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The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present)

Robert F. Adler[1], George J. Huffman[2], Alfred Chang[4],
Ralph Ferraro[5], Ping-Ping Xie[3], John Janowiak[3],
Bruno Rudolf[6], Udo Schneider[6], Scott Curtis[7], David Bolvin[2], Arnold Gruber[5], Joel Susskind[1], and Philip Arkin[8]

1: NASA/GSFC Laboratory for Atmospheres
2: NASA/GSFC Laboratory for Atmospheres and Science Systems and Applications, Inc.
3: NOAA/NWS National Centers for Environmental Prediction
4: NASA/GSFC Laboratory for Hydrospheric Processes
5: NOAA/NESDIS Office of Research and Applications
6: Deutscher Wetterdienst, Global Precipitation Climatology Centre
7: NASA/GSFC Laboratory for Atmospheres and University of Maryland Baltimore County
8: University of Maryland

Abstract

The Global Precipitation Climatology Project (GPCP) Version 2 Monthly Precipitation Analysis is described. This globally complete, monthly analysis of surface precipitation at 2.5° x 2.5° latitude–longitude resolution is available from January 1979 to the present. It is a merged analysis that incorporates precipitation estimates from low-orbit–satellite microwave data, geosynchronous-orbit–satellite infrared data, and rain gauge observations. The merging approach utilizes the higher accuracy of the low-orbit microwave observations to calibrate, or adjust, the more frequent geosynchronous infrared observations. The data set is extended back into the pre-microwave era (before 1987) by using infrared-only observations calibrated to the microwave-based analysis of the later years. The combined satellite-based product is adjusted by the raingauge analysis. This monthly analysis is the foundation for the GPCP suite of products including those at finer temporal resolution. The data set also contains the individual input fields, a combined satellite estimate, and error estimates for each field. The 23-year GPCP climatology is characterized, along with time and space variations of precipitation.

1. Introduction

Precipitation information is critical in understanding the hydrologic balance on a global scale and in understanding the complex interactions among the small- and large-scale components within the hydrologic cycle. The latent heating associated with precipitation is a primary atmospheric energy source and knowledge of the spatial and temporal distribution of precipitation around the globe is crucial for improving climate diagnostics and improving weather and climate forecast models. The distribution of precipitation is also important for water management for agriculture, electrical power and flood control, and for drought and flood monitoring. A better understanding of the global and regional hydrologic cycles is at the heart of the World Climate Research Program (WCRP) and its key Global Energy and Water cycle Experiment (GEWEX) component. The

Global Precipitation Climatology Project (GPCP) is the WCRP/GEWEX project devoted to producing community analyses of global precipitation.

The GPCP is an international project with input data sets and techniques being contributed to the monthly analysis by a number of investigators. Version 1 of the GPCP monthly data set was described by Huffman et al. (1997) and this paper will describe the improved, time-extended Version 2 of the data set. The description focuses on new data sets and techniques used in Version 2, differences between the old and new analyses and examples of applications.

The GPCP's present goal is to provide a long time series of monthly and finer time resolution precipitation analyses on a global scale. The primary product is a monthly analysis on a global 2.5°x2.5° latitude–longitude grid for the period 1979-present, which is the subject of this paper. A second product is a pentad (five day) global analysis adjusted by the monthly analysis. This GPCP pentad analysis is a modified version of Xie and Arkin (1997b) described by Xie et al. (2002). A third product is a daily, 1° x 1° latitude-longitude analysis from January 1, 1997 to the present as described by Huffman et al. (2001), also constrained by the monthly analysis. This suite of coordinated products provides the research community with global precipitation information useful for a large number of applications. These products are archived and distributed through World Data Center A at the NOAA National Climatic Data Center. They can be accesses at http://lwf.ncdc.noaa.gov/oa/wmo/wdcamet-ncdc.html and are also available at www.precip.gsfc.nasa.gov and http://www.dwd.de/research/gpcc/.

The GPCP monthly data set described in this paper is similar in form to that of Xie and Arkin (1997a), although the analysis methodologies are different. A comparison of that product to the older Version 1 GPCP data set is given by Gruber et al. (2000). A recent comparison of many satellite-based estimates of global precipitation, including the GPCP product, is described by Adler et al. (2001).

The general approach with the new GPCP monthly product is to combine the precipitation information available from each source into a final merged product, taking advantage of the strengths of each data type and removing biases based on hierarchical relations in the stepwise approach. The microwave estimates are based on Special Sensor Microwave/Imager (SSM/I) data from the Defense Meteorological Satellite Program (DMSP, United States) satellites, which fly in sun-synchronous low-Earth orbits. The infrared (IR) precipitation estimates are obtained primarily from geostationary satellites operated by the United States, Europe, and Japan, and secondarily from polar-orbiting satellites. Additional precipitation estimates are obtained based on TOVS (Television and Infrared Observation Satellite [TIROS] Operational Vertical Sounder) and OLR (Outgoing Longwave Radiation) measurements. Raingauge data are collected, quality-controlled and analyzed to contribute to the analysis over land.

2. Input Data Sets

This section describes the input data sets that are used in Version 2 of the GPCP monthly analysis. Most of the data sets used in Version 2 were also used in Version 1 and were described in Huffman et al. (1997). Only a brief summary will be given here (Section 2.1) and the reader is referred to the earlier paper for details on those data sets. The additional data sets that have contributed toVersion 2 are described in Section 2.2.

2.1 Data Sets Utilized in Versions 1 and 2.

2.1.1 GPCC raingauge analyses.

For the period 1986 to the present the monthly raingauge analyses are constructed by the Global Precipitation Climatology Centre (GPCC) operated by the German Weather Service. The GPCC uses a variant of the SPHEREMAP interpolation routine (Willmott et al. 1985) to interpolate the station data to regular gridpoints (0.5° lat/long mesh). These regular points are then averaged to provide area-mean, monthly total precipitation on 2.5° gridcells. The Version 2 raingauge product is based on about 6500 to 7000 raingauge stations worldwide, mostly synoptic and monthly climate reports collected from the Global Telecommunications Network in real time, supplemented by other worldwide data collections such as Monthly Climatic Data for the World.

Sophisticated quality control is performed before carrying out the analyses. First, station meta information (especially location) is checked. The precipitation data themselves are checked for coding, typing or transmission errors. In addition to that they are checked automatically for spatial homogeneity, compared to climatological normals and the data from the different sources are intercompared. Precipitation data flagged as questionable in the automatic process are then checked by an expert manually at a graphics workstation, where 3D-orography and other background fields can be overlaid and orographic conditions can be taken into consideration.

Precipitation measurements from rain gauges are also affected by systematic errors, primarily losses due to aerodynamic effects, especially with snow. An estimate of systematic error using bulk correction factors for monthly climatological conditions was derived by Legates (1987), based on work summarized by Sevruk (1989). This bulk correction is applied to the analyzed values to compensate for the systematic gauge-measuring error. An improved method taking into account the day-to-day variations of the weather conditions during the current month is in preparation (Fuchs et al., 2001; Ungersböck et al., 2001). A general description of the GPCC data processing and analysis system is given by Rudolf (1993), details on the sampling error and availability of data are discussed by Rudolf et al. (1994 and 1998).

2.1.2 Microwave emission estimates over ocean.

The microwave estimates over ocean utilize data from the SSM/I instruments and the Wilheit et al. (1991) histogram approach in which the rain rate is modeled as a mixed distribution, made up of a discrete probability of no rain and a lognormal distribution for rain events and related to T_b histograms using a combination of 19 and 22 GHz channels. The height of the freezing level, which is needed by the radiative transfer calculation, is estimated empirically using the brightness temperatures themselves. The resulting SSM/I rain-rate estimates are multiplied by a coefficient to account for the beam-filling bias (Wilheit et al. 1991, Chiu et al. 1993). The coefficient (1 + 0.062xFL) is a function of freezing level (FL). The microwave emission estimates are computed by the Laboratory for Hydrospheric Processes at the NASA Goddard Space Flight Center.

2.1.3 Microwave scattering estimates over land.

The primary GPCP scattering algorithm is an 85-GHz technique based on the Grody (1991) Scattering Index (SI) applied to SSM/I data, most recently described by Ferraro (1997). It has separate components for land and ocean, as well as screening tests for the removal of artifacts caused by various surface types. The coastline is thickened by 50 km, and the land component is applied over both land and "coast." The algorithm has been calibrated to instantaneous rain rates from ground-based radar measurements (Ferraro and Marks 1995). Recent efforts have focused on the development of error estimates to accompany the rain estimates (Li et al 1998; 2000) and further evaluate the error characteristics (McCollum et al., 2002). For the period from June 1990 to late 1991 failure of the 85 GHz channels on the operational SSM/I instrument led to the use of a secondary scattering algorithm using the 37 GHz scattering (SI) information. While the 85-GHz

SI technique can detect rain rates as low as 1 mm hr^{-1}, the 37-GHz SI is only sensitive to rain rates of 5 mm hr^{-1} or greater. The monthly scattering-based rainfall field is computed by the Office of Research and Application (ORA) of the NOAA National Environmental Satellite Data and Information Service (NESDIS). The ocean and land microwave estimates are merged in the near coastal areas based on relative sampling as described in Huffman et al. (1997).

2.1.4 Geosynchronous IR-based estimates

The geosynchronous IR-based estimates employ the GOES Precipitation Index (GPI; Arkin and Meisner 1987) technique, which relates cold cloud-top area to rain rate. The data are generated by each cooperating geostationary satellite operator (the Geosynchronous Operational Environmental Satellites, or GOES, United States; the Geosynchronous Meteorological Satellite, or GMS, Japan; and the Meteorological Satellite, or Meteosat, European Community). The data for the period 1986-1996 are accumulated every three hours into 16-class histograms of IR T_b on a 2.5° lat/long grid in the zone 40°N-S and saved for each pentad of days (Jan. 1-5, Jan. 6-10, ..., Dec. 27-31). Separate histograms are accumulated for each 3-hour period of the day (00Z, 03Z, 21Z), which preserves the mean diurnal cycle for each pentad. Starting in 1997 the data collection was modified to increase the resolution to a 1° lat/long grid, with data every three hours of each day, instead of pentads. The geo-IR data are corrected for viewing geometry and inter-satellite calibration effects based on the work of Joyce and Arkin (1997). The global IR rainfall estimates are then generated from a merger of these data at the Climate Prediction Center (CPC) of NOAA using the GPI. In cases where geostationary data are unavailable, data from Advanced Very High Resolution Radiometer (AVHRR) on the NOAA polar-orbiting satellites are used either in the form of T_b histograms or the integrated value of outgoing longwave radiation (OLR), depending on available historical data. These fields are converted to GPI estimates using the procedures of Janowiak and Arkin (1991). Depending on the satellites contributing, the polar-orbit data provide 0-4 images per day, never more than half the samples available from the geostationary data.

2.2 Additional Data Sets Used in Version 2

2.2.1 GHCN/CAMS gauge analysis.

During the pre-GPCC period, January 1979 - December 1985, the rain gauge analysis precipitation product used is a combination of rain gauge data from the Global Historical Climate Network (GHCN) [produced by NOAA/National Climate Data Center] and Climate Assessment and Monitoring System (CAMS) [produced by the Climate Prediction Center (CPC), National Centers for Environmental Prediction, NOAA] and analyzed using SPHEREMAP. The combined GHCN/CAMS gauge analyses for this period are produced routinely by the NOAA/CPC group using procedures described by Xie and Arkin (1996). This analysis includes error checking based on station availability. The same corrections for systematic error due to wind effects, etc. used with the GPCC gauge data set have been applied to this data set also.

2.2.2 TOVS-based estimates.

The TOVS precipitation product uses data from the TOVS instruments aboard the NOAA series of polar-orbiting platforms. A number of meteorological variables are retrieved or estimated from the TOVS data, including precipitation (Susskind and Pfaendtner, 1989; Susskind et al., 1997). The technique infers precipitation from deep, extensive clouds using a regression relationship between collocated rain gauge measurements and several TOVS-based parameters that relate to cloud volume: cloud-top pressure, fractional cloud cover, and relative humidity profile. The TOVS retrieval utilizes output from a general circulation model as part of the first-guess for the moisture retrieval, which in turn is used in the precipitation estimate. This relationship is allowed to vary seasonally and with latitude. Furthermore, separate relationships are developed for ocean and land. The TOVS precipitation estimates are routinely produced by the Laboratory for Atmospheres of NASA's Goddard Space Flight Center.

The TOVS data are used for the SSM/I period (July 1987 – present) and are provided at the one-degree spatial and monthly temporal resolution. The data covering the span July 1987 - February 1999 are based on information from two satellites. For the period March 1999 - present, the TOVS estimates are based on information from one satellite due to changes in satellite data format. A future release should include data from both NOAA satellites.

