica	
Japan	TG: 1863–2010
Johnston Islands (USA)	TS: 1986–2000
Jordan	S: 1986–1999 TM: 1985–2004
Kazakhstan	TG: 1881–2006
Kenya	TS: 1969–1990
Kiribati (New Zealand)	TG: 1989–1996
Korea, North	H: 1954–2003 TM: 1905–2003
Korea, South	TS: 1951–2008
Kuwait	
Kyrgyzstan	TG: 1889–2007
Laos	

Latvia	H: 1986–2011 TM: 1901–2011
Lebanon	
Lesotho	
Liberia	
Libya	TG: 1986–1992
Liechtenstein	TG: 1986–2003
Lithuania	TH: 1922–2010
Luxembourg	TS: 1949–2006
Macao	TG: 1901–2010
Macedonia	TH: 1986–2002
Madagascar	
Madeira (Port.)	TS: 1986–1996
Malawi	G: 1960–2004 TM: 1901–2004
Malaysia	S: 1986–1993 TM: 1951–2008
Maldives	TS: 1974–2008
Mali	S: 1987–1988 TG: 1987–1991
Malta	TG: 1922–2007
Mariana Island (USA)	TS: 1987–2000
Marshall Islands (USA)	TS: 1986–2000
Martinique	
Mauritania	
Mauritius	TS: 1986–2008
Mexico	H: 1986–1989 TM: 1893–2005
Micronesia (USA)	TS: 1986–2000
Midway Island	
Moldavia	TS: 1986–1998
Monaco	
Mongolia	H: 1937–2008
Morocco	TM: 1920–2007

Mozambique	TH: 1951–2008
Myanmar	TM: 1965–2003
Namibia	H: 1952–2008 TM: 1890–1993
Nauru	
Nepal	TS: 1947–2007
Netherlands Antilles	TS: 1970–1993
Netherlands	TS: 1951–2011
New Caledonia	
New Zealand	S: 1986–2010 TM: 1873–2011
Nicaragua	TG: 1952–2004
Niger	G: 1981–1991 TM: 1905–2008
Nigeria	TM: 1961–1997
Norway	TS: 1950–2008
Oman	S: 1986–1992 TM: 1942–2008
Pakistan	TM: 1961–2007
Panama	TS: 1955–2008
Papua New Guinea	
Paraguay	TM: 1986–1998
Peru	S: 1964–2005 TM: 1931–2006
Philippines	TM: 1902–2004
Pitcairn (New Zealand)	TG: 1993–1996
Poland	G: 1986–2011 TM: 1951–2011
Portugal	TS: 1951–2010
Puerto Rico (USA)	TS: 1986–2000
Qatar	S: 1986–1993 TM: 1962–2003
Romania	TS: 1961–2004
Russia	TM: 1966–2009
Rwanda	S: 1965–1991 TG: 1926–1991
Saint Kitts and Nevis	
Sweden	TS: 1961–2003

Switzerland	TS: 1864–2011
Syria	H: 1986–1992 TM: 1946–2004
Taiwan	TG: 1935–2011; 1897–2011
Saint Lucia	
Saint Vincent	
San Marino	
Sao Tome and Principe	
Saudi Arabia	
Senegal	
Seychelles	TS: 1971–2010
Sierra Leone	
Singapore	
Slovakia	TS: 1901–2011
Slovenia	TS: 1951–2009
Solomon Islands	TS: 1989–1996
Somalia	
South Africa	TS: 1951–2008
Spain	TS: 1900–2003
Sri Lanka	TG: 1986–1995
Sudan	TM: 1902–2004
Suriname	TM: 1852–2009
Swaziland	S: 1919–1992 TM: 1897–1993
Tajikistan	
Tanzania	TM: 1961–2006
Thailand	TH: 1951–2009
Togo	TS: 1901–2005
Tokelau (New Zealand)	TS: 1989–1996
Tonga (New Zealand)	TS: 1989–1996

Trinidad & Tobago	TG: 1986–1995
Tunisia	TG: 1986–1999
Turkey	G: 1961–2007 TM: 1846–2007
Turkmenistan	TM: 1986–1990
Turks and Caicos Islands	
Tuvalu (New Zealand)	TG: 1989–1996
Uganda	TM: 1951–2008
Ukraine	H: 1986–1992 TM: 1885–2009
United Arab Emirates	H: 1980–2000 TM: 1974–2008
United Kingdom	S: 1961–2011 TM: 1853–2011
Uruguay	TM: 1961–2004
USA	TS: 1878–2007
Uzbekistan	TM: 1879–2010
Vanuatu (New Zealand)	TG: 1952–2010
Venezuela	S: 1968–1996 TM: 1901–2005
Vietnam	S: 1959–1983 TM: 1886–2008
Virgin Islands (GB)	
Virgin Islands (USA)	TS: 1986–2000
Wake Island (USA)	TS: 1986–2000
Wallis and Futuna	
Western Sahara	TM: 1986–1989
West Samoa (New Zealand)	TG: 1989–1994
Yemen	TM: 1995–2005
Yugoslavia (Serbia + Montenegro)	TH: 1961–2004
Zambia	TM: 1933–2011
Zimbabwe	TG: 1986–1994

