Global Precipitation Analysis Products of the GPCC

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Introduction

Precipitation plays an important role in the global energy and water cycle. Accurate knowledge of precipitation amounts reaching the land surface is of special importance for fresh water assessment and management related to land use, agriculture and hydrology, incl. risk reduction of flood and drought. High interest in long-term precipitation analyses arises from the needs to assess climate change and its impacts on all spatial scales. Based on this demand national and international organizations initiated and support many research and monitoring programmes.

In this framework, the Global Precipitation Climatology Centre (GPCC) has been established in 1989 on request of the World Meteorological Organization (WMO). It is operated by Deutscher Wetterdienst (DWD, National Meteorological Service of Germany) as a German contribution to the World Climate Research Programme (WCRP). Mandate of the GPCC is the global analysis of monthly precipitation on earth's landsurface based on *in situ* raingauge data. Since its start, the centre is the *in situ* component of the WCRP Global Precipitation Climatology Project (GPCP). In 1994, the long-term operation of the GPCC has been requested by WMO in order to contribute to the climate monitoring activities of the Global Climate Observing System (GCOS). Since 1999, GPCC is the GCOS Surface Network Monitoring Center (GSNMC) with special emphasis on precipitation, the other one being responsible for temperature monitoring is operated by the Japan Met. Agency (JMA).

The aim of the GPCC is to serve user requirements esp. with regard to accuracy of the gridded precipitation analyses and timeliness of the product availability. The WCRP Global Energy and Water Experiment (GEWEX) for instance requests high spatial resolution and accuracy for the last two decades, while the priority of GCOS and IPCC is focused on long-term homogeneous time-series in the framework of climate change. Timeliness of products is ensured by cut-off dates for data processing and analysis. The GPCC analysis products (except the VASClimO data set) result from the same quasi-operational data management and analysis system. However, depending on the requirements they differ with regard to the number of stations (data sources) included and the level of quality-control being performed (Rudolf et al., 2011, Becker et al., 2012).

All GPCC products, gauge-based gridded monthly precipitation data sets for the global land surface, are available in spatial resolutions of 1.0° x 1.0° and 2.5° x 2.5° latitude by longitude, non real-time products based on the complete GPCC monthly rainfall station data-base (the largest monthly precipitation station database of the world with data from more than 85,000 different stations) are also available in 0.5° x 0.5° resolution. GPCC's new global precipitation climatology (available in 2.5° x 2.5°, 1.0° x 1.0°, 0.5° x 0.5°, and 0.25° x 0.25° resolution) based on data from ca. 67,200 stations is used as background climatology for GPCC analyses. Corresponding to international agreement, station data provided by Third Parties are protected. However the gridded GPCC analysis products are freely available via Internet (http://gpcc.dwd.de). In 2010 ca. 60,000 product downloads on GPCC's Website have been counted.

The different products of the GPCC are used world-wide by various institutions, in particular in context of water- and climate-related research and monitoring activities of WMO, WCRP, GCOS, FAO (UN Food and Agriculture Organisation), UNESCO (UN Educational, Scientific and Cultural Organization) and GEO (Group on Earth Observations, see Figure 11).

GPCC's suite of gridded precipitation analysis products

Note on GPCC's analysis methodology: GPCC's monthly precipitation analysis products described below are based on anomalies from the climatological normals at the stations (see Precipitation Climatology). The anomalies are spatially interpolated by using a modified version of the robust empirical interpolation method SPHEREMAP which is preferred by GPCC (the Climatology and Full Data Reanalysis are internally interpolated on a 0.25° sub-grid, Monitoring Product and First Guess Analysis on a 0.5° subgrid). The method constitutes a spherical adaptation (Willmott et al., 1985) of Shepard's empirical weighting scheme (Shepard, 1968) taking into account:
(a) the distances of the stations to the grid point (for a 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.

Willmott et al (1985) apply a weighting method for all stations beyond a minimum distance to the grid point (epsilon1, ca. 1% of the grid size). However, if stations closer are found he only relies on those stations and applies a simple arithmetic mean for them, while neglecting all stations outside this environment. This would lead to neglecting many potentially useful stations and information in areas of high station density.

Therefore GPCC has introduced the following modifications:
Epsilon-1 is defined by 10% of the grid size instead of as given by equation (14) in Willmott et al. (1985), a second distance epsilon-2 is introduced defined by 50% of the grid size.

- The simple arithmetic mean method is now only applied, if stations are found within epsilon-1, but not within the wider circle of epsilon-2.
- In all other cases, station data are interpolated to the grid point with the original weighting scheme, even for stations located closer than epsilon-1.
- For the normalization in the weighting method, we keep Shepard's method for the calculation of the combined weighting (term w in equation (7) of Willmott 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).

With regard to optimisation of the performance (in view of the potentially large number of stations involved in the interpolation process - 7,000-8,000 for the near real-time products, up to > 40,000 for the Full Data Reanalysis), 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 for each grid point, we apply in advance a clustering of stations on 2º×2º sized grid cells and limit the search algorithm to all clusters touched by a search window being sized as 1.75 times the cluster size (here 3.5º) across the equator. Towards higher latitude the size of the search window is conserved in the canonical manner by scaling with the cosinus of the latitude. The oversizing of the search window warrants that it does not miss stations just outside the closest clusters. Target number of stations to be ranked is 16. If the original search window finds fewer stations than the 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 circum-polar cluster giving one for each pole region.

The gridded anomaly analyses are then superimposed on GPCC's new background climatology (except for VASClimO data set V1.1).

- The new Global **Precipitation Climatology** (Version 2011) is focusing on the period 1951-2000 and consists of data from ca. 67,200 stations. The climatology 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. In case that time series of sufficient length (more than 40 years) for the period 1951-2000 were not available from a specific station, then climatological normals have also been calculated for 30-year reference periods 1961-1990, 1951-1980 or 1971-2000 with at least 20 years of data. If even this was not possible for a station, then normals have been calculated for the period 1931-1960, or for any other period with at least 10 complete years of data. Figure 1 displays the climatological mean precipitation for July as an example.