During the SSM/I period, the TOVS estimates are used for filling in data voids - the polar and cold-land regions for which SSM/I-based estimates are unavailable due to shortcomings in retrieving precipitation information over frozen surfaces. In the span 40°N - 40°S, the SSM/I data are used as is. Where there are holes as the result of cold land, the TOVS data are adjusted to the zonally averaged mean bias of the SSM/I data and inserted. Just outside of the zone 40°N - 40°S, the SSM/I and TOVS data are averaged using equal weighting. Moving further towards the poles, the SSM/I data become progressively less reliable, and the SSM/I-TOVS average is replaced with zonally-averaged, bias-adjusted TOVS data. The bias adjustment is anchored on the equator side by the SSM/I-TOVS average and on the polar side by climatological rain gauge estimates. From 70°N to the North Pole, TOVS data are adjusted to the bias of the available monthly rain gauge data. From 70°S to the South Pole, TOVS data are adjusted to the bias of the annual average climatology of the rain gauge data. The monthly climatological values are not used in the Antarctic as the lack of sufficient land coverage there yields unstable results. The end result is a globally complete SSM/I/TOVS precipitation field based on the polar orbiters, with preference given to the microwave estimates where available.

2.2.3 OLR Precipitation Index (OPI)

The OPI technique (Xie and Arkin, 1998) is based on the use of low-Earth orbit satellite outgoing longwave radiation (OLR) observations. Lower OLR radiances are directly related to higher cloud tops, which are related to increased precipitation rates. It is necessary to define radiance anomalies locally, so OLR and precipitation climatologies are computed and a regression relationship is developed between OLR anomalies and precipitation anomalies. In use, the total precipitation inferred is the estimated anomaly plus the local monthly climatological value. A backup direct OLR-precipitation regression is used when the anomaly approach yields unphysical values. For use as part of the GPCP the OPI estimates are calibrated against the globally complete GPCP estimates from 1988-1998. During the pre-SSM/I period January 1979 - June 1987 and December 1987, the OPI data, calibrated by the GPCP satellite-gauge estimates for the SSM/I period, are used as a replacement for the multi-satellite estimates. The OPI estimates calibrated by the GPCP analyses are produced routinely by the Climate Prediction Center, National Centers for Environmental Prediction NOAA.

2.3 Error estimates

The error estimates for the input fields and combination products are based on Huffman (1997) and Huffman et al (1997). The estimates are for <u>random error</u> (bias error is assumed removed in the analysis procedure) and includes both algorithm and sampling random errors. The final form of the relation is

$$\sigma^2 \cong \frac{\mathrm{H}(\bar{r}+\mathrm{S})}{N_i}\left[24+49\sqrt{\bar{r}}\right] \quad (1)$$

where σ^2 is the error variance of an average over a finite set of observations, H is taken as constant (actually slightly dependent on the shape of the precipitation rate histogram), $\bar{r}$ is the average precipitation rate (in mm d^{-1}), S is taken as constant (actually σ for $\bar{r} = 0$), N_i is the number of independent samples in the set of observations, and the expression in square brackets is a parameterization of the conditional precipitation rate based on examination of satellite estimates and gauge analyses. The "constants" H and S are set for each of the input single-source data sets by comparison against gauge data. Once the error estimates are calculated the combination procedure can be based on weights that are a function of realistic errors and the users of both the input products and combined analyses have information with which to judge the utility of the data set for their particular application.

3. Combination methods

The merging techniques used for the GPCP monthly product are different for the SSM/I period of 1987 to the present and for the 1979 to 1987 period when no microwave-based estimates were used. A block diagram of the product generation is shown in Fig.1.

3.1 Combination method for 1987-present.

For the 1987-present period, during which SSM/I data is available, the combination method is very similar to that described in Huffman et al. (1997). It is designed to use the strengths of each input data set to produce merged global, monthly precipitation fields that are superior to any of the individual data sets. The technique is also designed to reduce bias in each step by using the input original or interim product with the presumed smallest or zero bias to adjust the bias of other products. For example, microwave-based estimates are presumed to have lower biases than IR-based estimates and gauges are presumed to be unbiased relative to the combination of satellite estimates over land.

A key feature of the GPCP merge technique has centered on combining the superior physical basis of the microwave-based observations from a low-orbit satellite and the frequent time sampling of the geo-IR observations. Adler et al. (1991, 1993) described a technique for using precipitation estimates from low-orbit microwave data to "adjust" precipitation estimates made from geo-IR data. The resulting "microwave-adjusted IR" estimates provide an objective means of correcting known biases in the geo-IR estimates, while retaining the high sampling rate of the geosynchronous satellite. This approach was then adapted to be applied on a global, tropical basis as described by Adler et al. (1994) and by the GPCP (Huffman et al.1997). First, for each month the microwave estimates are approximately time- and space-matched with geo-IR observations to derive additive and multiplicative microwave/IR calibration factors (see Fig. 1). In regions lacking geo-IR data, rainfall estimates from the NOAA polar orbiting satellites are adjusted using a smoothly varying interpolation of the microwave/geo-IR adjustment ratio. The spatially varying arrays of adjustment coefficients are then applied to the full month of GPI estimates, producing the adjusted GPI (AGPI) precipitation field, which has the desirable, 3-hr sampling of the geosynchronous data and the typicallysmall bias of the instantaneous microwave estimates. Verification against rain gauge analyses over water and land and subjective examination of the resulting maps and zonally averaged fields indicate that known biases in the GPI in the subtropics and over land are reduced using this adjustment approach (Adler et al. 1993, 1994).

The GPCP Version 2 merging procedure introduces TOVS-based estimates to fill in the high latitudes, where SSM/I-based estimates are unavailable or unreliable. Equatorward of seasonally varying latitude boundaries (about 40-50° N and S, chosen by inspection of monthly climatological zonal profiles) the microwave is used by itself. Poleward of 70° N and S the TOVS is adjusted based on a comparison of TOVS and climatological gauge values. In the mid-latitudes an average of TOVS and SSM/I is used, with a smooth transition over 60-70° N and S to the gauge adjustment at 70° N and S. Areas lacking SSM/I equatorward of 60° N and S (generally over land) are filled with TOVS adjusted by the ratio of zonal-average SSM/I (or SSM/I-TOVS average) and TOVS.

A multi-satellite precipitation product is formed of AGPI, between 40°N and 40°S, and SSM/I and TOVS values elsewhere. In areas of the Tropics where geosynchronous data are unavailable (e.g., Indian Ocean) microwave-adjusted low-orbit IR is combined with SSM/I estimates.

Next, the large-scale (5x5 grid box) average of the multi-satellite analysis is adjusted to agree with the large-scale average of the gauges (over land and where available). This keeps the bias of the satellite and gauge combination close to the (presumably small) bias of the gauge analysis on a regional scale. Finally, the gauge-adjusted, multi-satellite estimate and the gauge analysis are combined with inverse-error–variance weighting to produce the final, merged analysis. This gauge/satellite combination approach allows the multi-satellite estimate to provide important local detail variations in gauge sparse areas, while still retaining the overall gauge bias. The efficacy of this proceduerewas demonstrated by McCollum et al., 2000in their study of biases in satellite estimates relative to gauges over equatorial Africa.

Random error fields are computed for each of the underlying fields and final product. The nominal error depends on the particular field (e.g., microwave) and fluctuations depend on sampling and rain amount. The theoretically-based functional form currently used was derived in Huffman (1997) and validated by Krajewski et al. (2000).

3.2 Combination method for 1979-1987.

The GPCP analysis is extended back to 1979 using the OLR Precipitation Index (OPI; Xie and Arkin 1998) trained against a concurrent period of the GPCP merged data set. The OPI was developed based on the observation that, while the mean annual cycle of OLR (calculated using the NOAA AVHRR data stream) reflects both the surface temperature and cloudiness, OLR *anomalies* have a clear negative correlation with precipitation *anomalies* over most of the globe. This information was used to develop regression coefficients that relate OLR anomalies to precipitation. While these coefficients are spatially inhomogeneous and seasonally varying, they can be expressed rather accurately as a globally uniform linear function of the local mean precipitation anomalies. The precipitation anomalies are computed from the OLR anomaly relationship and then added to base period mean values to generate monthly precipitation accumulations. In this application the OPI is trained against the GPCP merged analysis for the 1988-1997 period. The OPI relations developed with the GPCP data set are then applied to the OLR anomalies for the 1979-1985 period to produce the monthly OPI-based precipitation estimates. The OPI estimates take the place of the SSM/I and Geo-IR estimates for this early period and are then merged with the gauge analysis over land as in the later period.

4. Results

4.1 Example Month

Figure 2 (top panel) shows an example of the GPCP monthly merged final product, in this case for February 2001. The general rainfall patterns for this month are typical of Northern Hemisphere winter months with heavy rainfall in the western Pacific Ocean, especially in the South Pacific Convergence Zone (SPCZ). Heavy rains extend across northern Australia and Southeast Asia is dry, as is typical of the Asian Monsoon at this time of year. The Northern Hemisphere (N.H.) mid-latitude storm tracks in the Atlantic and Pacific Oceans are evident, as are the Southern Hemisphere

(S.H.) storm tracks, which tend to be more zonal. Over southeast Africa a maximum of precipitation (20 mm/day) is associated with the devastating floods which occurred there at this time.

The middle panel of Fig. 2 has the random error field associated with the merged monthly estimate. The error estimate includes both error due to the algorithm and sampling error. The pattern closely follows the rain field in the top panel due to the close relation of the error to the estimated rain as indicated in Eq. 2. This relation can be seen in Fig. 3, which shows the relation between estimated error and rainrate for this month, with each point representing the result for a 2.5° square. The general increase of error with rainrate can be seen, but there is fairly large scatter. However there are also identifiable curves formed by collections of points that relate to particular regions which contain the same combination of input data. The collection of points extending out to the letter A in the diagram are for ocean areas in the 40°N-40°S area where both SSM/I and geosynchrous IR data are used. The sampling provided by the IR data lowers the random error as compared to the ocean areas outside latitude 40°, which have only the sampling of the polar orbit satellite, which are indicated by B in the figure. The letter C denotes the near end point of a collection of points over land, which have a generally lower error due to the gauge input (in addition to satellite), but have significant error variability due to the variation in number of gauges in each box. Overall the errors range between 10-30% at rain amounts above 100 mm/month (3 mm/day). This percentage error is for a 2.5° latitude-longitude square and time and space averaging will significantly reduce the estimated random error.

To better see variations in the quality of the final estimate, a quality index (QI) has been defined (Huffman et al., 1997) so that QI is approximately equivalent to the number of gauges required to produce the error in question (for the given amount of rain). The map of QI for the sample month is shown in the bottom panel of Fig. 2. In general the land areas have a higher QI because the land areas have the gauge information in addition to that from the merged satellite estimates. Variations in QI over land are related mainly to variations in gauge density with Europe and southeastern Australia having some of the areas of highest QI. Over the ocean the QI is higher (2-4) in the 40°N-40°S region relative to a QI of 1-2 at higher latitudes. The higher QI (lower error for same rainfall) is due to the added sampling available with the geosynchronous satellite observations. The QI and error fields should be helpful for evaluation of research results utilizing this data set. However, it should be remembered that the error estimates are for random error only, but include estimates of both retrieval error and sampling error.

4.2 Climatology

Fig. 4 displays the 1979-2001 precipitation climatology map based on the GPCP V2 final merged product. The GPCP climatology shows the expected main features, with maxima in the tropics in the Inter-Tropical Convergence Zone (ITCZ) in the Atlantic, Pacific and Indian Oceans, in the South Pacific Convergence Zone (SPCZ), and over tropical Africa, South America, and the Maritime Continent between the Pacific and Indian Oceans. Dry zones in the eastern parts of the subtropical oceans are evident, as are the desert areas over land. The Pacific ITCZ is a narrow band on the Northern Hemisphere side of the Equator, with peaks in both the western and eastern parts of the ocean with nearly equal values of 8.8 mm/day and 9.1 mm/day, respectively. The Atlantic Ocean ITCZ maximum is weaker and the Indian Ocean feature extends westward from Sumatra and narrows along the Equator.

In the midlatitudes, the storm tracks in the Northern Hemisphere oceans are very distinct with peak values in the Atlantic and Pacific Oceans greater than in the Southern Hemisphere circumpolar storm track. A secondary maximum is evident along the northwest coast of North America from Alaska to California at the eastern end of the Pacific Ocean storm track. The Southern Hemisphere does have weak maxima southeast of Africa and South America and a poleward extension of the

SPCZ in the South Pacific Ocean. The narrow, circumpolar maximum at 65 °S indicates the Southern Hemisphere storm track, but also is the latitude zone where the combination technique is transitioning from SSM/I-based precipitation estimates to TOVS-based estimates. Therefore, although the feature certainly exists, the magnitude and exact placement are more questionable than the other features in the climatology.

A comparison of the new Version 2 with the GPCP Version 1 climatology indicates slightly lower rainfall amounts over the Tropical oceans due to a modification of the passive microwave algorithm over the ocean (Chang et al., 1995) and an increase at high latitudes (> 50°) over ocean due to the merger of the TOVS-based estimates with the SSM/I-based estimates at these latitudes.

The zonal-averaged latitudinal profile of precipitation is given in Fig. 5 for the GPCP climatology and for two conventional climatologies, from Jaeger (1976) and Legates and Willmott (1990). The GPCP peak of 5.5 mm/day at 6°N is nearly the same as that from Jaeger (hereafter referred to as J). The Legates-Willmott (hereafter referred to as LW) peak is related to a very strong maximum shown in their climatology in the central Pacific Ocean, which is not supported by satellite observations. The GPCP curve shows a secondary tropical peak at 5°S, which appears in the other climatologies as changes in slope of the decrease from the main peak. This secondary peak can be thought of, perhaps, as a manifestation of a second ITCZ on the south side of the Equator, but the peak is actually made up of various ocean and land features that do not connect over any large longitudinal range (see the map in Fig. 4). The overall Tropical peak in the GPCP climatology (Fig. 5) is somewhat narrower than in either of the conventional climatologies and the sub-tropical minima of just below 2 mm/day are located a little equatorward of the climatologies, especially in the Southern Hemisphere. The land and ocean breakdown of the latitudinal profile is shown in Fig. 6, where it can be seen the double peak exists in the ocean by itself, but that the land profile has its overall peak just south of the Equator. The land peak is closer to the Equator than the ocean peak.