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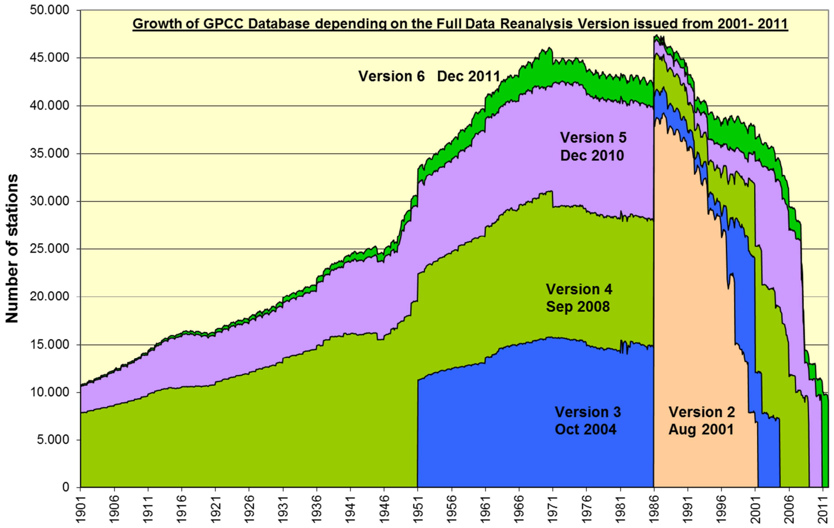

Fig. 1. Growth of the GPCC data base in terms of number of precipitation gauge stations per data month integrated. Five evolution stages are depicted, concurrent with the dates of issuance of Version 2 (2001), 3 (October 2004), 4 (September 2008), 5 (December 2010) and 6 (December 2011) of the Full Data Reanalysis. The ticks denote the Januaries of each year.

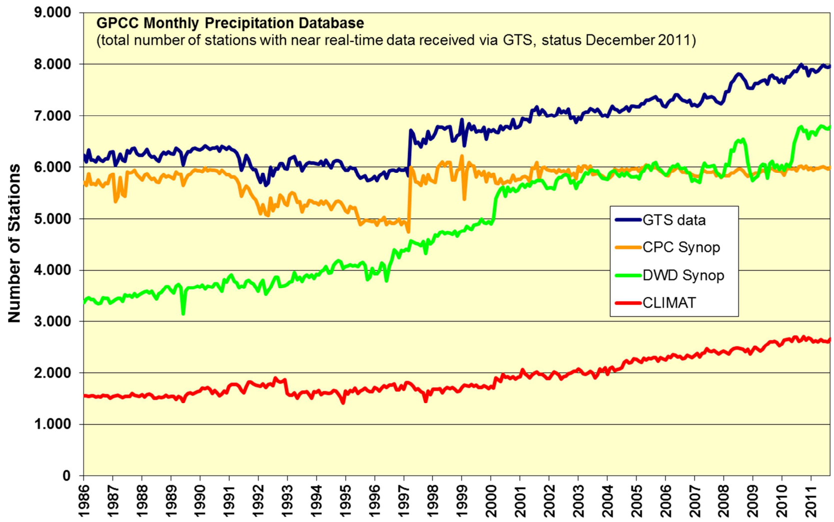

Fig. 2. Total number of unique stations (blue line) received via GTS from 1986 until 2011 when more than 8000 stations reached GPCC. In addition the three sources forming the total (CPC- and DWD-SYNOP and CLIMAT) are also depicted by orange, green and red lines.

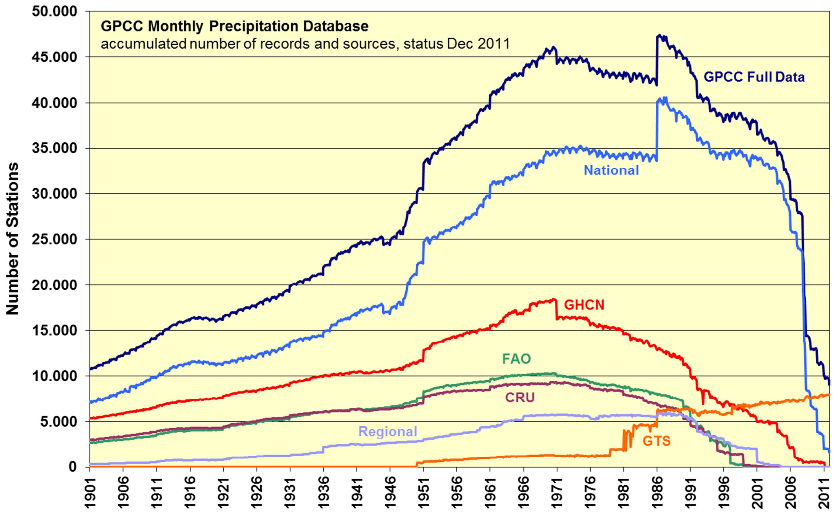

Fig. 3. Number of monthly precipitation data in the GPCC data base as a function of time across the periods covered by GPCC products for the GTS based and the five different historical data sources in the GPCC database. Moreover the total number of unique stations (dark blue line) is shown. The ticks denote the Januaries of the years.