- The **First Guess Product** of the monthly precipitation anomaly is based on interpolated precipitation anomalies from more than 6,000 stations worldwide. Data sources are synoptic weather observation reports (SYNOP) received at DWD via the WMO Global Telecommunication System (GTS) and climatic mean (mainly 1951-2000, or other reference periods as described before) monthly precipitation totals at the same stations extracted from GPCC's global normals collection. An automatic-only quality-control (QC) is applied to these data. Since September 2003, GPCC First Guess monthly precipitation analyses are available within 5 days after the end of an observation month. Main application purpose is to serve as input for near-realtime drought monitoring applications, e.g. by the FAO and the University of London Hazard Research Centre. Fig. 2 shows a drought monitoring application based on First Guess analyses.
- The **Monitoring Product** of monthly precipitation for global climate monitoring is based on SYNOP and monthly CLIMAT reports received near-realtime via GTS from ca. 7,000 –8,000 stations (after high level QC) and is available within 2 months after observation month. This is the GPCC product with the longest history: Operational monthly analysis started with year 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. 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). It also supports regional climate monitoring. Figure 3 illustrates the heavy rainfall in Pakistan during the La Niña event in summer 2010.
- The **Full Data Reanalysis Product** is of much higher accuracy compared to the GPCC near real-time products mentioned above. Therefore, its application is recommended for hydrometeorological model verification and water cycle studies, e.g. in context of UNESCO, GEWEX, and GTN-H (Global Terrestrial Network for Hydrology). This analysis product is based on all stations, near real-time and non real-time, in the GPCC data base supplying data for the individual month for which a climatological normal is available (for details see Precipitation Climatology). The GPCC Full Data Reanalysis Product Version 6 covers the period from 1901 to 2010 (see example in Figure 4); this new extended product version using the new GPCC climatology as analysis background was generated in Dec. 2011. The data coverage per month varies from 10,700 to more than 47,000 stations (Figure 7). The Full Data Reanalysis will be updated at irregular time intervals subsequent to significant data base improvements.
- The **VASClimO 50-Year Data Set** supplying gridded time-series of monthly precipitation for the global land areas for climate variability and trend studies is based on data selected with respect to a (mostly) complete temporal data coverage and homogeneity of the time-series. The version 1.1 based on time-series of 9,343 stations covering at least 90% of the period 1951-2000 has been developed at the GPCC in the research project VASClimO (Beck, Grieser and Rudolf, 2005). The Kriging interpolation is based on relative precipitation (ratio of monthly and long-term mean) time series of the stations and provides gridded monthly data covering the global land areas with a spatial resolution of 0.5° x 0.5° latitude and longitude. These long-term analyses of homogenised area-averaged precipitation time-series are of special interest for GCOS and supported the Intergovernmental Panel on Climate Change (IPCC) Working Group I Fourth Assessment Report (FAR), published in 2007. The VASClimO Data Set will be replaced

in spring 2012 by the new homogenized precipitation analysis HOMPRA covering the period 1951-2005 (will be based on ca. 16,500 stations).

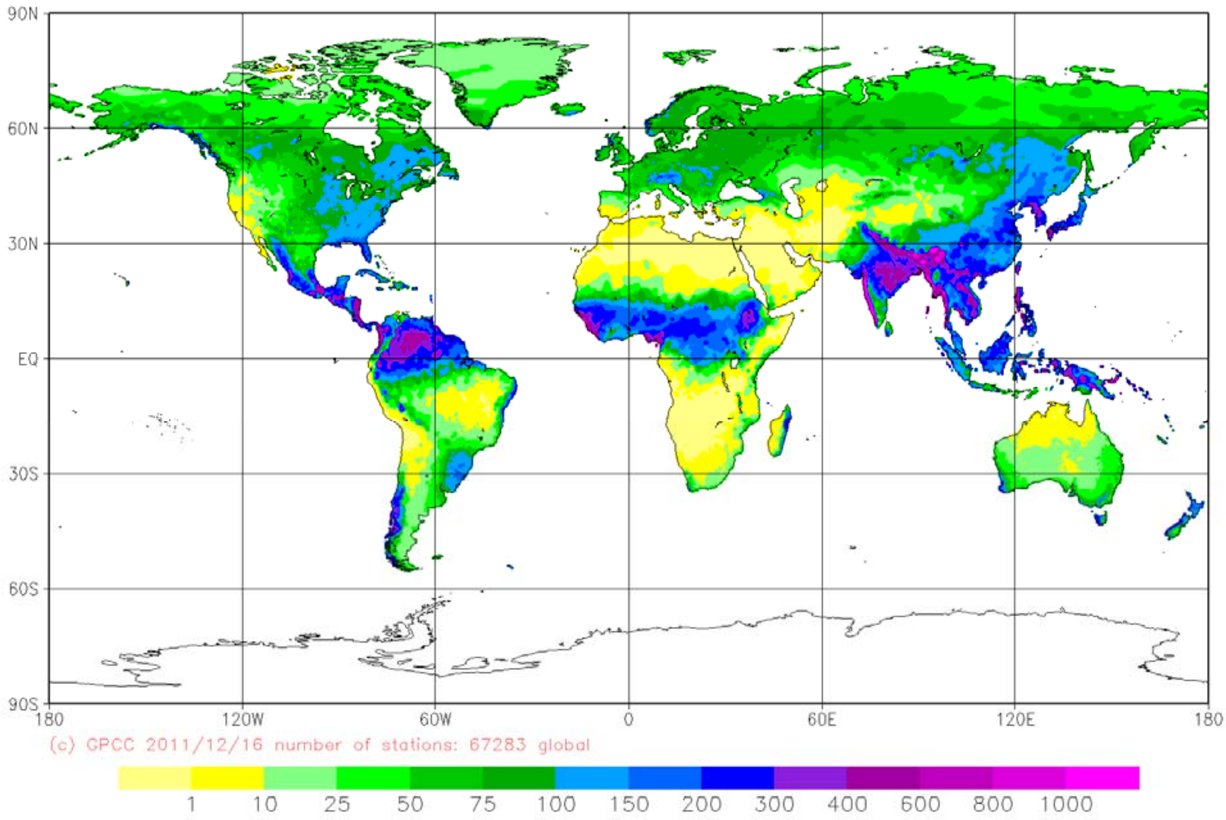

Figure 1: *Climatological mean precipitation for July (based on GPCC's new Precipitation Climatology V.2011 focusing on the period 1951-2000, 0.25° x 0.25° resolution)*