The GPCP Northern Hemisphere (N.H.), mid-latitude peak is similar in magnitude and shape to that of the LW profile (Fig. 5) with higher values than the J profile. The main peak, at about 40° N is an ocean peak, not showing up over land (see Fig.6). It is mainly composed of the two oceanic maxima east of Asia and North America. Poleward of that peak the GPCP curve in Fig. 5 has a weak secondary maximum at 55°N, which is clearly based over land (see Fig. 6). The LW climatology has a similar feature. The ocean profile in Fig. 6 does show a leveling off before a steep drop off to the pole. This high latitude activity perhaps reflects a separate cyclone track at this latitude, and also the southwest –to-northeast (ocean to land) orientation of the main mid-latitude rain features in the N.H. From 55° N the mean precipitation decreases rapidly toward the pole dropping below 1 mm/day at 70° N. In this zone the GPCP agrees fairly well with the conventional climatologies.

In the Southern Hemisphere (S.H.) the broad GPCP mid-latitude maximum between 40°-60°S has two peaks, the larger being at 57°S. The exact latitude of the peaks in this zone varies among the climatologies. The distinct peak at 57°S in the GPCP field is also evident in the map in Fig. 4. As mentioned before, this zone is also where the GPCP merger technique transitions from SSM/I-based estimates to those from TOVS and since that transition is done as a function of latitude this peak, or at least the magnitude of the peak, is open to question and requires further analysis. From the mid-latitude maximum the mean precipitation drops off rapidly toward the pole similar to that of J.

In comparing the precipitation of the two hemispheres in Fig.6 it is evident that the N.H. has more mean rainfall in the 0°-25° zone, probably due to the more extensive land mass in the N.H., which in turn draws the ITCZ into the N.H. and also helps produce the stronger Asian monsoon in the N.H. However, in the 25°-65° zone the S.H. has somewhat greater precipitation overall, but the

N.H. has a greater total in this zone, if only oceans are considered. Thus it seems that the standing waves in the N.H. help produce larger precipitation values over the oceans there, but the drier land masses in this latitude zone reduce the total precipitation to slightly below the S.H. ocean and total values, which are nearly the same because of the relative lack of land in that zone.

4.3 Global totals

Table 1 contains the global total precipitation totals for the GPCP Version 2, along with those for the two conventional climatologies. For the entire globe (90°N-90°S) the GPCP total is 2.61 mm/day, comparable to the value of J, but lower than that of LW. However, the LW value is affected by the questionable rainfall maximum in the central Pacific Ocean in that climatology (see Huffman et al., 1997 and Janowiak, et al., 1995 for discussion) so that its global total value is questionable. The breakdown between ocean and land indicates higher values over ocean and because the ocean also occupies the larger area, this means that 76 % of global precipitation falls over the world's oceans according to the GPCP climatology.

When the latitude band is restricted to the Tropics, *i.e.*, 30°N-30°S, the mean goes up to 2.93 mm/day and the difference between land and ocean is much smaller. The GPCP values in the Tropics are also in close agreement with those of J, but very different than those of LW for the aforementioned reason. As indicated in Fig. 5 the LW values appear very reasonable outside the Tropics and even within the Tropics climate maps are similar to those of GPCP, except for the central Pacific Ocean. The GPCP Version 2 values for the Tropics are about 5% lower than the GPCP Version 1 means over the oceans (over land they are nearly identical because of the influence of the raingauges). The ocean difference is due to a modification of the microwave algorithm as mentioned earlier.

The lower part of Table 1 shows the totals for various latitude bands. When the globe is divided into the N.H. and S.H. Table 1 indicates that the N.H. has slightly more precipitation. When only considering oceans, the N.H. is still larger, but over land the S.H. has a higher mean precipitation rate. When the hemispheres are divided into Tropics and extra-tropics (bottom part of Table 1) the N.H. has more precipitation in the Tropics and the S.H. has more precipitation in the extra-tropics.

A time series of monthly, global anomalies from the 23-year mean value in Table 1 is shown in Fig.7. A 12-month running mean is also shown. The curve for land and ocean combined in the top panel indicates no noticeable trend over the observation period. This lack of a positive trend might be surprising considering predictions based on climate models of a precipitation increase associated with global warming. However, the size of the predicted increase is small and may not be detectable over a short period such as 20 years.

The monthly anomalies occasionally reach near a magnitude of 0.2 mm/day, but typically stay below 0.1 mm/day, a 4% variation when compared to the mean of 2.6 mm/day. The ocean and land separately have larger anomalies because of the smaller area, and the land variations are most obvious and are generally related to ENSO variations. Fig. 8 shows a similar diagram limited to 30°N-30°S and includes a plot of the Nino 3.4 Sea Surface Temperature (SST) index along with the indicators of the occurrence of major volcanic eruptions. The variations over land in the bottom panel are clearly connected to ENSO. Two major land areas in this latitude range, South America and the maritime continent have dry periods during El Niño, and also the Indian summer monsoon rainfall is weaker, which results in the negative correlation between Nino 3.4 and land precipitation. A positive correlation with ocean rainfall is present, especially pronounced during the 1986-87 and 1997-98 El Niño events and the subsequent switches to La Niña conditions, but not so obvious with the 1982-1983 and 1991-1992 events. The major volcanic events also may play a role and might help to explain some decreases in precipitation and the lack of a positive ocean anomaly during the 1982 and 1992 El Niños. Research is ongoing in exploring these relations and possible causes.

4.4 Seasonal Cycle

The evolution of the annual cycle of precipitation is seen in Fig. 9 in terms of mean maps for selected months. Fig. 10 shows the zonally-averaged annual cycle, separately for land and ocean and together. In Tropical regions the major precipitation peaks in the Indian and Pacific Oceans, South America and the maritime continent are below the Equator in January. In mid-latitudes the N.H. ocean peaks are the strongest and are located further south in January. In the S.H. storm track the precipitation maximum is weakest. In April the Western Pacific Ocean maximum is already larger north of the Equator, but a double ITCZ pattern exists in the Eastern Pacific Ocean. By July the precipitation in the Tropics has followed the sun northward and both the land and ocean peaks are farthest north. The N.H. storm tracks are weak, but the circumpolar track in the S.H. is at its strongest. The impact of land is in evidence in Fig. 10, which shows the mean zonally-averaged annual cycle (two cycles are shown). The range of latitudes covered by the precipitation maximum during the annual cycle is clearly larger for the land areas than for the oceans, indicating the effect of the land heating at amplifying the annual cycle. In northern mid-latitudes the ocean peak is clearly defined in winter at 40°N, while over land the peak is in summer, at 50-60°N.

The regional characteristics of the seasonal cycle are given by the magnitude and phase of the first annual harmonic of precipitation seen in Fig. 11. The areas of large amplitude are associated with monsoonal regimes and shifts of the ITCZ. Shifts in phase of 180° are noted between South Asia and northern Australia, the Amazon and north coast of South America and along the Equator across the Pacific Ocean. The amplitude of the strong feature in the eastern Pacific is partly due to the impact of tropical cyclones there in July-September. The N.H. mid-latitude storm tracks have broad maxima with approximately a January peak. In the S.H. storm track at 50°S from south of Africa to south of Australia has a June peak.

Other interesting features include variation in the sub-tropical dry areas. The S.H. oceanic dry areas west of South America and Africa stay dry year around, but their N.H. counterparts vary seasonally to a much greater degree with a relatively wet winter. The N.H. polar region also shows a seasonal variation with peak precipitation in the summer.

4.5 Example of ENSO variations

One of the most important prospective uses for any analysis of global precipitation is to examine and understand interannual changes in the distribution of large-scale precipitation and their relationship to variations in the general circulation. It has long been clear that a significant portion of the interannual variability in the large-scale atmospheric circulation is associated with the ENSO phenomenon (Bjerknes 1969, Arkin 1982, Schneider and Fleer, 1989). ENSO-related changes in global precipitation as inferred from rain gauge observations have been presented by Ropelewski and Halpert (1987, 1989, 1996), and Janowiak and Arkin (1991) and Arkin et al. (1994) have described the ENSO signal in precipitation estimated from satellite observations. GPCP Version 2 has already been used by Curtis and Adler (2000) to create indices of ENSO based on patterns of precipitation anomalies. These indices are extended into real-time by using the Goddard Profiling Algorithm to estimate precipitation (Kummerow et al. 2001). The standard rainfall index, the ENSO Precipitation Index (ESPI), is plotted with Nino 3.4 and precipitation anomalies divided by 4.0 over the Nino 3.4 domain (Fig. 12). The Nino 3.4 SST index leads the collocated precipitation index, which is expected considering the relationship between temperature and convection. Nino 3.4 and ESPI are highly correlated (0.87). However, an equally large correlation is found when ESPI leads Nino 3.4 by a month. ESPI leads Nino 3.4 because it uses precipitation information over the Maritime Continent and evidence suggests that a decrease in convection there leads the warming signal in the central Pacific (Curtis and Adler 2000, Curtis et al. 2001).

The Twenty-three-year record contains six El Niños, including the powerful events in 1982-83 and 1997-98 (Fig. 12). An important application of GPCP is to characterize the evolution of global precipitation during ENSO. An initial study (Curtis et al. 2001) focused on the role of precipitation during the 1997-1999 ENSO cycle. Here we complement this work by examining rain rates, anomalies and normalized anomalies for the seasons July-August-September (JAS) 1997, January-February-March (JFM) 1998, JAS 1998, and JFM 1999 (Fig. 13).

The boreal summer of 1997 (Fig. 13a) was characterized by a reversal of the Walker circulation, as defined by the East-West precipitation gradient in the equatorial Pacific (Curtis and Adler 2000). The strongest precipitation anomalies (Fig. 13b) were confined to the equator, with increases in rainfall over much of the Pacific and decreases over the Maritime Continent, the Amazon, and Central Africa. However, normalized anomalies, ranked percentiles of rain rate based on a gamma distribution (Ropelewski and Halpert 1987), show significant changes in seasonal precipitation in the mid- to high-latitudes (Fig. 13c). Enhanced precipitation is evident off the west coast of the U.S. and northwest Canada. Reduced precipitation is clearly seen over central Asia and through the Drake Passage. A large area of rain rates in excess of 16 mm day-1 occurred in the central Pacific in JFM 1998 (Fig. 13d). Negative precipitation anomalies are found to the north of the Equator (Fig. 13e). Also, dry conditions are consistent with the severe droughts recorded over much of central Africa, the Maritime Continent, and Amazon basin this season. Areas of positive precipitation anomalies are centered in coastal waters off the horn of Africa and California (Fig. 13e). Normalized anomalies suggest that 1998 was one of the driest winters on record off the west coast of Mexico (Fig. 13f). A weak La Niña emerged in the boreal summer of 1998 (Fig. 13g). A strong gradient of precipitation anomalies is seen across the Maritime Continent, with positive values southwest of Sumatra and negative values north of New Guinea (Fig. 13h). However, the normalized anomalies (Fig. 13i) do not show the global extremes observed during the El Niño. The La Niña strengthened into the beginning of 1999 (Fig. 13j). Above normal rainfall was observed for the Maritime Continent and Amazon, but central Africa was as dry as JFM 1998 (Fig. 13k). Normalized anomalies show significantly dry conditions over the southwestern U.S. and southern Indian Ocean (Fig. 13l).

5. Comparison with independent gauge data

The GPCP products (Version 1) have been the subject of comparison with surface rainfall data in previous studies (Huffman et al., 1997; Krajewski et al., 2000), with generally positive results. In this section the GPCP Version 2 data set will be compared with two independent gauge data sets, one over ocean and one over land. More detailed comparison with independent surface data sets is ongoing.

In Fig. 14 the final merged GPCP product is compared to the atoll raingauge data described by Morrissey and Green (1991). The monthly GPCP merged data does not contain the atoll data. The plot in Fig. 14 is limited to 2.5° monthly grid squares that have at least two rain gauges in the box. The plot shows significant scatter, some of which is related to how poorly a few raingauges represent a 2.5° square. The most meaningful statistic is the bias, which is –34 mm/month, or –16%. One can see from the scatter plot that the GPCP is high compared to the atoll gauges at low values, but low compared to the atolls above about 150 mm/month. The overall difference of 16% is related to a similar difference between the ocean passive microwave technique used and the atoll gauges, since the microwave technique is used to calibrate the geosynchronous IR-based estimates. It is possible the satellite technique is underestimating the precipitation, but there is also the possibility that the atoll gauges are not completely representative of the open ocean precipitation. Because of this question and the fact that the atoll stations are only located in the Western Pacific Ocean and are therefore not representative of the entire Tropical ocean, the GPCP data set has not been adjusted to take into account the difference. Additional research is ongoing to determine the representativeness of the atoll mean values.