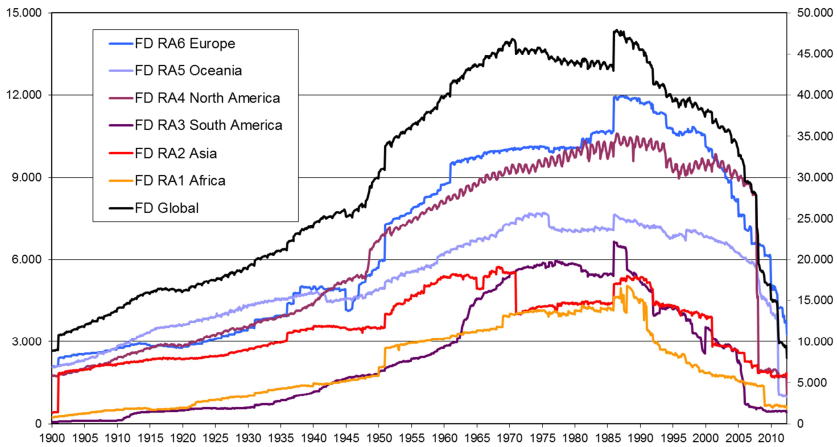

Fig. 4. Number of rain gauges (coloured lines, left y-axis) supplying monthly precipitation data in the GPCC data base as a function of time across the periods covered by GPCC products for the six different regions defined by the WMO regional associations (RAs). Moreover the global total is also plotted (black line, right y-axis). For a map of the RAs consult http://www.wmo-dra.info/gmap/WMO_NMHS_regions/metservices.html.

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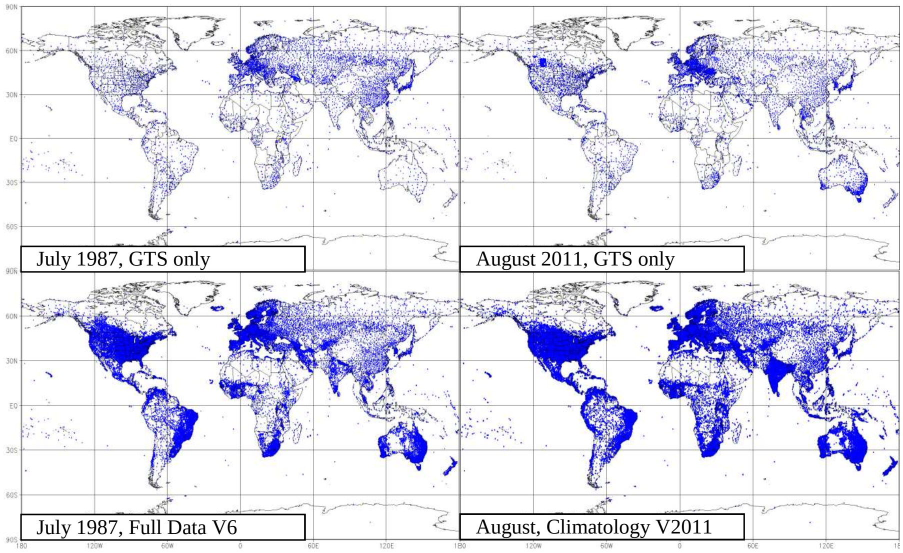

Fig. 5. Left Side: mapping of the 6325 stations reporting online via the GTS (top left) thus available for the GPCC monitoring product of July 1987 versus the 46 711 stations available for GPCC full data reanalysis of this well covered month (bottom left). Right Side: mapping of the 7964 stations reporting via the GTS for a recent monitoring product (August 2011) (top right) versus more than 67 200 stations available for the background climatology (Version 2011) of this month (bottom right) featuring time series longer than 10 yr at every station.

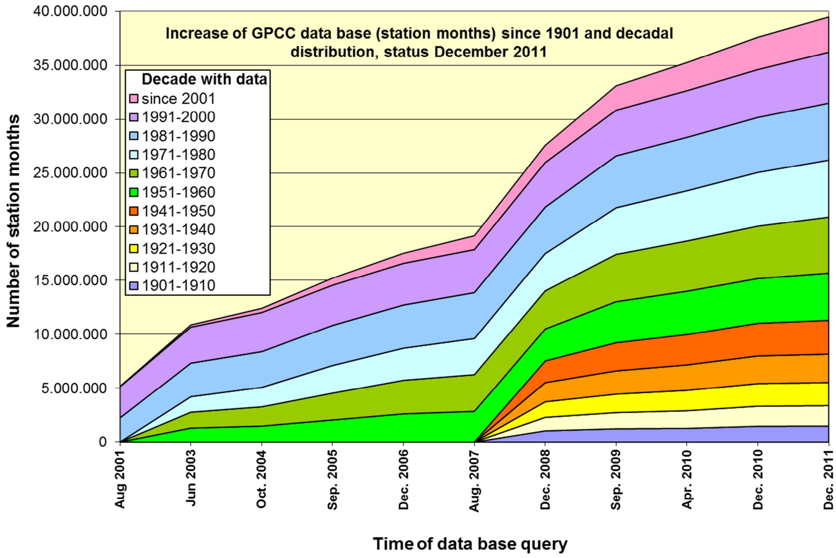

Fig. 6. Evolution of the GPCC Monthly Precipitation Database between August 2001 and December 2011 shown by the number of station months already accumulated at the date (time) of the data base query. The decades covered are additionally colour coded.