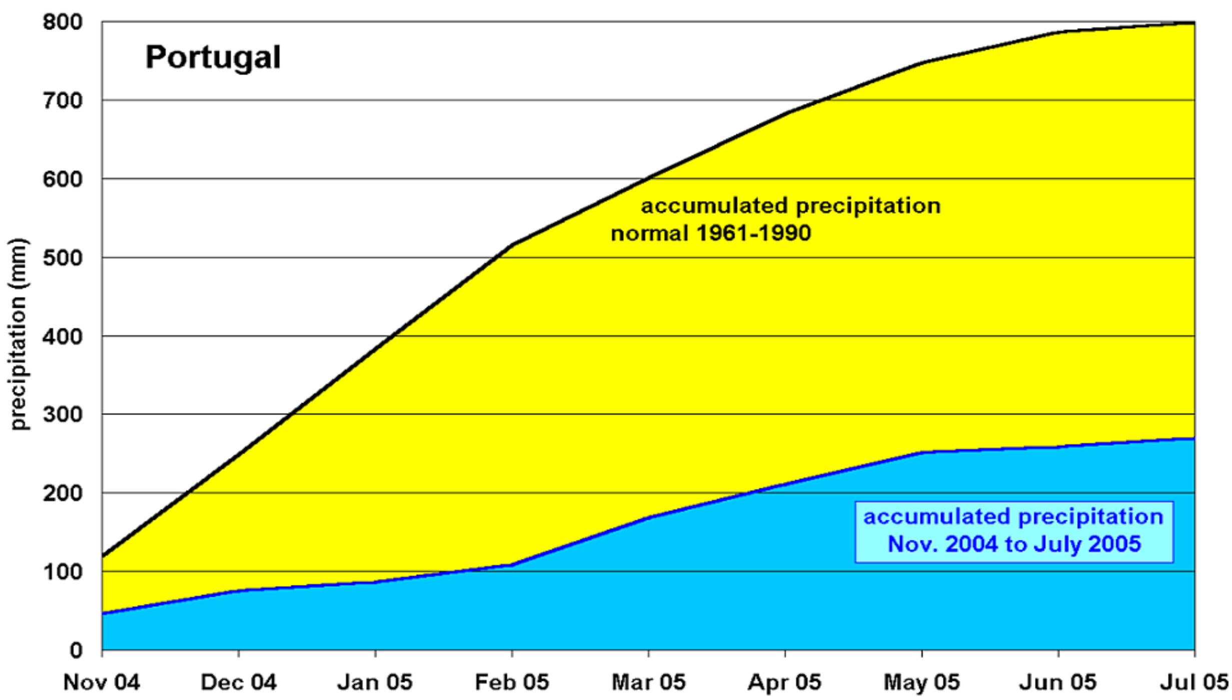

Figure 2: *Accumulated precipitation totals (based on GPCC First Guess) and accumulated precipitation normals 1961-1990 indicating an increasing precipitation deficiency in 2005 in South West Europe*

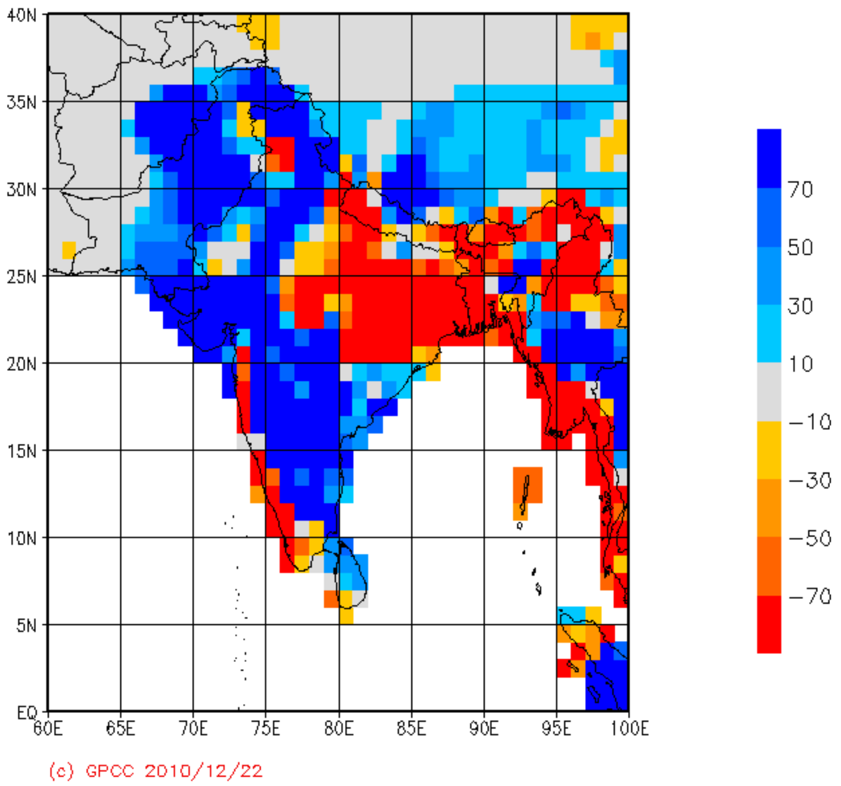

Figure 3: *Example of monthly precipitation anomalies in August 2010 (La Niña event) for Pakistan/ India (based on GPCC Monitoring Product, 1.0° x 1.0° resolution)*