An example of comparison of the GPCP analysis with independent gauges over land can be seen in Fig. 15. The comparison gauges are from the Oklahoma mesonet (Brock et al., 1995) for two 2.5° grid boxes in Oklahoma. None of these gauges were used as part of the GPCP gauge analysis. The Oklahoma boxes are located just inside the 40°N boundary where both SSM/I and geosynchronous IR observations are used in the analysis. There was typically 30 mesonet gauges located in each 2.5 ° GPCP grid box. This area is therefore sub-tropical to mid-latitude with an annual cycle varying from summertime thunderstorms to wintertime stratiform precipitation, including some snow.

Fig. 15c shows the scatter plot for the final merged GPCP product which includes the raingauges as described in sections 21.1 and 2.2.1. The low bias (+1%) and high correlation indicate that the merger process and the incorporation of the gauge information has succeeded in producing a reasonable product, at least over this area. The average number of GPCP gauges used in the analysis per grid box was four. To better understand the influence of the GPCP gauge information on the resultant analysis and to estimate the quality of the GPCP analysis in areas of no or limited gauge information Figs. 15a,b are shown. Fig. 15a gives the scatter plot for the multi-satellite analysis before any gauge information enters the analysis. The scatter is significant, although there is obvious skill and a relatively small bias, under 10%. Fig. 15b shows results after an intermediate analysis step where gauges over a wide area (7.5° on a side) are used to adjust the overall satellite bias in each 2.5° grid box. The correlation increases and the bias decreases from the satellite-only case in Fig. 15a. This intermediate step can be thought of representing the case of having some gauge information available in the general area, but not many gauges in the particular analysis box. The three panels in Fig. 15 therefore roughly represent the cases over land of a) only satellite-based estimates, b) satellite with a relatively poor sampling of gauges and c) satellite with good gauge coverage.

Another comparison with gauge information can be seen in Fig. 16 which shows the annual cycle averaged over three years as seen by the GPCP product and gauge networks over two parts of Europe. The GPCP merged satellite and gauge product uses monthly raingauge data that are bias corrected using long-term mean monthly correction factors after Legates (1987). In Fig. 16 these estimates are compared with daily raingauge data from high-resolution networks of the Baltex Sea Experiment (BALTEX) that have been bias corrected "on-event" using information about precipitation type and wind speed from the individual daily synoptic data (Rubel and Hantel, 2002). The annual cycles of area-mean precipitation over Sweden (55-65°N/10-15°E , Fig. 16a) and Poland (50-55N/15-25E, Fig. 16b) show good agreement between GPCP V2 and BALTEX corrected gauge analysis. The curves for uncorrected BALTEX data illustrate the importance of the correction for winter months.

6. Limitations

Although the GPCP monthly analysis described in this paper is a very valuable addition to the global climatology of precipitation and very useful for the study of climate variations, the data set does have a few limitations. Because of the desire for the longest record possible and the limited length of record of the various satellites and satellite types, the record is inhomogeneous in terms of its input data sets. The basic period is the mid-1987 to present period that contains the SSM/I data that is used to calibrate the geosynchronous IR estimates. The earlier period is dependent on the Outgoing Longwave Radiation (OLR) data as the main satellite input, at all latitudes. The inhomogeneity is minimized by calibrating the OLR technique during the later SSM/I period. However, the monthly maps from the earlier (OLR-based) period are also smoother, *i.e.*, have weaker gradients. This data set inhomogeneity during the period should be kept in mind when analyzing, for example, global and regional trends with this data set.

Also, mean climatological values of precipitation over the ocean are still open to discussion, especially over middle and high latitudes. Polar latitude precipitation estimates over land also need further validation and examination. Since they are dependent on either TOVS or OLR-based estimates the precipitation values are a function solely of cloud information. The error fields associated the GPCP product help the user to quantify these limitations.

It has also been shown that the GPCP analysis over land may be underestimating precipitation in some regions with orographic features (Nijssen et al., 2001). This underestimation has been examined and related mainly to the relative lack of raingauges in mountainous regions. The density of the raingauge data being used may not sufficient to reliably reproduce spatial structures even if the orographical information would be used as part of the analysis. Unfortunately the satellite observations, both passive microwave and IR, also have difficulty detecting shallow, orographic precipitation. Improvement in this area will probably require additional gauges going into the analysis and/or gauge analysis techniques that use terrain information to adjust the gauges that are available.

7. Summary and future work

A new, improved version of the Global Precipitation Climatology Project (GPCP) monthly analysis is now available and is described in this paper. The GPCP is a part of the World Climate Research Program (WCRP) and the associated Global Water Cycle and Energy Experiment (GEWEX) activity. The data set covers the period January 1979 through the present on a monthly 2.5°x2.5° latitude/longitude grid and is globally complete using satellite and ground observations. The final merged product is produced a few months after real-time through the data inputs and products of a number of scientists and organizations. This monthly analysis is the foundation data set for the GPCP suite of products, which also include finer time resolution analyses: a pentad analysis (Xie et al., 2002) for the full period, and a daily, global analysis from 1997 to the present (Huffman et al., 2001).

Each input and combination field in the monthly analysis is a separate product, and estimates of the random part of the error are provided with each precipitation field. These spatially and temporally varying errors allow users to assess the value of the grid values for their own application. Such applications might include validation of climate models and model-based reanalyses, calibration of hydrological models, and comparison with experimental rainfall estimation techniques.

The 23-year (1979-2001) climatology shows the key features of the mean precipitation pattern for our planet, with an estimated mean precipitation rate of 2.6 mm/day (2.8 mm/day for oceans, 2.1 mm/day for land). The mean GPCP field compares favorably with conventional climatologies with some distinct and subtle differences. Seasonal variations are documented including Asian and other monsoon changes along with differences between the Northern Hemisphere and Southern Hemisphere. The 23-year record shows no noticeable increase in global or Tropical precipitation during that period, although some variations in global totals over land and ocean can be related to ENSO events. The precipitation patterns and anomalies related to the 1997-1999 ENSO event are also described. Because of its use of satellite data over ocean, and even over land, and the length of record this GPCP climatology could be considered a new standard.

Comparison of the GPCP monthly values with surface gauge data sets not used in the analysis indicates that WesternPacific Ocean atoll raingauge data are16% higher than the GPCP estimates. This may reflect an underestimate by the satellite-based technique in this particular area, but the representativeness of the gauge data as to open ocean remains. Over land the comparison in Oklahoma indicates biases of 9% (satellite information only) down to 1% when the global gauge analysis is included. These values are probably typical of flat land areas, but the data sets and techniques used may lead to underestimation in some areas with orography.

The raingauge data base at GPCC has already been expanded by additional data from up to 40,000 stations (non real-time) and by data of the period 1979-1985 (Rudolf et al. 1998). Analyses based on the dense raingauge dataset will help to estimate the bias resulting from the sparse data density and orographical structures. The bulk correction method due to systematic raingauge measuring errors will be replaced by a new method partitioning liquid and solid precipitation (Fuchs et al. 2001).

In the future the authors and others will continue to improve the GPCP analyses for monthly and finer time scales. A key thrust of improvement will be incorporating results and data from the Tropical Rainfall Measurement Mission (TRMM), which carries the first rain radar in space and a passive microwave radiometer with the finest spatial resolution to date (Kummerow et al., 2000; Adler et al., 2002). As the TRMM algorithms mature and the length of record becomes substantial (four years at the end of 2001) the TRMM data will improve GPCP in a number of ways. The improved passive microwave observations along with independent radar observations on TRMM are providing the basis for improvement of passive microwave algorithms that can then be applied to the15 year period of SSM/I passive microwave observations. The combination of radar and radiometer on TRMM will lead to the best instantaneous estimates available and these are already being used to calibrate and adjust other satellite information (Adler et al., 2000). One option being studied is to calibrate or adjust the GPCP monthly analyses to the TRMM-based estimates using the four or more years of overlap, and applying that calibration to the remaining years. This calibration would produce a long-period data set with the means and other statistics of the TRMM data, at least in the Tropics between 40°N-40°S.

TRMM data are also being used to calibrate and combine with SSM/I and geosynchronous IR data to derive 3-hr resolution analyses. Precipitation information from the NOAA's Advanced Microwave Sounding Unit (AMSU) and Japan's Advanced Microwave Scanning Radiometer (AMSR) which will fly on NASA's AQUA and NASDA's ADEOS II are candidates to add to this analysis. GPCP may take advantage of these efforts and data sets to provide research quality precipitation analyses at fine time resolution and then build the daily, pentad and monthly fields from summation of these observations with adjustment and calibration using surface gauge and other information.

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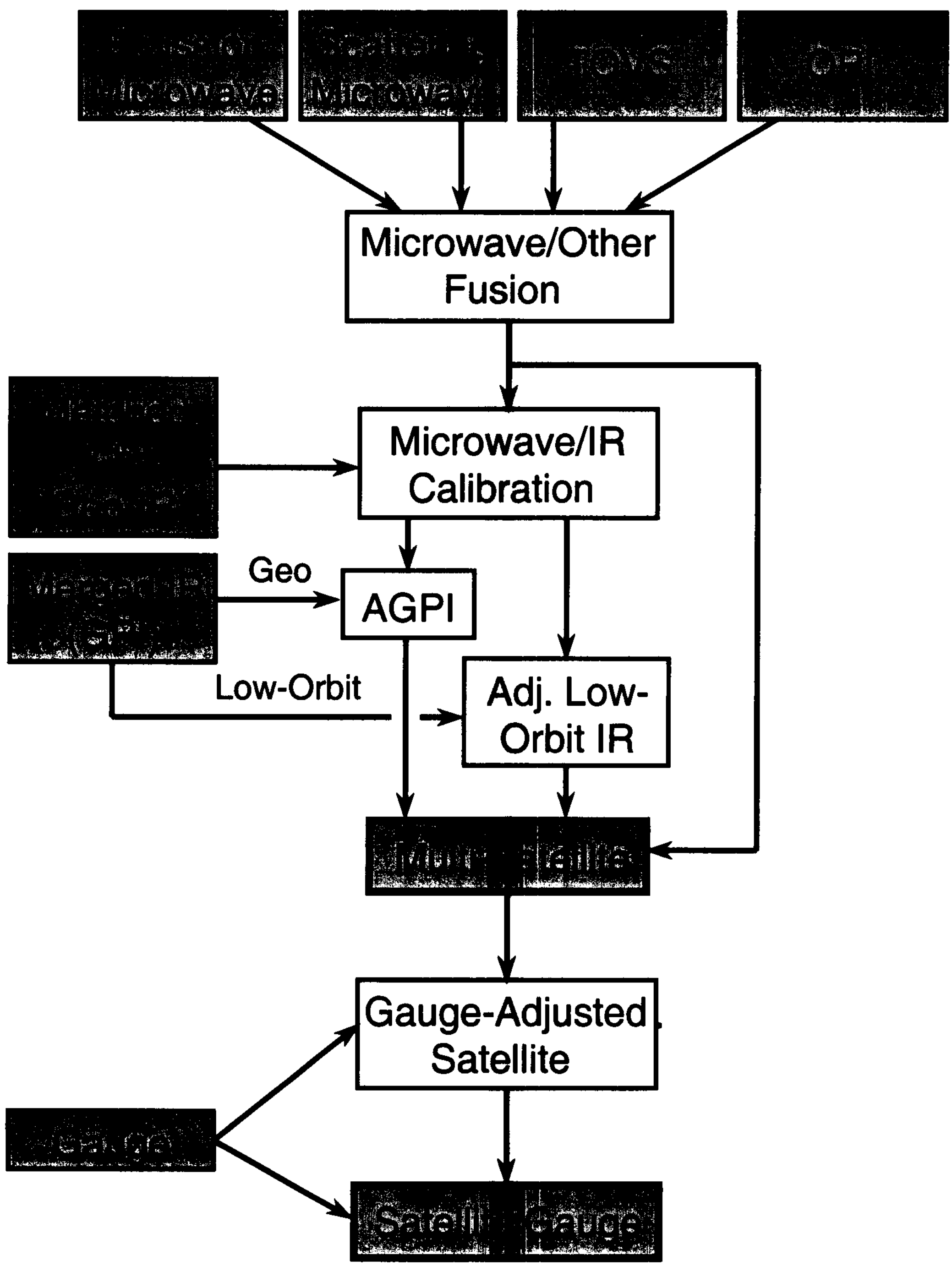
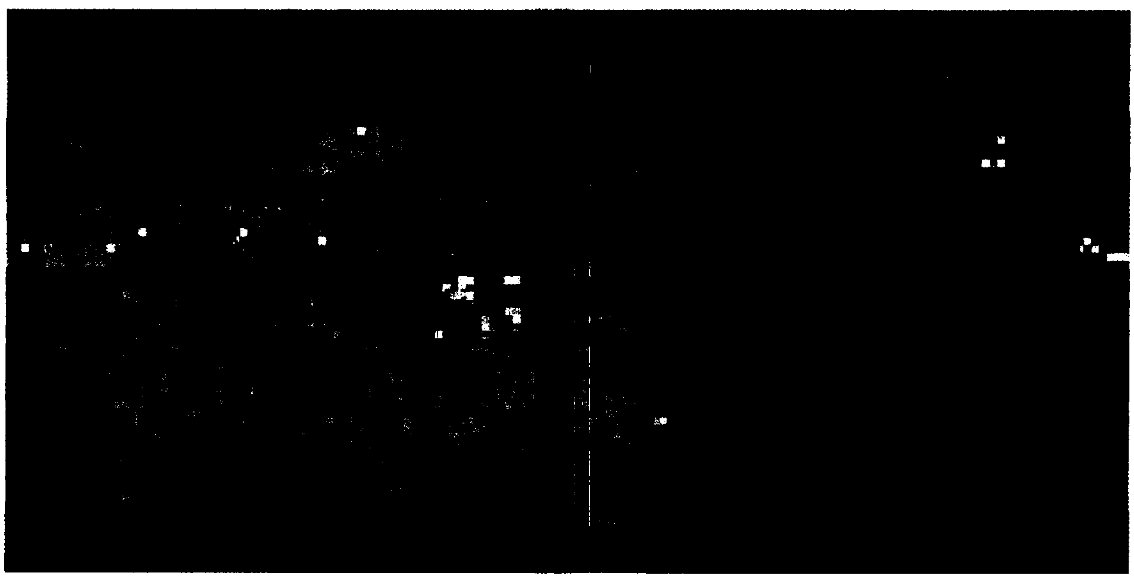