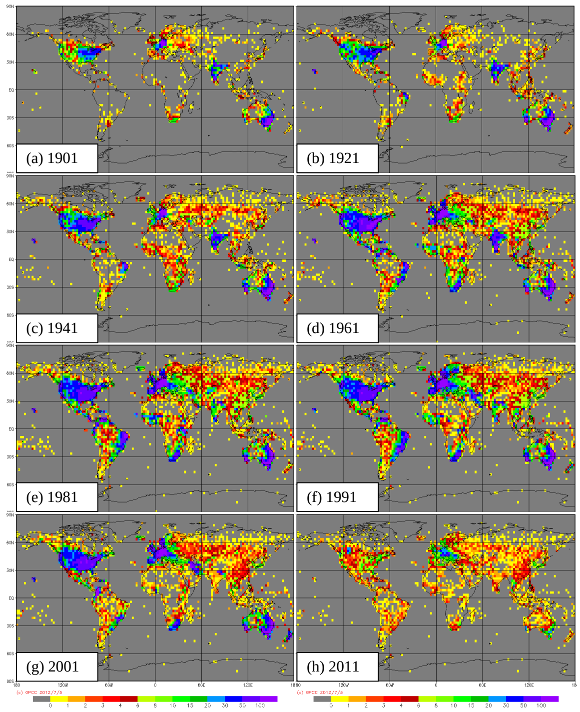

Fig. 7. Spatial distribution of the number of stations per 2.5° × 2.5° grid available for the July reanalyses (Version 6) of **(a)** year 1901 with 10 907 stations, **(b)** year 1921 with 16 688, **(c)** year 1941 with 24 602, **(d)** year 1961 with 41 032, **(e)** year 1981 with 42 670, **(f)** year 1991 with 42 511, **(g)** year 2001 with 36 156, and **(h)** year 2011 with 9726 stations.

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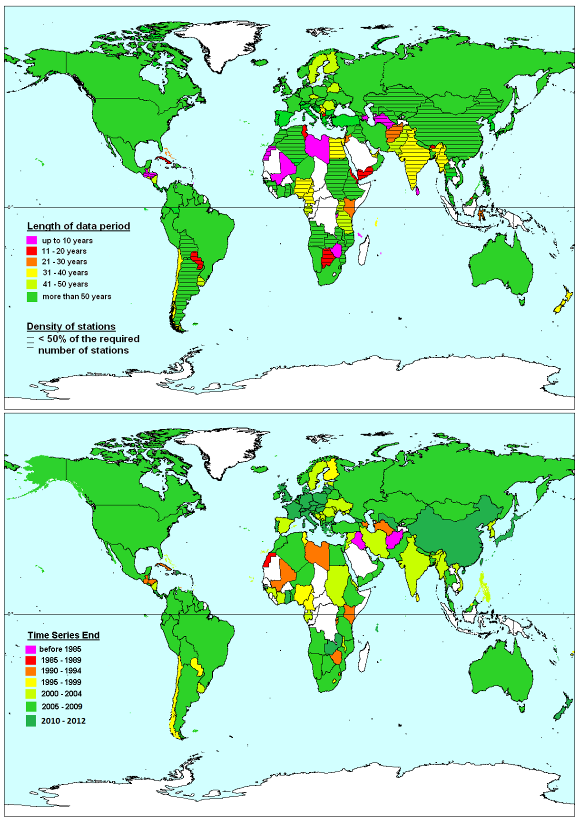

Fig. 8. Contributions of historic precipitation data sets by WMO member countries to GPCC in terms of length of data period covered (top) and most recent historical data involved (bottom).

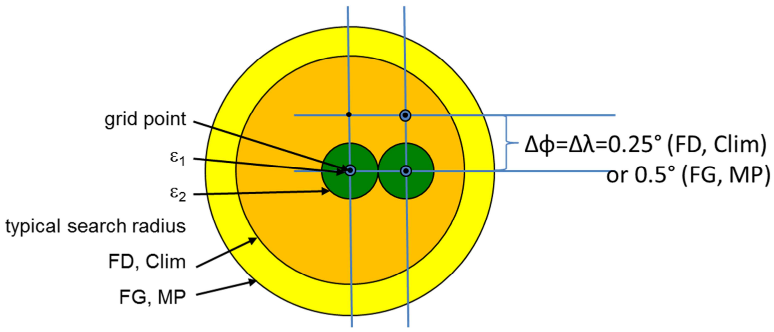

Fig. 9. Schematic view on distance circles around each point of the GPCC analysis grid being relevant to describe the GPCC modification of the SPHEREMAP interpolation of station data.