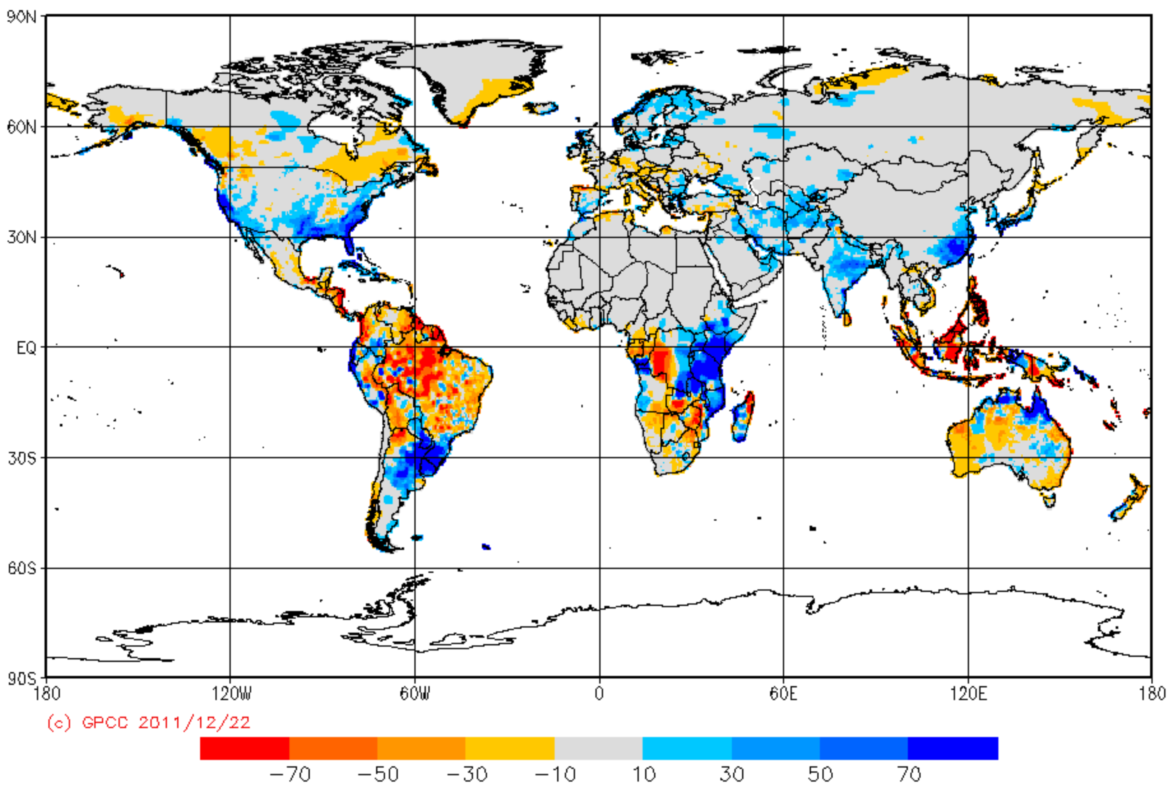

Figure 4: *Example of precipitation anomalies in DJF 1997/1998 (El Niño event) in mm/month (based on GPCC Full Data Product Version 5, 0.5° x 0.5° resolution)*

GPCC analyses are well suited to study relations of large-scale precipitation regimes to changes in atmospheric circulation patterns like El Nino/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) as can be seen from Fig. 5 showing the correlation patterns between between monthly time series of gridded precipitation anomalies for the period 1901-March 2011 and ENSO and NAO indices.