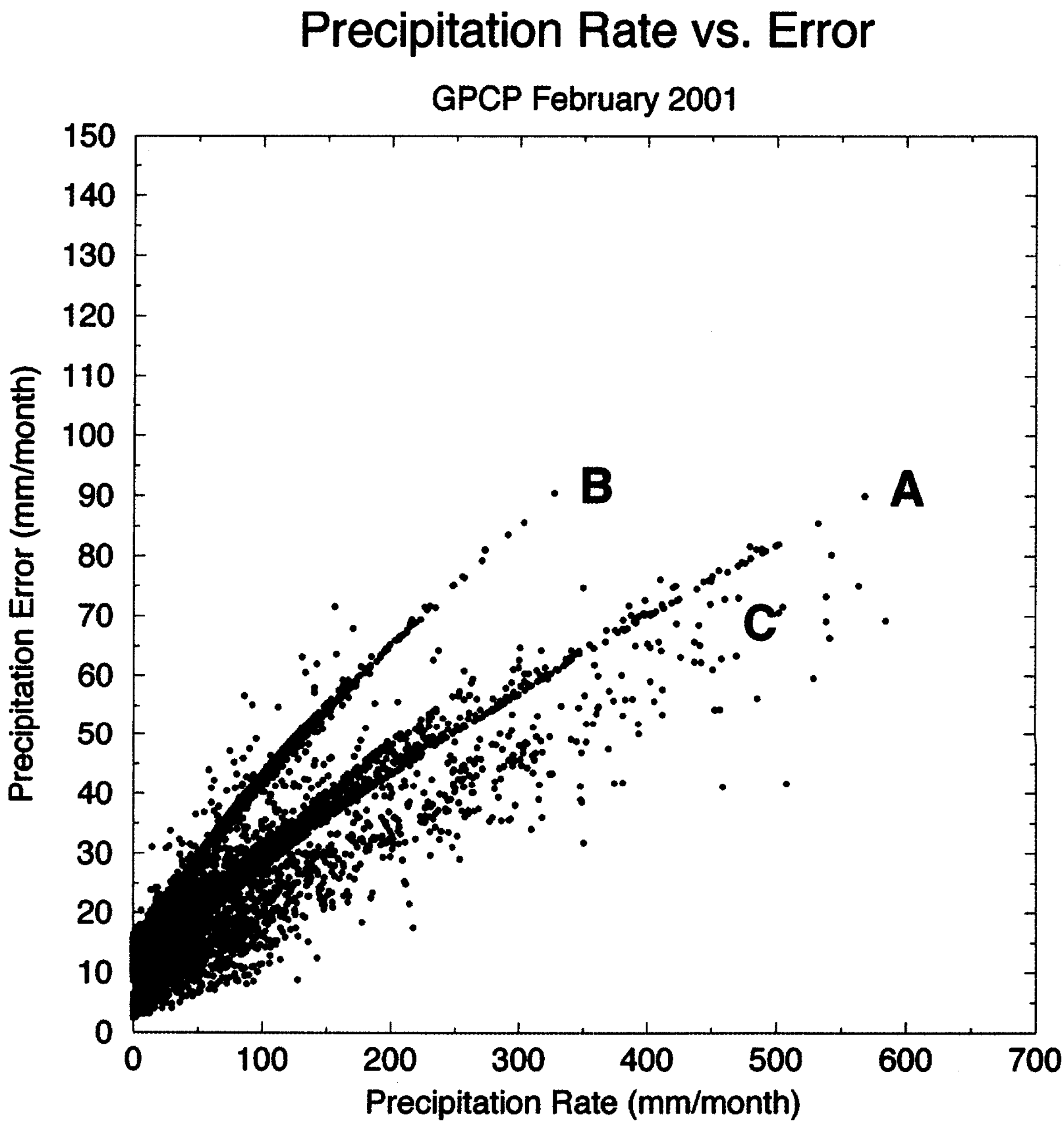
Microwave/Other Fusion
Microwave/IR Calibration
Geo
AGPI
Low-Orbit
Adj. Low-Orbit IR
Gauge-Adjusted Satellite

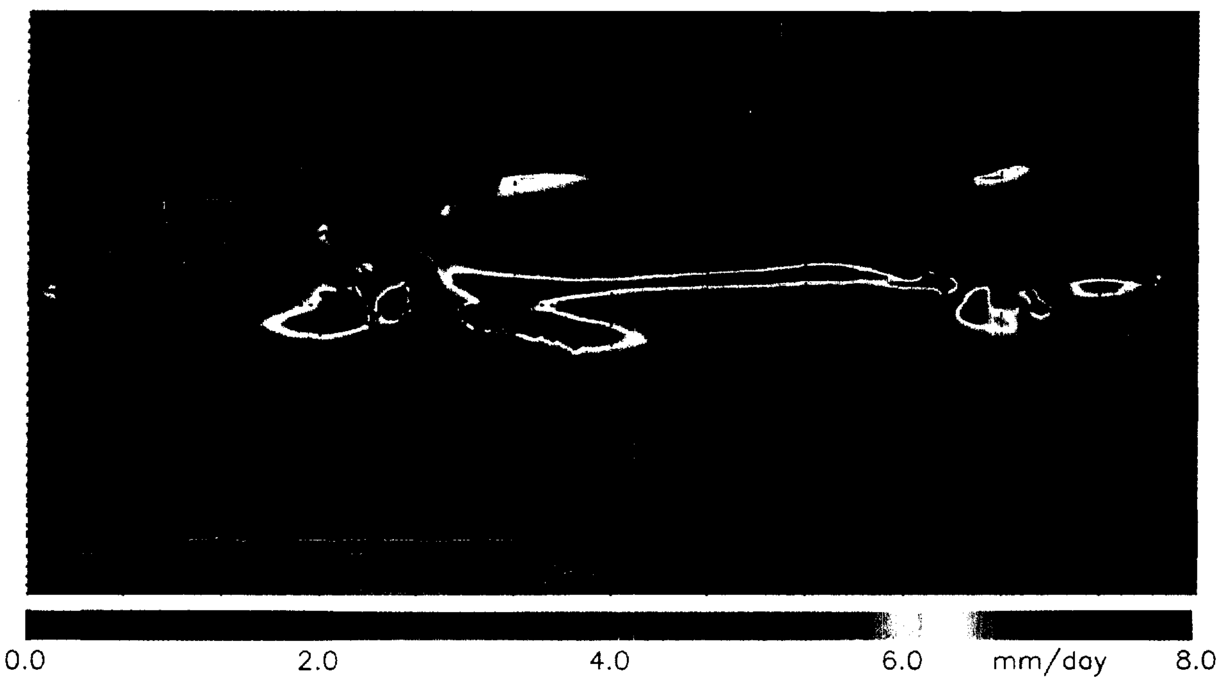
GPCP V2 Precip Feb 2001 (mm/d) 0 4 8 12 16 20+



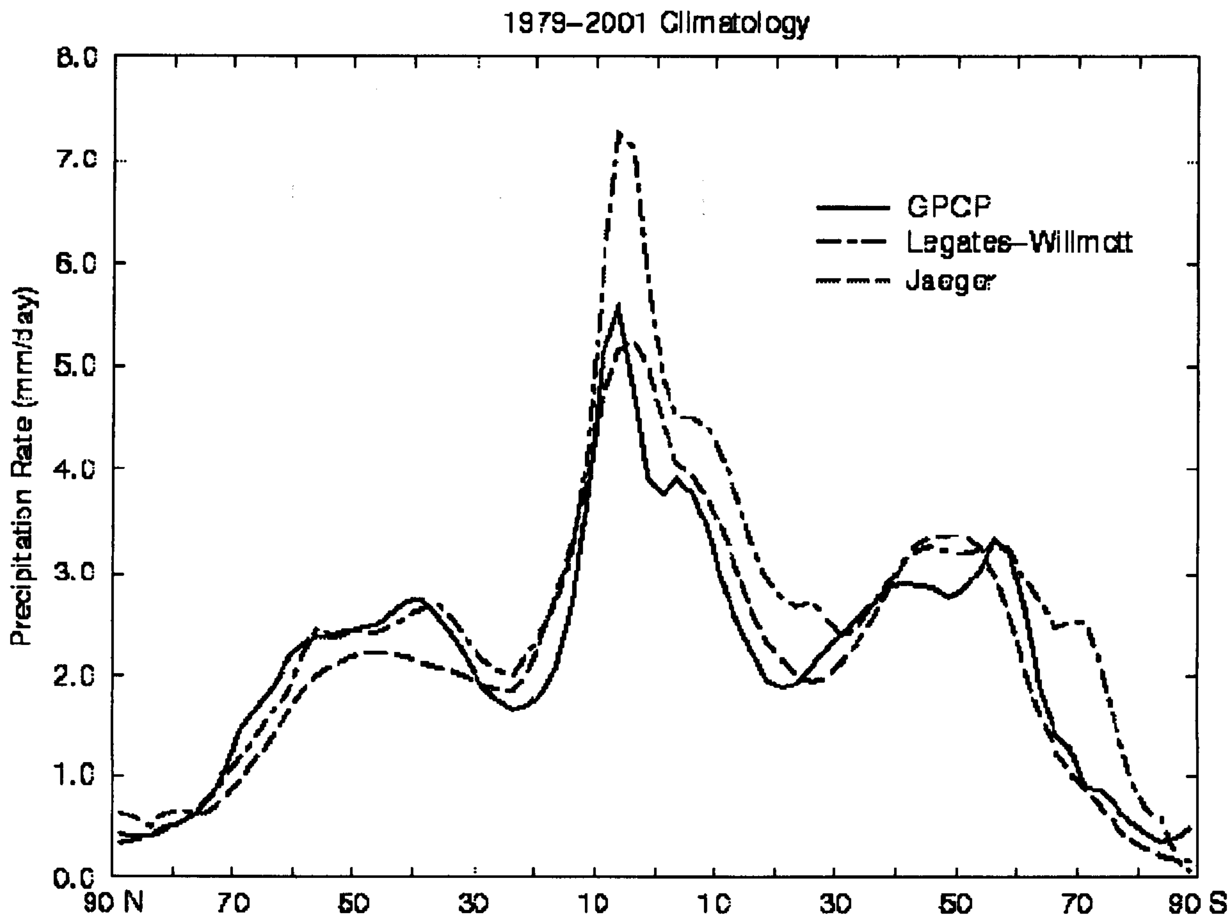
GPCP V2 Precip Error Feb 2001 (mm/d) 0 1 2 3 4 5+