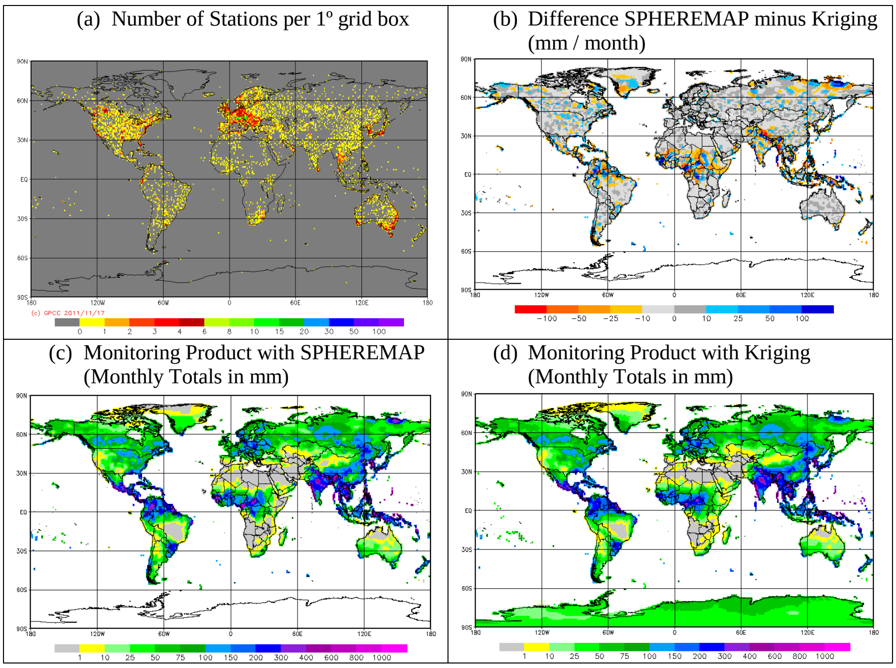

Fig. 10. Comparison of the two GPCC interpolation methods for the GPCC July 2011 monitoring product. **(a)** Stations available via GTS for the real-time analysis **(b)** Difference of SPHEREMAP and Kriging based interpolation **(c)** SPHEREMAP results **(d)** Kriging based result.

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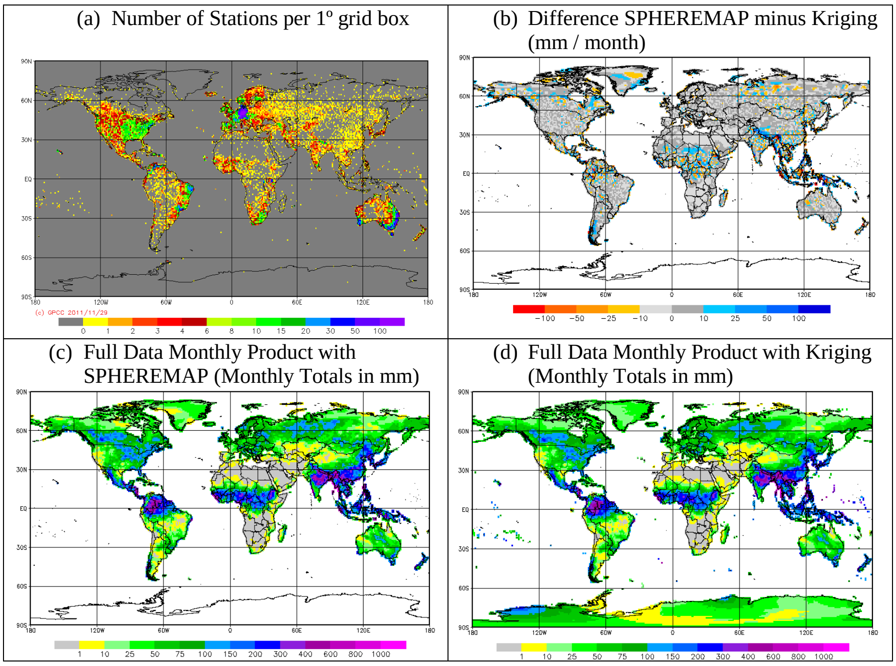

Fig. 11. As Fig. 10 but utilized for the GPCC July 1986 Full Data reanalysis product.