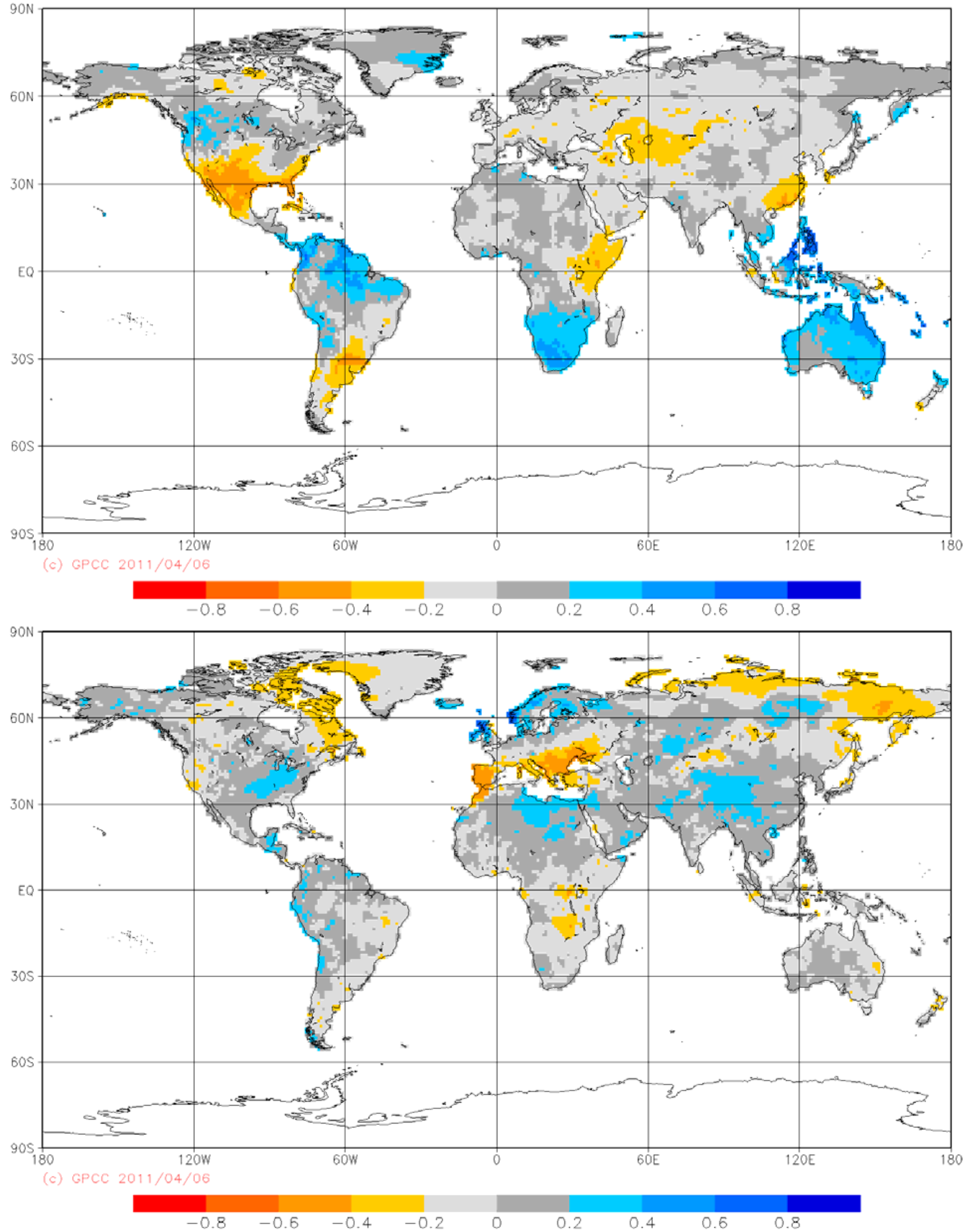

Figure 5: *Correlation between monthly time series of gridded precipitation anomalies for the period 1901-March 2011 and (top) SOI and (bottom) NAO index*
(based on GPCC Full Data Reanalysis V.5, 0.5° x 0.5° resolution, since Jan. 2010 Monitoring Product V.3)

The GPCC Data Base

The accuracy of raingauge based precipitation analyses mainly depends on the spatial density of stations being used. In order to calculate monthly area-mean precipitation on 2.5° gridboxes with a sampling error of not more than 10%, between 8 and 16 stations per gridbox are needed (WMO 1985, Rudolf et al. 1994). For the global land-surface this accuracy requirement, as requested by the GPCP implementation and data management plan (WMO, 1990), adds up to 40,000 equally distributed stations worldwide.

We distinguish two types of observed precipitation data with regard to their timeliness: data being available near real-time (based on synoptic weather observation data and climate reports exchanged via the WMO GTS), and additional data being obtained with a larger time delay. The reason for GPCC to supply a set of different products is that a near real-time analysis is requested by international programmes for various applications, but the data base available near real-time is insufficient in many regions with regard to the requested product accuracy (in addition to the spatial density of stations the quality-control (QC) of station meta information and precipitation data performed is crucial (see section GPCC data processing).

GPCC near real-time data base

The data base for GPCC's Monitoring Product is merged from three sources: monthly precipitation totals derived from synoptic weather reports (SYNOP) at the DWD, Germany, and at NOAA/NCEP, USA, and monthly precipitation totals extracted from CLIMAT-bulletins received at the DWD, JMA (Japan Met. Agency) and UKMO (UK Met. Office). The data base available near real-time comprises ca. 7,000–8,000 stations and provides in some regions a sufficient data base for quantitative precipitation estimates, if the grid resolution is not too high. Users are advised to carefully take into account the number of stations per grid, which is provided as additional information to every GPCC product. Within the data pool, the CLIMAT data – after a quality check – are of higher quality and provide a reference for quality assessment of the SYNOP-based data. The GPCC First Guess Product includes the DWD SYNOP-based monthly precipitation totals from ca. 6,000-7,000 stations.

GPCC Full data base

With respect to the limited real-time availability of raingauge data, additional data from dense national observation networks of individual countries are collected at the GPCC. The data acquisition is supported by recommendation letters of the WMO. So far, National Meteorological and/or Hydrological Services (NMHSs) from about 190 countries of the world contributed data to the GPCC. However, the delay of the deliveries varies between 1-5 years or even more due to the processing time needed by the data originators (Figure 7).

In addition, other available global and regional collections of climate data (Global Historical Climatology Network, GHCN; University of East Anglia Climate Research Unit, CRU; FAO; GEWEX related projects; Asia-Pacific/Matsumoto, etc.) have been integrated in the GPCC data base. Thereby GPCC has compiled the most comprehensive global collection of monthly precipitation data from *in situ* observations (Figures 6-8). With respect to the interests and conditions given by the data originators (NMHSs), the GPCC cannot redistribute the station related precipitation data to other parties.

The temporal data coverage of the GPCC products is illustrated by Fig. 7. The near-realtime First-Guess analysis is including the monthly totals accumulated from SYNOP reports received at DWD. For GPCC's Monitoring Product all SYNOP and CLIMAT data are used if available within ca. 1 month after observation.

