LONG-TERM TREND OF GLOBAL LAND PRECIPITATION: UNCERTAINTIES IN GAUGE-BASED ANALYSES

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1. INTRODUCTION

An important aspect in global climate changes, long-term trend of surface temperature and precipitation has traditionally been examined using station observations (e.g. Karl et al. 1993; Lamb and Peppler, 1991). While analysis of quality-controlled historical records at carefully selected stations yields quantitatively accurate results over the station locations, information on spatial distribution of the long-term trend is needed for many applications such as numerical model verifications and water resource planning.

In recent years, several sets of analyzed fields of global land precipitation have been constructed by interpolating gauge observations (e. g. Dai et al. 1997; New et al. 2000; Chen et al. 2002). With quasi-complete spatial coverage and multi-decade time periods, these data sets are potentially very useful in examining the spatial distribution of long-term trend in the global land precipitation.

Uncertainties, however, exist in the long-term trends derived from these analyzed fields of precipitation due to changes in the configuration of gauge networks throughout the data period. Fig. 1 displays the spatial distribution of available gauge stations for four selected months (Julys of 1948, 1970, 1995, and 2000) used to define the monthly precipitation analysis of Chen et al. 2002 (see Section 2 for details). Substantial differences are observed in gauge networks for different times. Collected from archives of Global Historical Climatology Network (GHCN) of NOAA/NCDC and the Climate Anomaly Monitoring System (CAMS) of NOAA/CPC, the coverage of gauge network is quite good over most regions during 1950s and 1960s. Number of gauge reports presents gradual decrease from later 1970s to mid 1990s. Only monthly reports from ~3000 CAMS stations are available after 1997. These changes in gauge network configuration may yield time-changing bias in the gauge-based analyses, creating aliases in the long-term trends computed from them.

The objective of this work is to describe the global features of long-term trend of precipitation using gauge-based analysis over land and to explore ways of quantifying the uncertainties in the long-term trend derived from the gauge-based analyses due to the changes of gauge network.

2. DATA

Gauge-based analysis of Chen et al. (2002) is used in this study to examine the long-term trend and its uncertainties. Called PREC/L (Precipitation REConstruction over Land), analyzed fields of monthly precipitation are constructed on a 2.5^o lat/lon grid over the global land areas for a 56-year period from 1948 to the present. The analyzed values of monthly precipitation are calculated by interpolating station observations through the Optimal Interpolation (OI) technique of Gandin (1965). Monthly station observations collected from two individual data sets, the Version 2 data set of the Global Historical Climatology Network (GHCN) of NOAA National Climatic Data Center (NCDC) and the precipitation data set of the Climate Anomaly Monitoring System (CAMS) of NOAA Climate Prediction Center (CPC), are used in the interpolation.

3. TREND UNCERTAINTIES OVER THE SAHEL REGION

Before examinations of the uncertainties in precipitation trend are performed over the global domain, two sets of experiments are conducted

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for the Sahel region where significant drying trend in precipitation is reported during recent decades. Fig. 2 shows the time series of number of reporting stations over the region from 1911 to 2003. Relatively good gauge coverage is available from 1930s to 1970s.

In the first set of experiments, we targeted on a 50-year period from 1931 to 1980 when the gauge availability is the best over the region. Monthly reports at stations with 80% or higher reporting rates over the 50-year period are used to define the 'standard' analyses of monthly precipitation. In the meantime, ten addition sets of gauge-based analyses are constructed for the same period using gauge observations at stations available at 1911, 1921, …, and 2001. These 10 sets of gauge-based analyses are then compared with the 'standard' data set to examine how changes in gauge network configuration may alter the long-term trend computed. Two different algorithms, the Optimal Interpolation (OI) method of Gandin (1965) and the technique of Shepard (1968), are used to create the gauge-based analyses described above to get insights into how sensitive the resulting trend is to different interpolation strategies. In the OI technique, analyses of total monthly precipitation is defined by modifying the analyzed fields of monthly climatology by anomaly interpolated from nearby station observations. In the Shepard (1968) algorithm, meanwhile, the total precipitation is defined by directly interpolating the total precipitation at neighboring stations.

Figure 3 shows time series of areal mean precipitation of the analyses for June to September from 1931 to 1980 over the Sahel region. Red line shows the mean values calculated from the 'standard' analysis while blue shading indicates range of root mean square differences (RMSD) between the 'standard' analysis and the 10 sets of analyses based on different gauge networks. Figure 4 displays spatial distribution of mean precipitation (a&b), linear trend (c&d), RMSD of trends (e&f), and relative RMSD (g&h) calculated from the OI- (left panels) and the Shepard-based analyses (right panels) over the 50-year period.