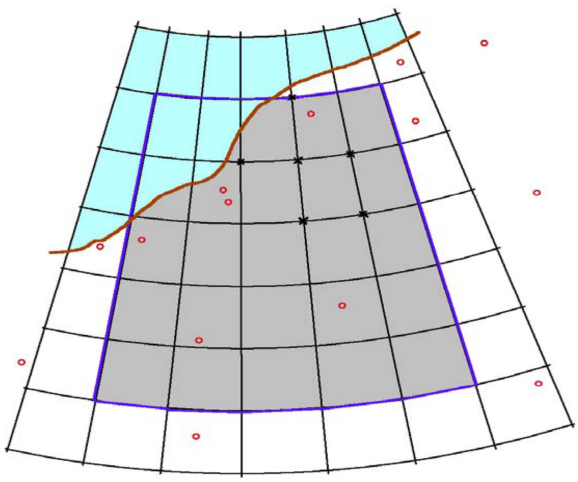

Fig. 12. Topology of GPCC's analysis products showing: station locations (circles), 0.5° grid points (crosses), 0.5° grid cells (inner boxes), one 2.5° grid cell including 25 basic grid cells (bounding box), the coastline, and southeast of it the part of the area represented by the gauge observations.

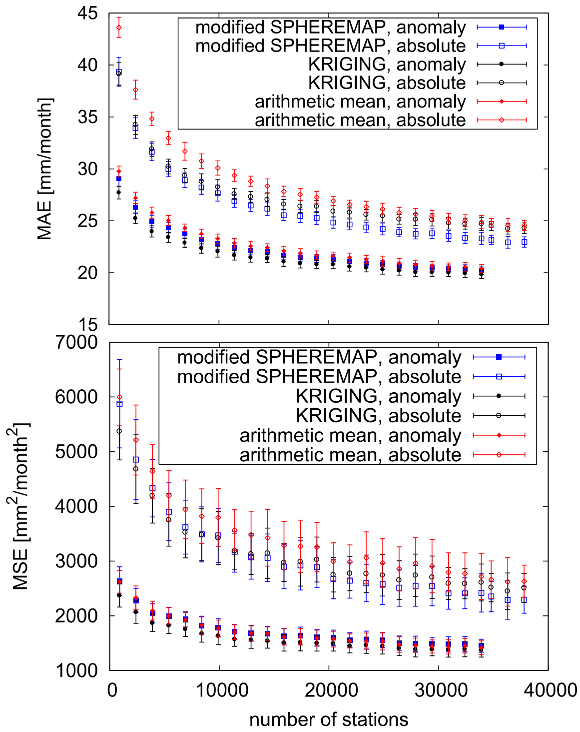

Fig. 13. Mean absolute error (MAE, top plot) and mean square error (MSE, bottom plot) of 50 Jackknife errors calculated from an according number of re-samplings. The calculation has been repeated in dependence of the number of stations available to the network (staggered by steps of 1500 stations) and the interpolation method (six choices) utilized.

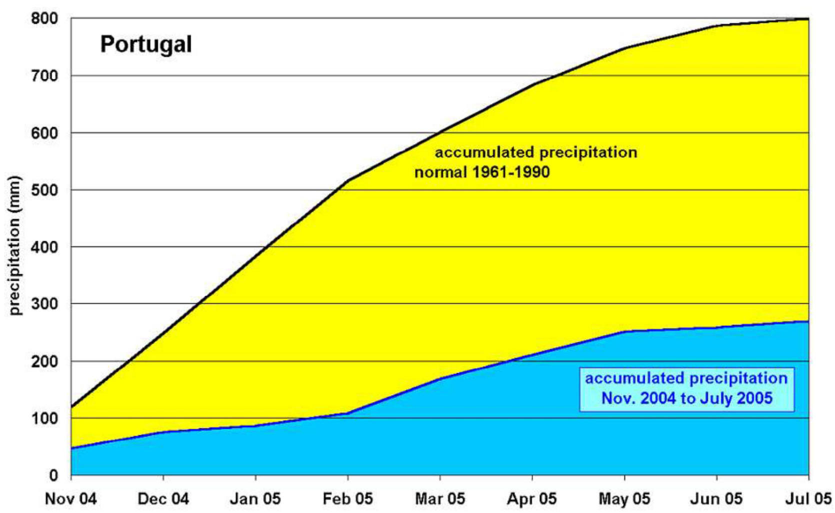

Fig. 14. Accumulated precipitation totals (based on GPCC First Guess) and accumulated GPCC precipitation normals 1961–1990 indicating an increasing precipitation deficiency in year 2005 in Portugal.

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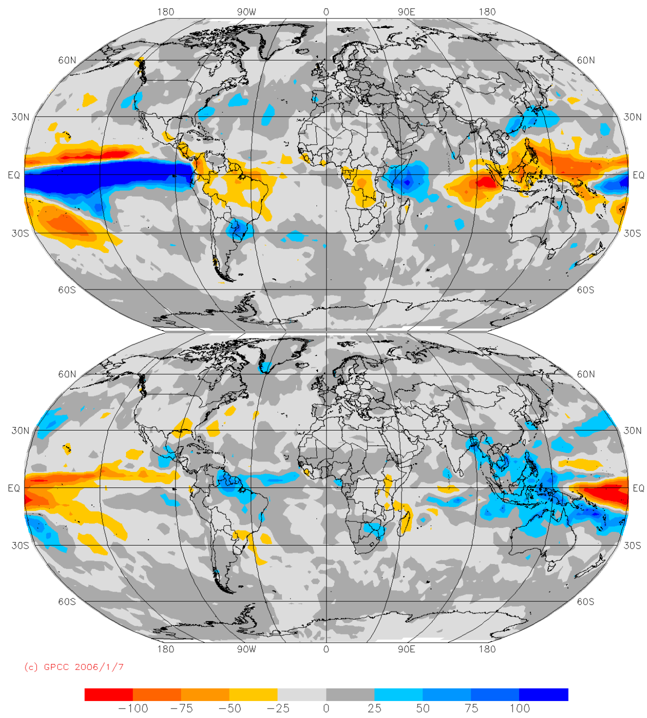