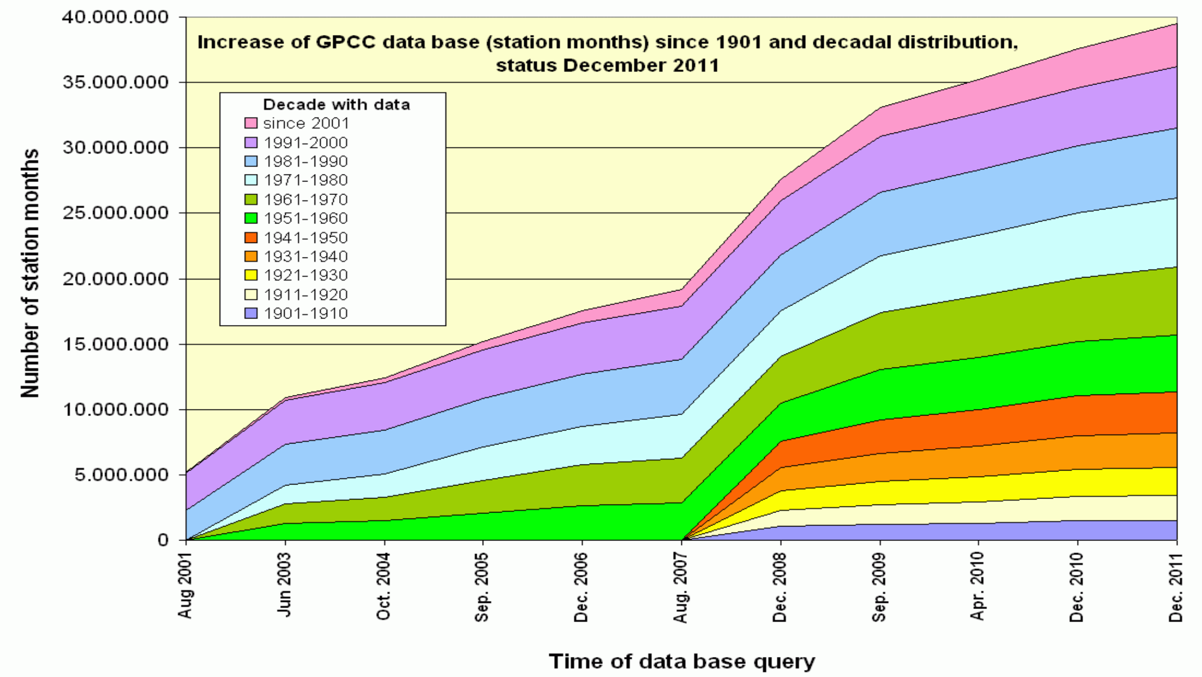

***Figure 6:** Temporal evolution of GPCC Monthly Precipitation Database between 2003/06 and 2011/12*

The Full Data Reanalysis Product includes all data being supplied later by the individual countries, if the stations have a climatological normal (at least 10 years of data, fragments of time-series aren't used any more). The year with the best data coverage is 1987 with data for more than 47,000 stations. The decrease of the number of stations from more than 40,000 in 1961-1991 down to 10,000 stations after 2010 is caused by the delay of the data delivery to and by post-processing at GPCC. The data base continuously increases by delivery of updates for recent years, supplements with additional stations and complementation by long time-series of data. All data suppliers are encouraged to provide annual updates to GPCC. GPCC updates its non real-time products at irregular time intervals subsequent to significant data base improvements.

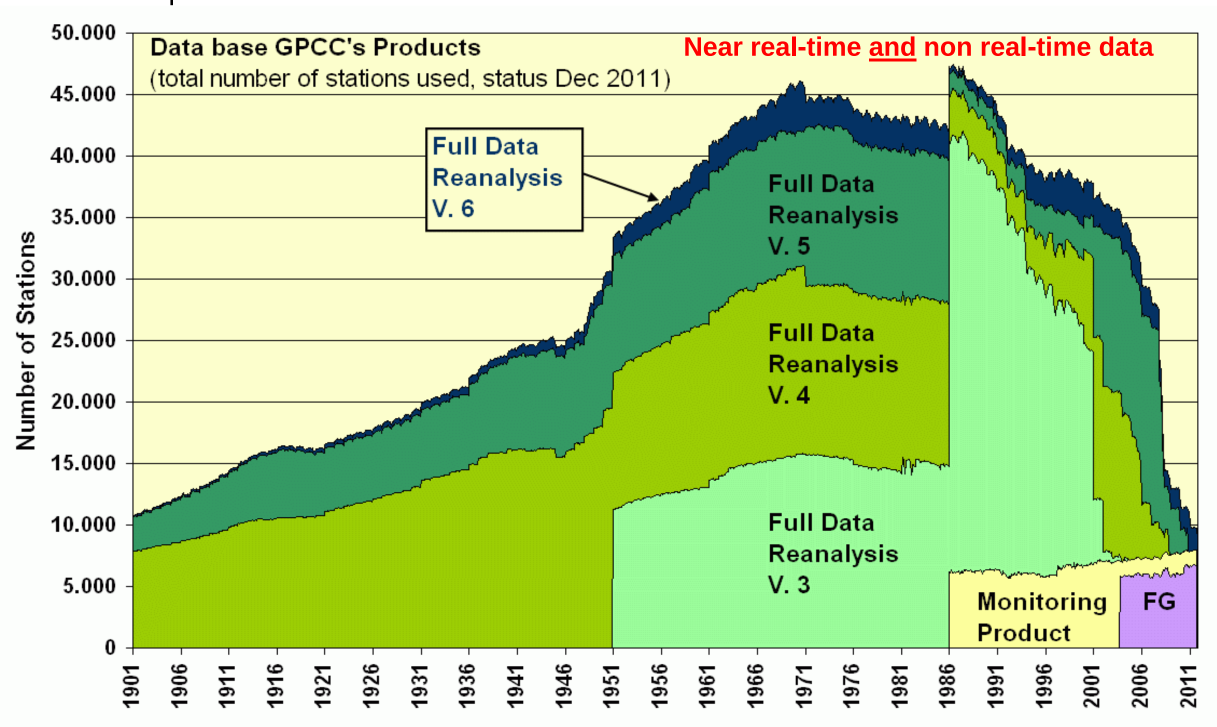

***Figure 7:** Total number of stations used for the GPCC products (Near real-time First-Guess Product, Monitoring Product; non real-time Full Data Reanalysis Product (Versions 3 to 6))*