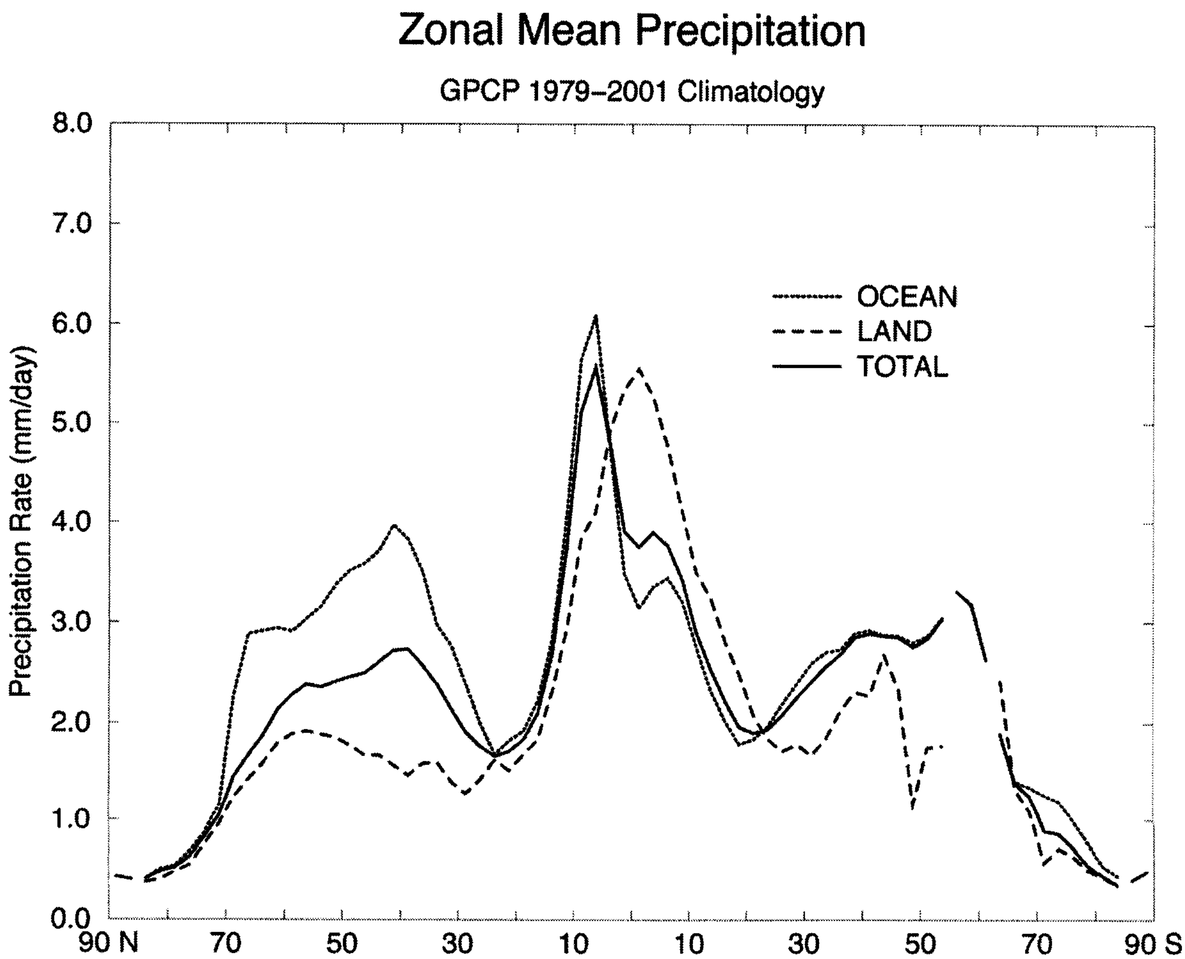
GPCP V2 Equiv Gauges Feb 2001 0 4 8 12 16 20+


Precipitation Rate vs. Error
GPCP February 2001
Precipitation Error (mm/month)
Precipitation Rate (mm/month)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
100
200
300
400
500
600
700
A
B
C

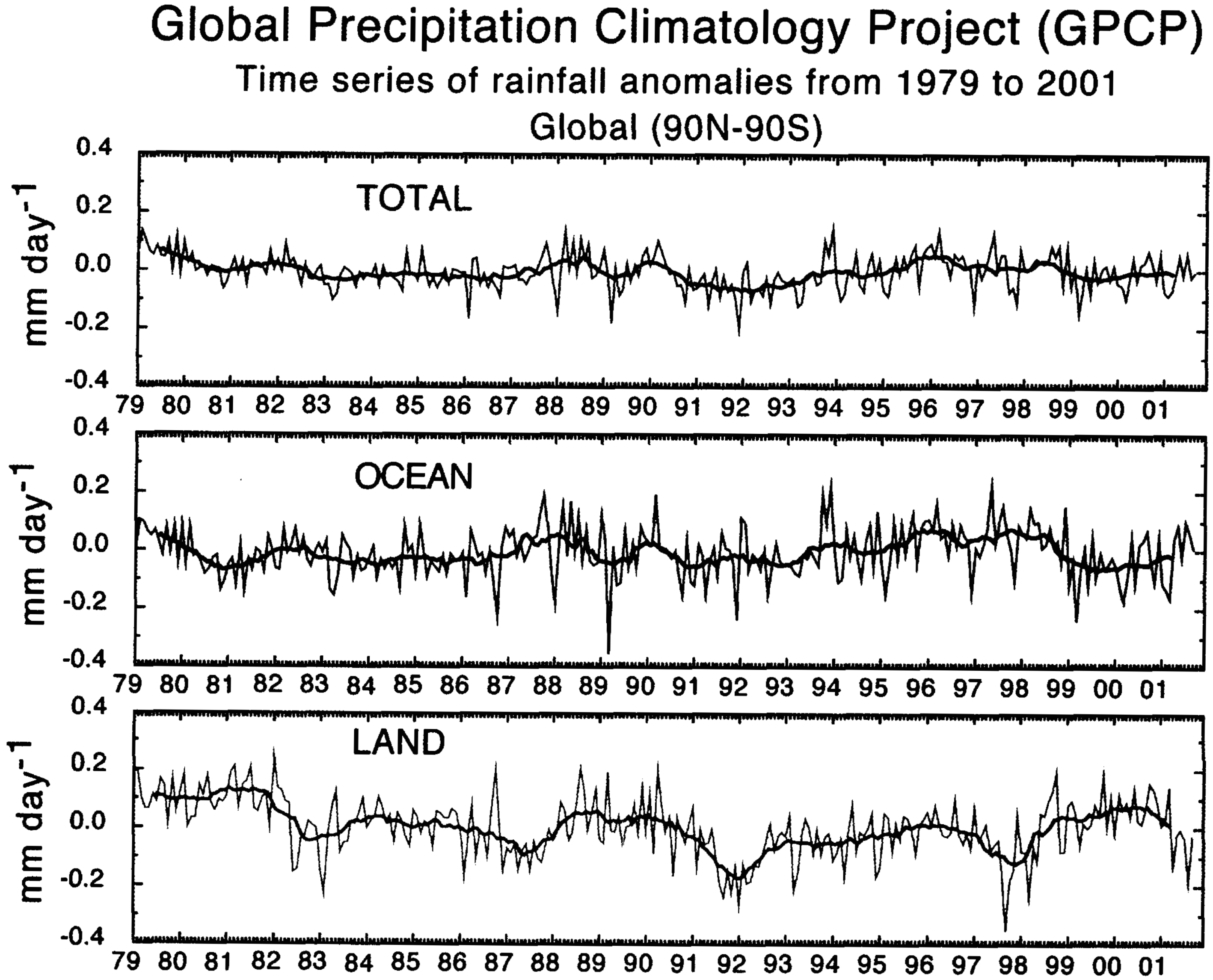

0.0
2.0
4.0
6.0
mm/day
8.0

Zonal Mean Precipitation





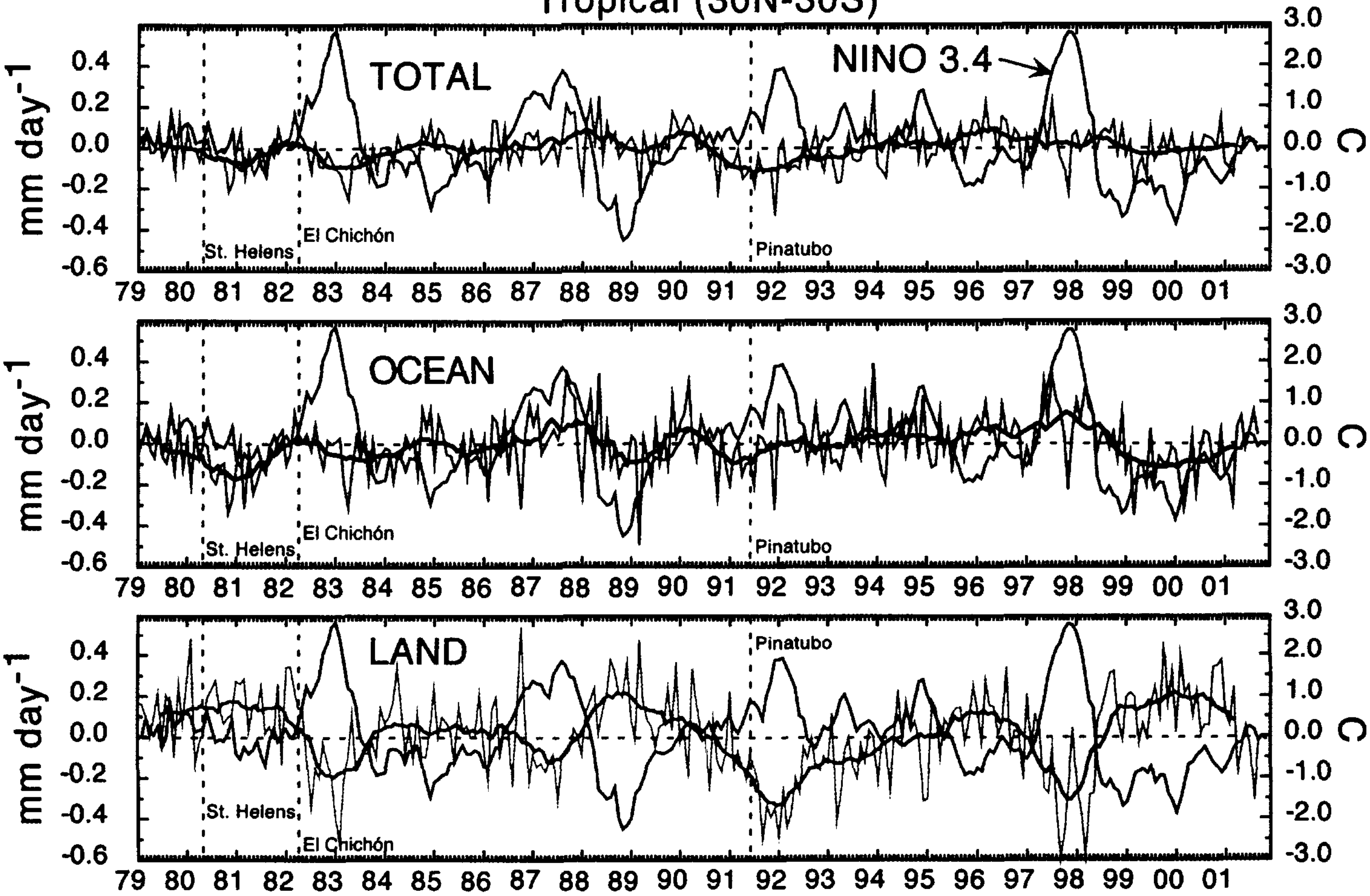
Zonal Mean Precipitation
GPCP 1979–2001 Climatology
Precipitation Rate (mm/day)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
90 N
70
50
30
10
10
30
50
70
90 S
OCEAN
LAND
TOTAL

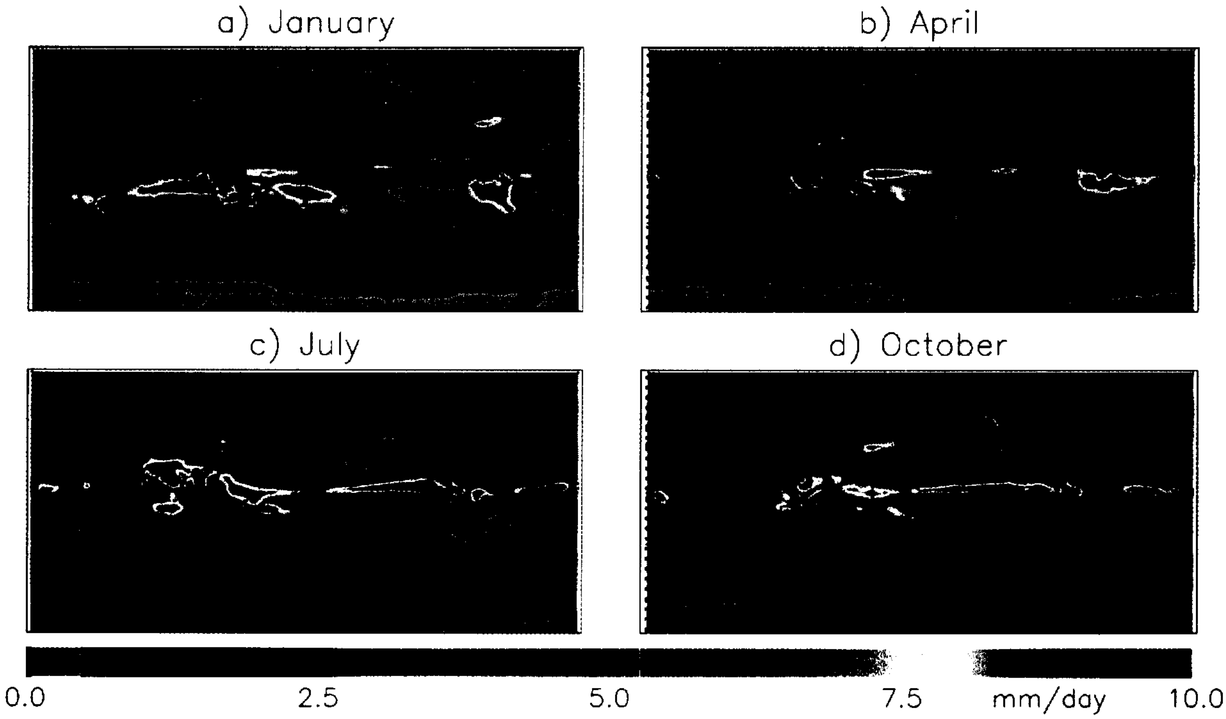

Global Precipitation Climatology Project (GPCP)
Time series of rainfall anomalies from 1979 to 2001
Global (90N-90S)
TOTAL
OCEAN
LAND
mm day-1
0.4
0.2
0.0
-0.2
-0.4
79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01

Global Precipitation Climatology Project (GPCP)