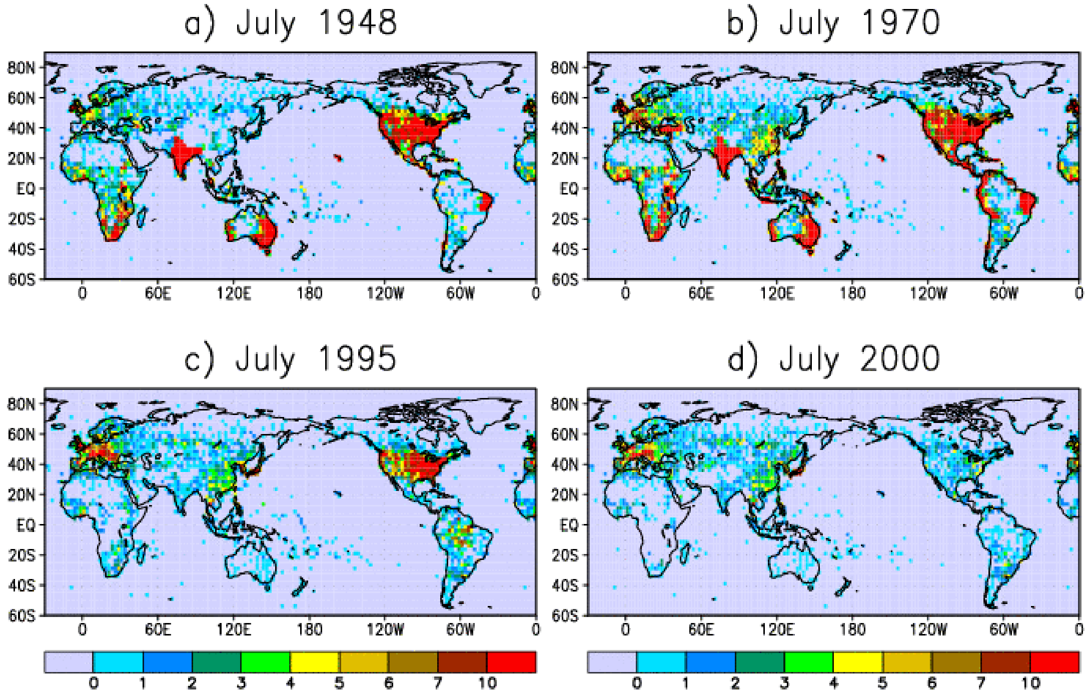

FIG. 1. Spatial distribution of the number of available gauges at each 2.5^{o}lat/lon grid box used to define the PREC/L analysis for four selected months of July of 1948 a), 1970 b), 1995 c), and 2000 d).

Mean precipitation derived from various gauge networks are very close and show similar drying trends through the 50-year period. The magnitude of alias in trend caused by changes in gauge network configuration is much less than that of the trend itself over the Sahel region. The analyses based on OI present more stable magnitude than the Shepard.

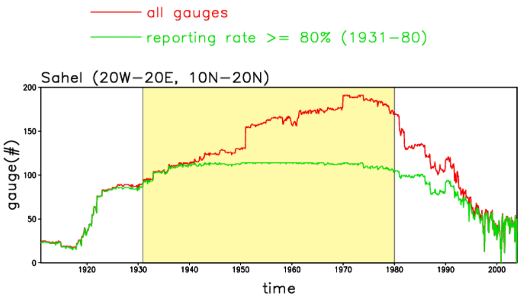

FIG. 2. Time series of the number of reporting stations from 1911 to 2003 over the Sahel region. Red line is the number of all reporting stations and green is the number of stations with the reporting rates of 80% or higher during 1931-1980.

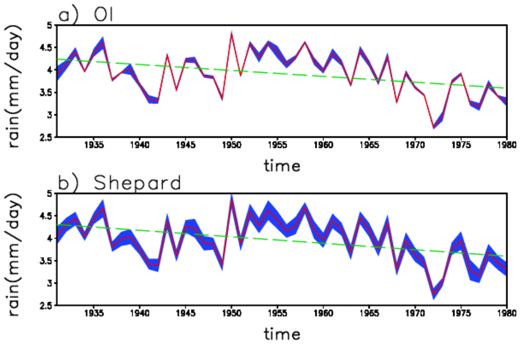

FIG. 3. Time series of areal mean precipitation for June-September from 1931 to 1980 calculated from the 'standard' analysis(red line). Also shown (blue shading) is the range of the RMSD between the 'standard' analyses and the 10 additional analyses based on different gauge networks. Results for OI- and Shepard-based analyses are shown in the top and bottom panels, respectively.