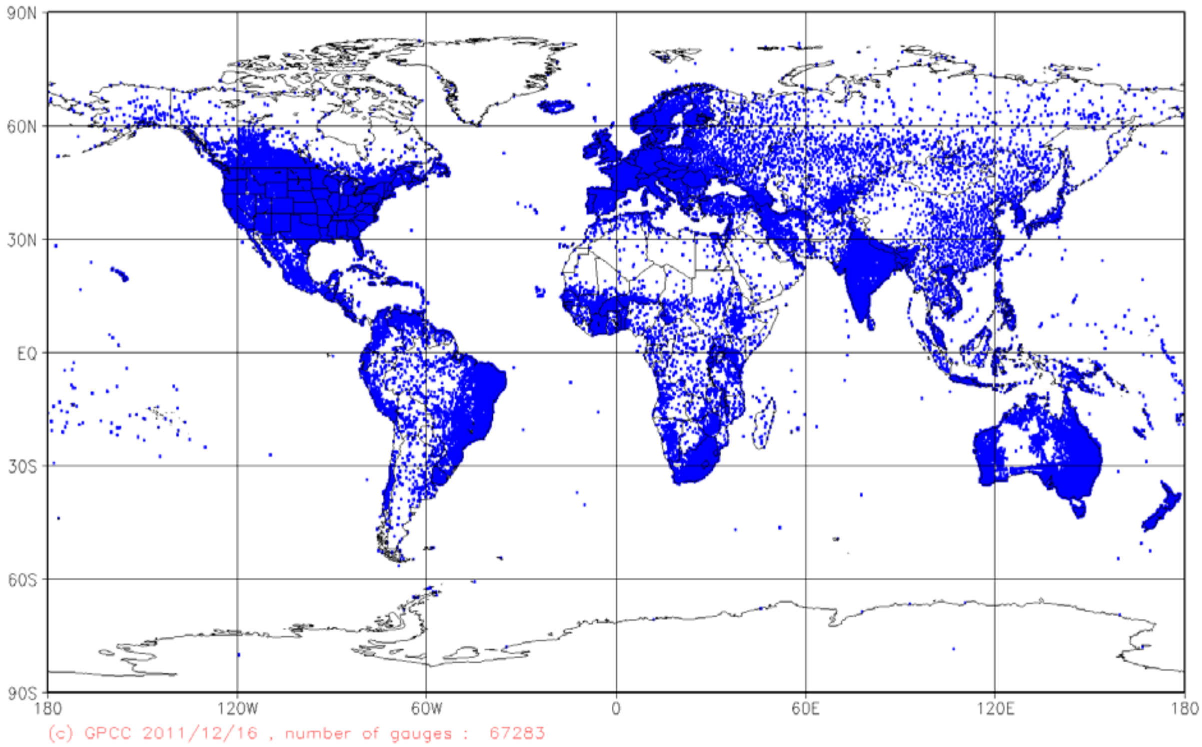

Figure 8: *Spatial distribution of monthly in-situ stations with a climatological precipitation normal, based on at least 10 years of data in GPCC data base (number of stations in July: 67,283)*

The GPCC Data Processing

All data reaching the GPCC are checked, processed, reformatted and integrated in a Relational Data Base Management System (RDBMS). Since 2009 all data being imported into the RDBMS are checked against background statistics enabling the GPCC to detect and correct data errors in this early stage. Within the data bank, the records from the different sources (SYNOP, CLIMAT, national data etc.) are stored in parallel (source specific slots) under addition of quality flags indicating the results of data processing. By this an intercomparison and cross-check is possible, which is very helpful in the quality-control (QC) and product generation process.

The data processing steps include QC and harmonization of the meta data (station identification), quality-assessment of the precipitation data, selection and intercomparison of the data from the different sources for the particular products, interpolation of the station-related data to a regular mesh system, and calculation of the spatial means on the 2.5° respectively 1.0° latitude/longitude gridbox area. The Full Data Reanalysis as well as the 50-year VASClimO data set are also available in 0.5° resolution, the new global precipitation climatology is available on a 0.25° resolution, too. The basic information about the methods used is published by Rudolf et al. (1994) and Rudolf and Schneider (2005), additional information is given on GPCC's website (http://gpcc.dwd.de).

The near-realtime Monitoring Product and the non-realtime Full Data Reanalysis Product provide the following variables calculated on the grid:

- Monthly precipitation totals for the individual month
- Mean monthly precipitation totals focussing on the period 1951-2000 ("normals")
- Monthly precipitation anomaly i.e. deviation from the mean 1951-2000
- Monthly precipitation percentage related to the mean 1951-2000
- Number of gauges used per gridcell for the individual month
- Systematic gauge-measuring error per gridcell for the individual month (since Jan. 2007)

- Fraction of liquid and solid precipitation in % of total precipitation per gridcell for the individual month (since Jan. 2007)

In GPCC's reanalyses of non-realtime products (Full Data Reanalysis V.6) as well as in the processing of near-realtime products (Monitoring Product V.4, First Guess Analysis) the normals as in GPCC's precipitation climatology (focussing on the period 1951-2000) are used.

About the accuracy of the gridded results

The two major error sources are: (1) The systematic measuring error which results from evaporation out of the gauge and aerodynamic effects, when droplets or snow flakes are drifted by the wind across the gauge funnel, and (2) The stochastic sampling error due to a sparse network density. The GPCC provides a gridded quantification for the following errors:

The systematic gauge-measuring error is – except for very specific situations – an undercatch of the true precipitation. 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 climatological mean for each calendar month. The error is large in snow regions respectively in cold seasons. Since the GPCC analysis for January 2007, a new on-event correction method for systematic gauge measuring errors is available at GPCC (Fuchs et al., 2001). This event-based 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 from synoptic observations of ca. 6,000 stations available worldwide.

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 raingauges 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.

Access to GPCC's gridded products

The different gridded monthly precipitation data sets of GPCC as well as the GPCP Version 2.1 Combined Data Set are freely available. They can be visualized in maps like Figs. 1, 3 or 4 or downloaded in ASCII format using the GPCC-Visualizer (Fig. 9) from our Website http://gpcc.dwd.de. The 50-Year VASClimO data set is also available from this site. Other products can be provided on email request.