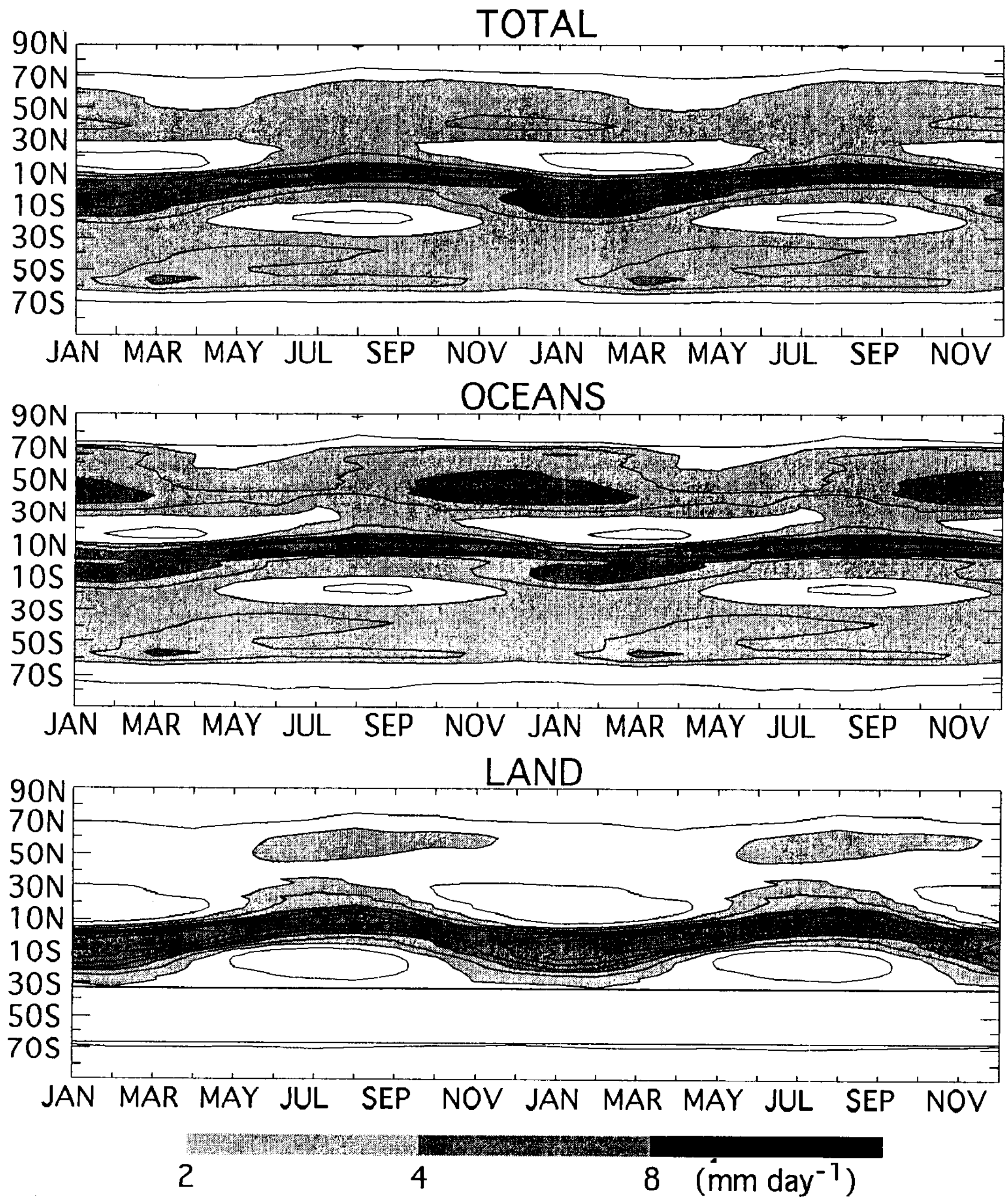
Time series of rainfall anomalies from 1979 to 2001

Tropical (30N-30S)

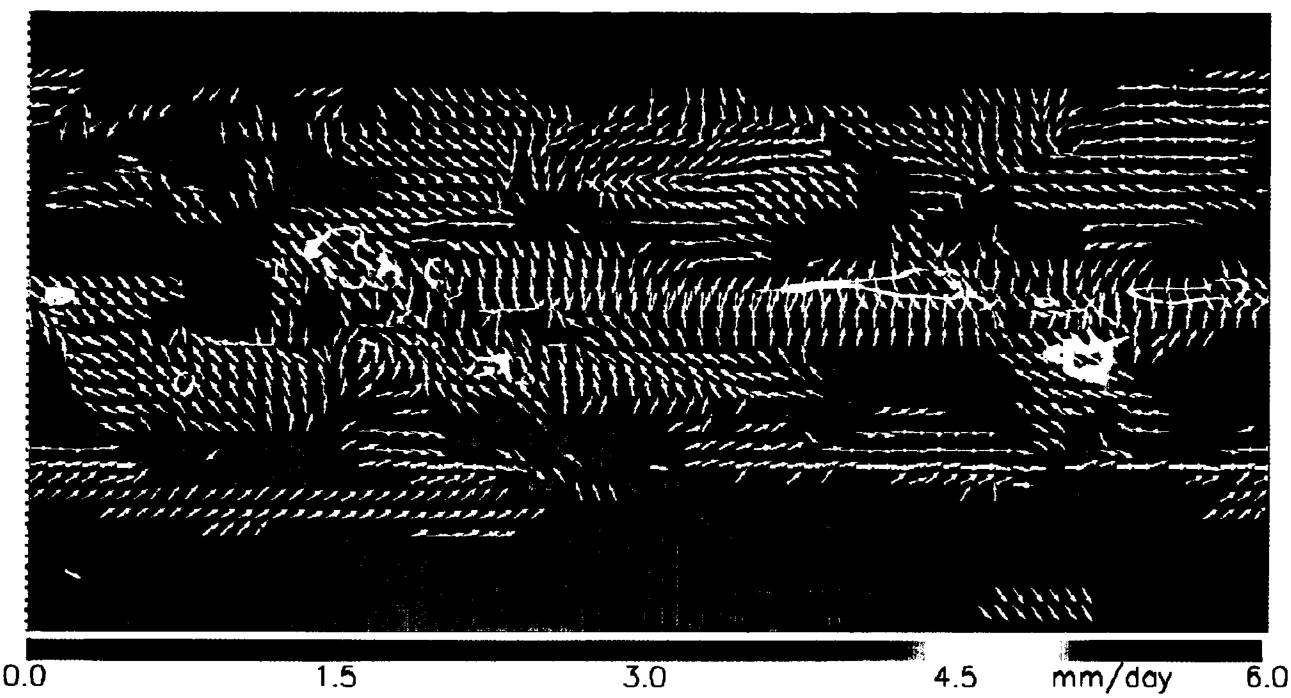




a) January
b) April
c) July
d) October
0.0
2.5
5.0
7.5
mm/day
10.0

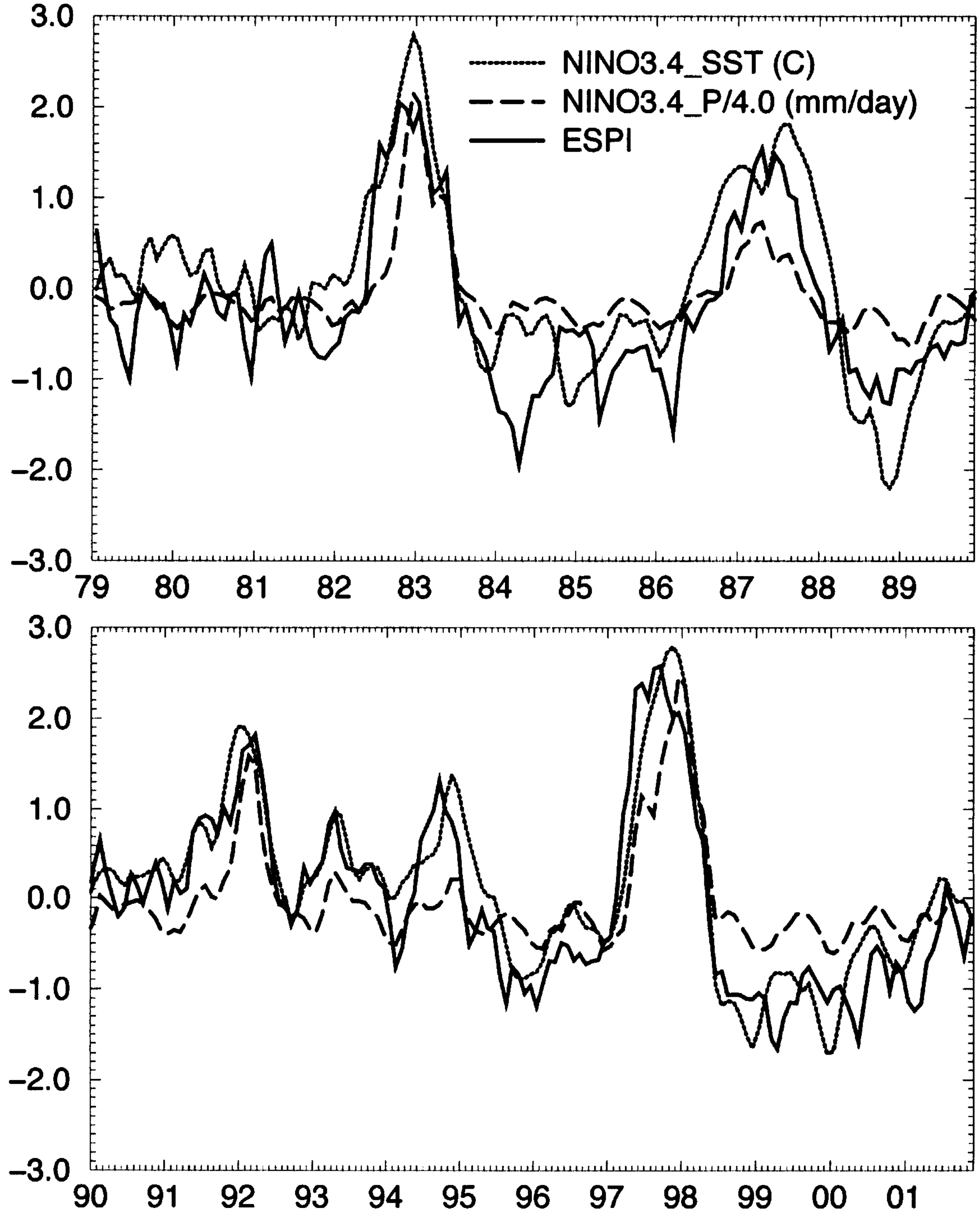


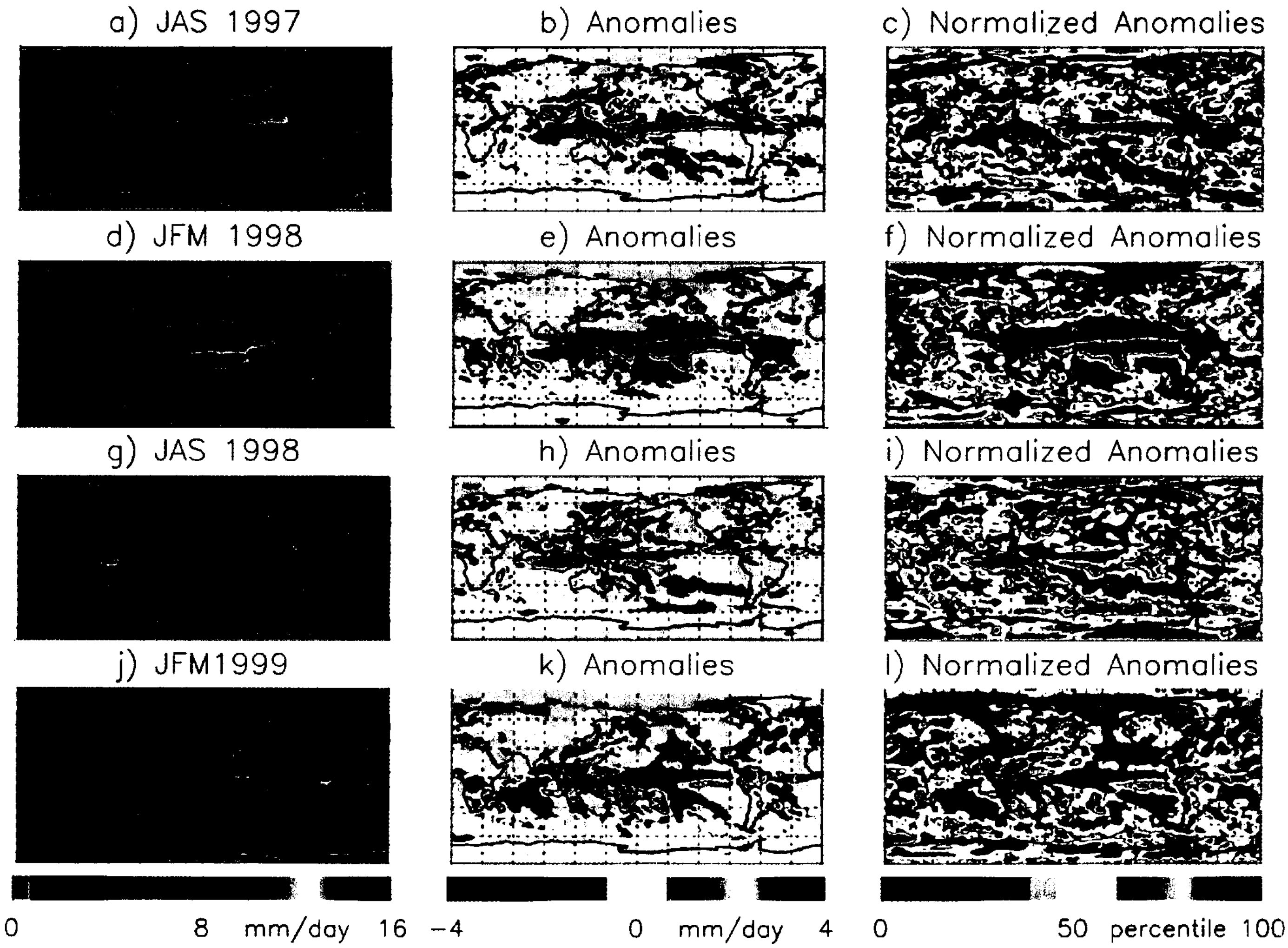
TOTAL
OCEANS
LAND
90N
70N
50N
30N
10N
10S
30S
50S
70S
JAN MAR MAY JUL SEP NOV JAN MAR MAY JUL SEP NOV
2
4
8
(mm day-1)