Fig. 15. Example visualizations of the annually averaged precipitation anomaly (absolute deviations in mm/month) based on the GPCP Version 2 product that is calibrated against the GPCC Monitoring Product reference across land-surfaces. The plots show the typical inversion of the anomaly patterns controlled by the El Niño Southern Oscillation (ENSO) for the southern hemispheric years ending in June 1998 (top, El Niño) and June 2000 (bottom, La Niña).

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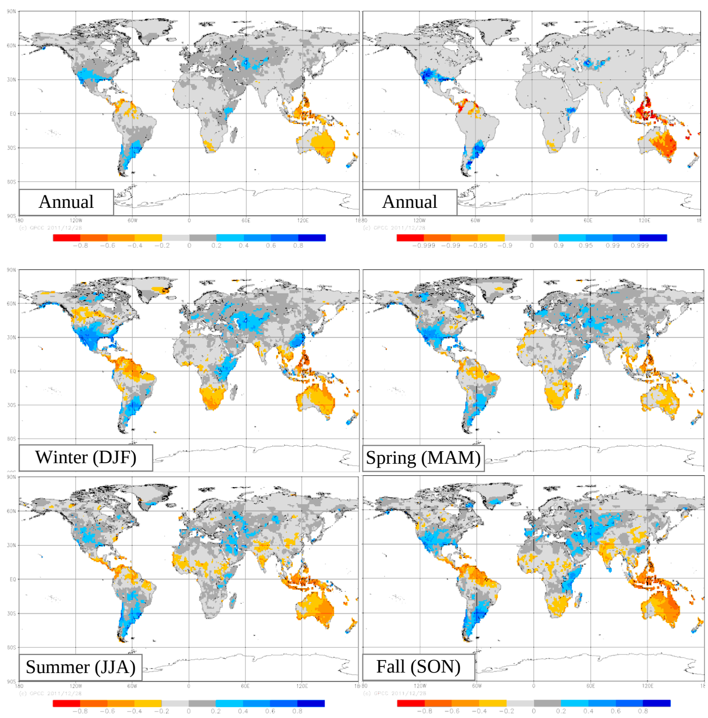

Fig. 16. Upper Panel, Left: correlation of the negative, annually averaged Southern Oscillation Index (-SOI) against the precipitation time series at every 0.5° sized grid cell for the period 1901–2010. Top Right: significance of this annual correlation. Bottom Panels: as upper panel left but for the seasons winter (DJF, upper left), spring (MAM, upper right), summer (JJA, lower left) and fall (SON, lower right).

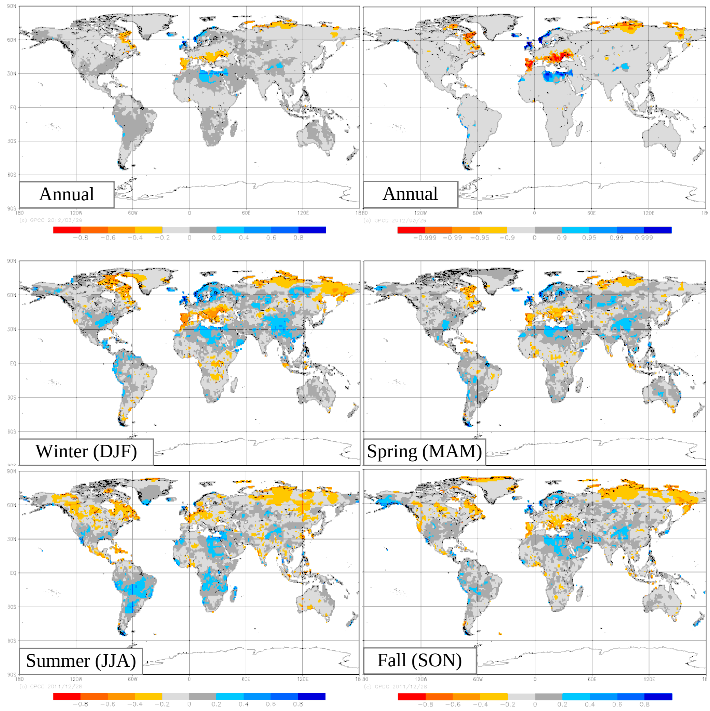

Fig. 17. As Fig. 16 but for the North Atlantic Oscillation (NAO) index.