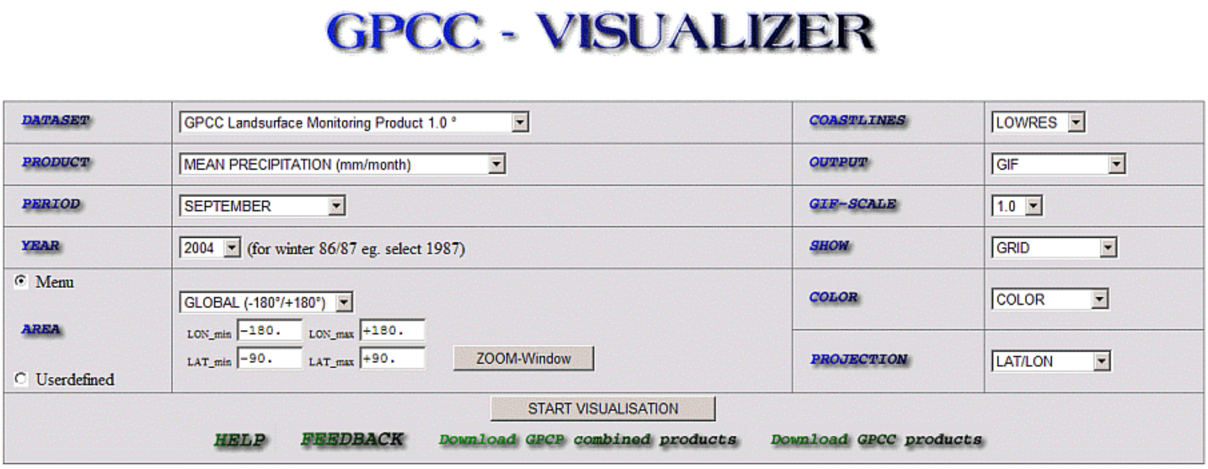

Figure 9: *GPCC Visualizer for online visualization and download of gridded GPCC products*

Some hints and recommendations to GPCC product users

- 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.
- 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 the GPCC VASClimO product has been adjusted to support long-term precipitation variability and trend analyses.
- Gridded anomalies can be generated in two different ways: (#1) calculation of the anomaly on the stations which requires the availability of both, data from the considered month and normal values, and (#2) by the relation of gridded data sets, which were separately generated for the considered month and for the normal precipitation totals. Method #1 is consistent with regard to the stations used, method #2 includes a much larger number of stations. For technical reasons, method #2 is used by the Visualizer, results based on the anomaly interpolation are available on email request.
- Reference to the GPCC is requested from the users, and feedback about the application of the products is very welcome. You might provide your feedback to gpcc@dwd.de.

The GPCC kindly requests all responsible national agencies to follow the WMO call for data and to provide the GPCC with the required precipitation and meta data. The analysis results are of high importance e.g. concerning the verification of global climate models and climate variability studies based on observed data. The analysis results of the GPCC are published and freely accessible. But the station-related data delivered by the countries will not be distributed to third parties, in order to respect and protect the ownership of the originators.

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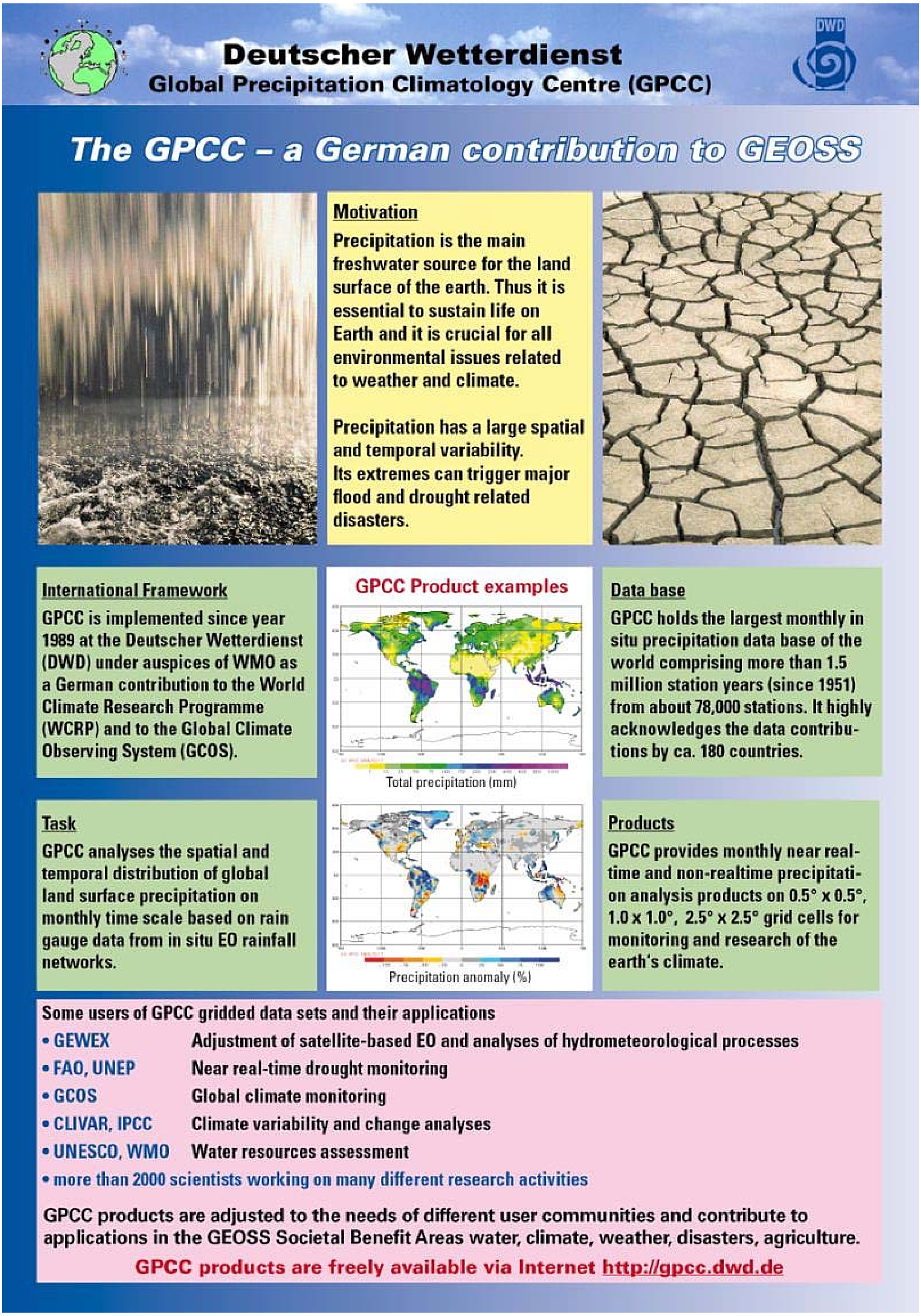

Fig. 11 GPCC poster presented at the GEO-IV plenary meeting
Cape Town, South Africa, 28-30 Nov 2007