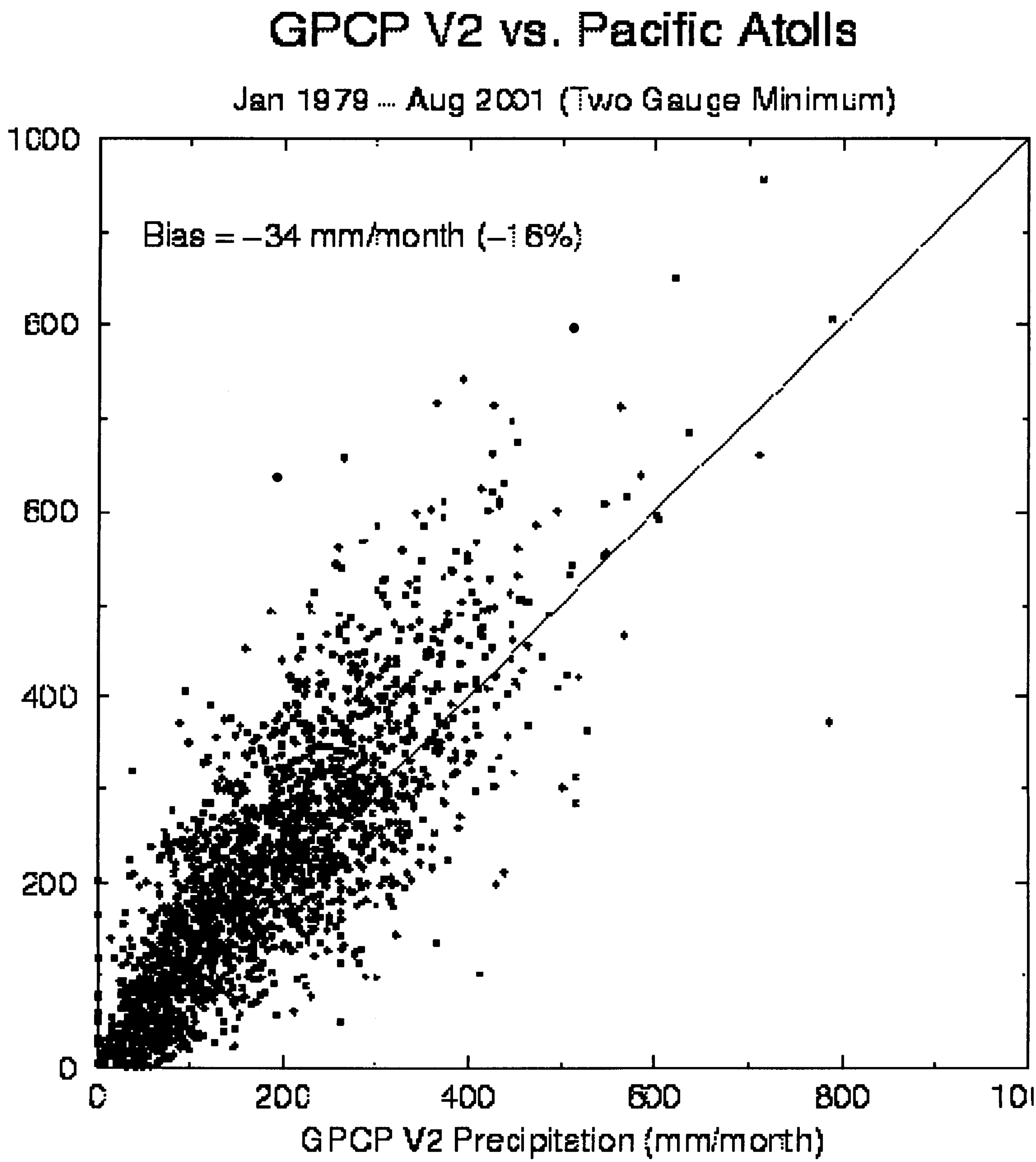

0.0
1.5
3.0
4.5
mm/day
6.0

Bimonthly ENSO Indices

1979–2001

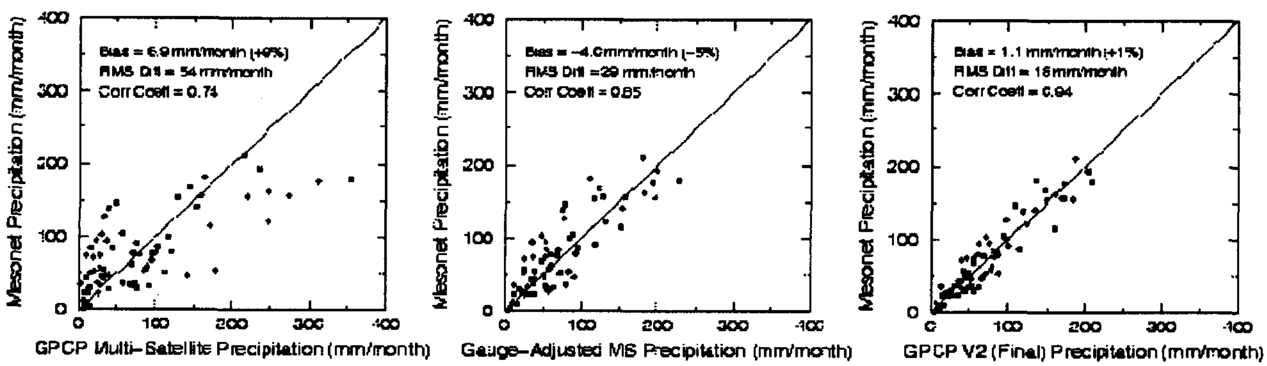


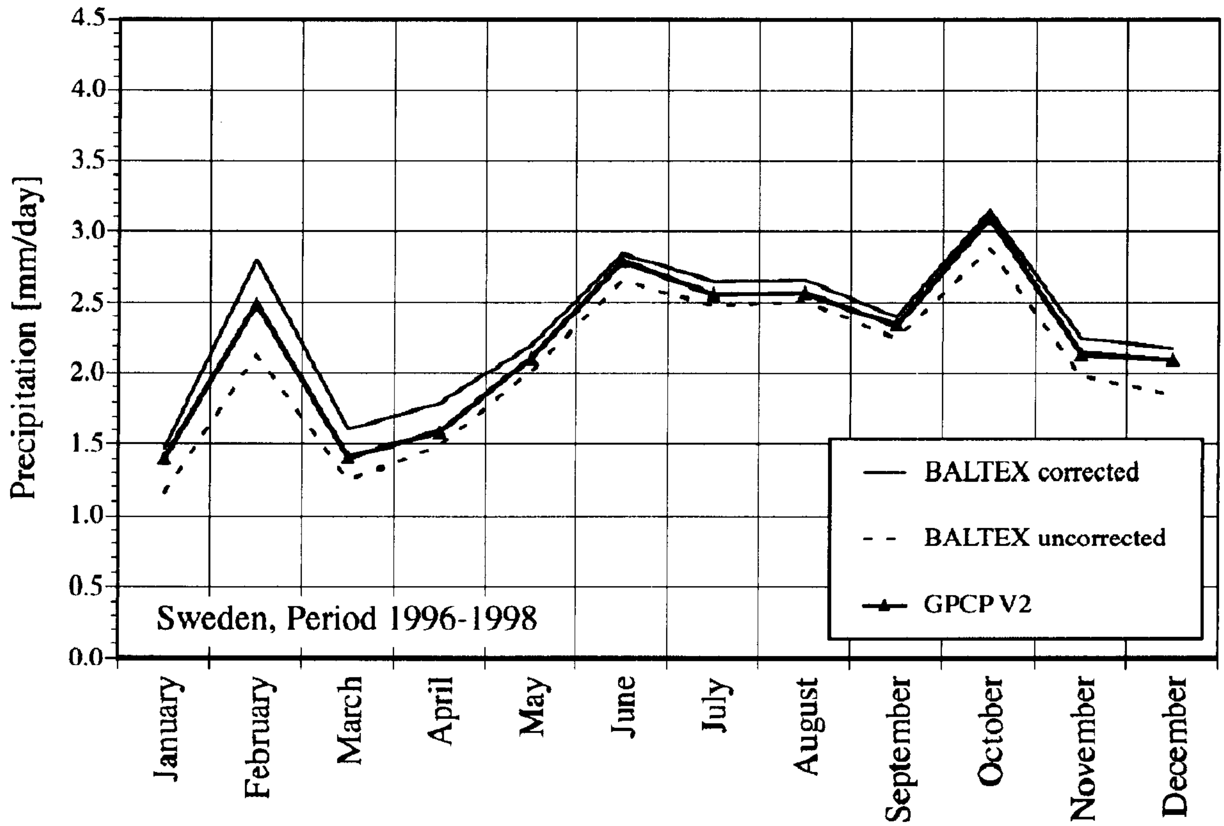

a) JAS 1997
b) Anomalies
c) Normalized Anomalies
d) JFM 1998
e) Anomalies
f) Normalized Anomalies
g) JAS 1998
h) Anomalies
i) Normalized Anomalies
j) JFM1999
k) Anomalies
l) Normalized Anomalies
0 8 mm/day 16
-4 0 mm/day 4
0 50 percentile 100


GPCP V2 vs. Pacific Atolls
Jan 1979 ... Aug 2001 (Two Gauge Minimum)
Bias = −34 mm/month (−16%)
1000
800
600
400
200
0
0
200
400
600
800
10
GPCP V2 Precipitation (mm/month)

GPCP vs. Oklahoma Mesonet

1998 – 2000 (Two 2.5-Degree Boxes)





4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Precipitation [mm/day]
Sweden, Period 1996-1998
BALTEX corrected
BALTEX uncorrected
GPCP V2
January
February
March
April
May
June
July
August
September
October
November
December

90N-90S Average (1979-01)

Surface	GPCP Version 2	Willmott	Jaeger
Ocean	2.84	3.50	2.89
Land	2.09	2.32	2.13
Total	2.61	3.13	2.65

30N-30S Average (1979-01)

Surface	GPCP Version 2	Willmott	Jaeger
Ocean	2.94	3.80	3.08
Land	2.89	2.86	2.76
Total	2.93	3.53	2.99

GPCP Version 2: Northern Hemisphere / Southern Hemisphere

Surface	90N - 90N	0 - 90N	0 - 90S
Ocean	2.84	3.17	2.62
Land	2.09	1.93	2.46
Total	2.61	2.64	2.58

GPCP Version 2: Latitude Bands

Surface	90N - 30N	30N - 0	0 - 30S	30S - 90S
Ocean	2.86	3.38	2.55	2.68
Land	1.58	2.53	3.35	1.06
Total	2.16	3.11	2.75	2.42

The Version 2 Global Precipitation Climatology Project (GPCP)
Monthly Precipitation Analysis (1979-Present)

Robert F. Adler, George J. Huffman, Alfred Chang, Ralph Ferraro, Ping-Ping Xie, John Janowiak, Bruno Rudolf, Udo Schneider, Scott Curtis, David Bolvin, Arnold Gruber, Joel Susskind, and Philip Arkin

POPULAR SUMMARY

Global precipitation information is important for understanding how water cycles through the atmosphere, leading to better weather forecasts and preparedness for climate changes. There are many sources of rainfall data. Rain gauges provide good measurements over land, but several satellites are also observing precipitation as they orbit around the Earth. The ideal strategy is to combine these different measurements, in such a way as to take advantage of their individual strengths, in order to come up with the best estimates of global precipitation. The Global Precipitation Climatology Project (GPCP) is an international group of scientists that have come together to achieve this goal. This paper describes the techniques used in the analysis and their Version 2 monthly data set, which is an improvement over an earlier Version 1. Additional data sources have allowed Version 2 to be globally complete and extend back to 1979. The paper uses the new analysis to describe the climatology of global rainfall, the seasonal cycle, variations related to El Niño, and long-term trends or changes. Finally, the authors make suggestions for improvements in future versions - one of those being the addition of the high quality Tropical Rainfall Measuring Mission (TRMM) data.

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