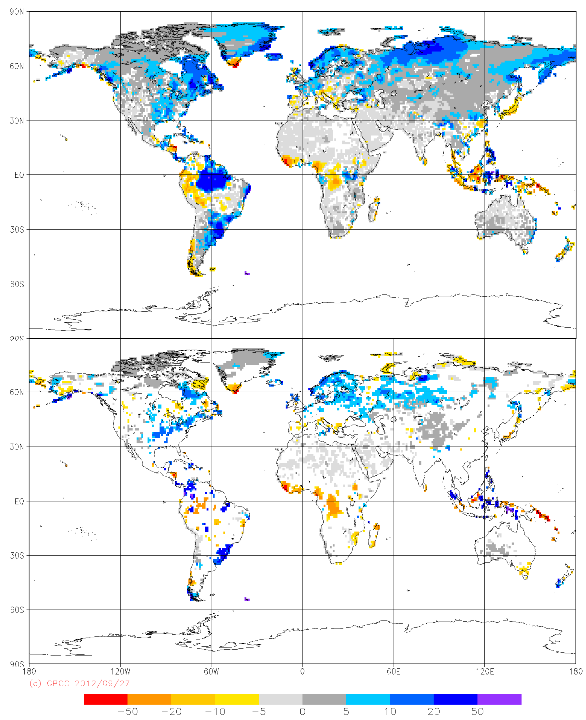

Fig. 18. 110 yr (January 1901–September 2011, top) and 55 yr (January 1951–September 2011, bottom) total precipitation trends after Sen (in mm) based on the GPCC FD product at 0.5° resolution. Regions without trends above 95 % significance level and Antarctica are kept in white.

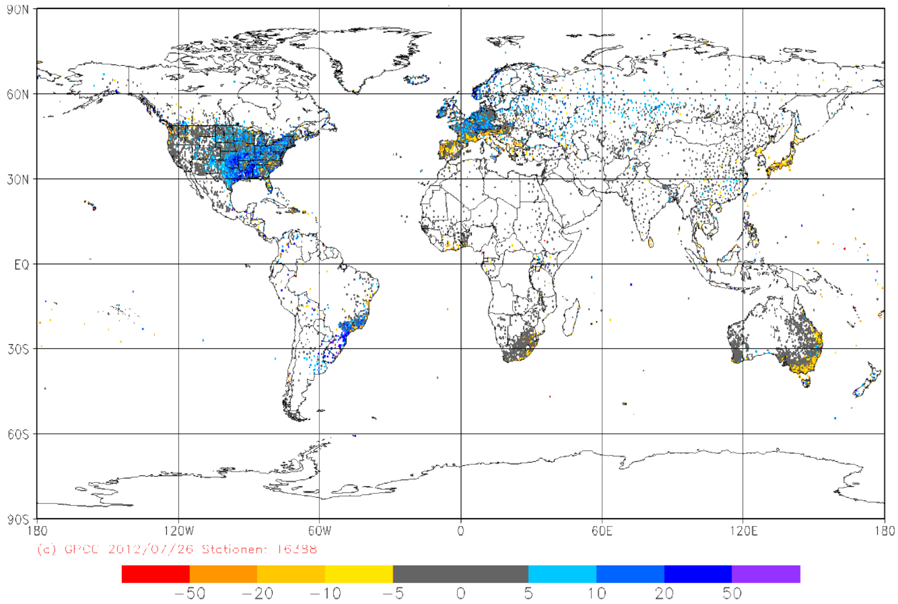

Fig. 19. Total precipitation trends (Sen-Method) in mm for the 16 388 stations chosen for the HOMPRA data set under development. These stations feature a 90 % data coverage across the entire trend period regarded. Please note that the trend periods are station specific and can deviate from the HOMPRA period 1951–2005 in dependence of stations data availability.

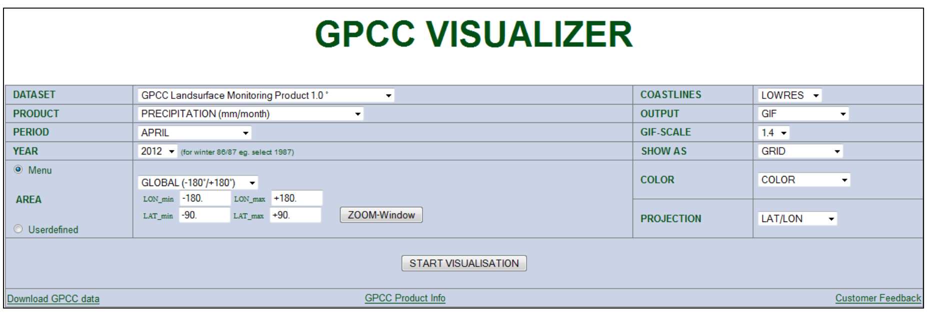

Fig. 20. Web based Graphical User Interface of the GPCC Visualizer public available on http://kunden.dwd.de/GPCC/Visualizer for online visualization and download of gridded GPCC products through the bottom left located link pointing to the GPCC download gate on ftp://ftp.dwd.de/pub/data/gpcc/html/download_gate.html.