The second set of experiments is designed to examine the trend and its uncertainties over the Sahel region for a 56-year period from 1948 to 2003 for which our gauge-based analyses of PREC/L are available. A different approach is undertaken to examine how much the uncertainties might be in the current version of our PREC/L analysis which utilizes all available gauge reports. Linear trend in annual precipitation is first calculated from the PREC/L data set for the 56-year period. Assuming that the trend at a station is the same as that at the grid box where the station is located, analyzed fields of trend is re-interpolated from station values with gauge networks for each of the 56 year period. Figure 5 presents the calculated trend and station distribution for several selected networks. In general, the resulting trends present very similar spatial distribution patterns and close magnitude even when very sparse gauge network, such as that available for year 2000, is used. Spatial distribution patterns are smoother and the magnitude is reduced over regions with poor gauge coverage.

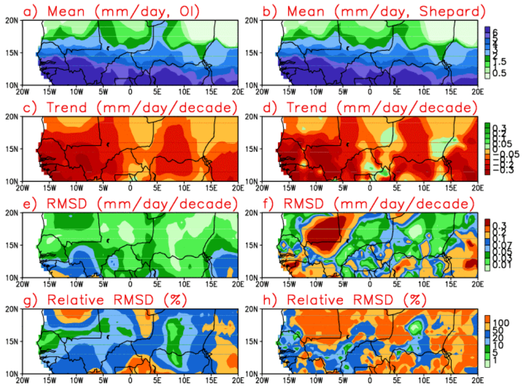

FIG. 4. Spatial distributions of the mean precipitation (a&b), linear trend (c&d), RMSD of trends (e&f), and relative RMSD (g&f) for a 50-year period from 1931 to 1980. Results for the OI- and Shepard-based analyses are shown in the left and right panels, respectively.

4. TREND UNCERTAINTIES OVER THE GLOBAL LAND

Due to the regional differences in the gauge availability through the data period, it is very time consuming to repeat the first set of experiments for the Sahel for the global land areas. Only the second set of the experiments are conducted over the global land areas to examine the uncertainties in precipitation trend (Fig. 6).

Major increasing trends are observed over the US, northwest of Australia, and Argentina, while drying trend appears over the South Africa, the southeast of Asia, the east of Australia, and over most of tropical regions such as the equatorial Africa and Sahel region. Similar patterns are reported in several published work based on gauge analyses (e.g., Dai et al. 1997; New et al. 2000).

Uncertainties in the precipitation trend due to the changes of gauge networks, as indicated by the RMSD of trends, are smaller over regions with stable networks (e.g. US) and greater over regions with poor and changing gauge coverage (e.g. around Angola and Congo in central Africa). Overall, calculated trends are significant over 95% confidence level over most regions.

5. SUMMARY

Spatial distribution of long-term trend in annual mean precipitation has been described using the PREC/L gauge-based analysis for a 56-year period from 1948 to 2003 over global land areas.

Uncertainties in the calculated trend have been examined in respect to the changes of gauge network configuration through the data period as well as interpolation algorithms.

Alias exists in the calculated trend due to the changes in gauge networks, but its magnitude is much less than that of the trend itself over most of the global land areas.

Compared to the Shepard algorithm, the Optimal Interpolation (OI) technique yields precipitation analysis with less aliases in long-term trend due to the gauge network changes.

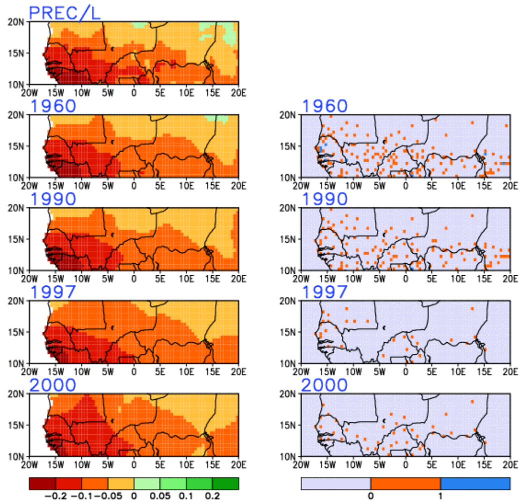

FIG. 5. Spatial distributions of the trend calculated from the PREC/L (the left top panel) and trends re-interpolated from the selected gauge networks available for years 1960, 1990, 1997, and 2000 (the rest of the left panels). Shown in the right panels are the corresponding gauge networks.

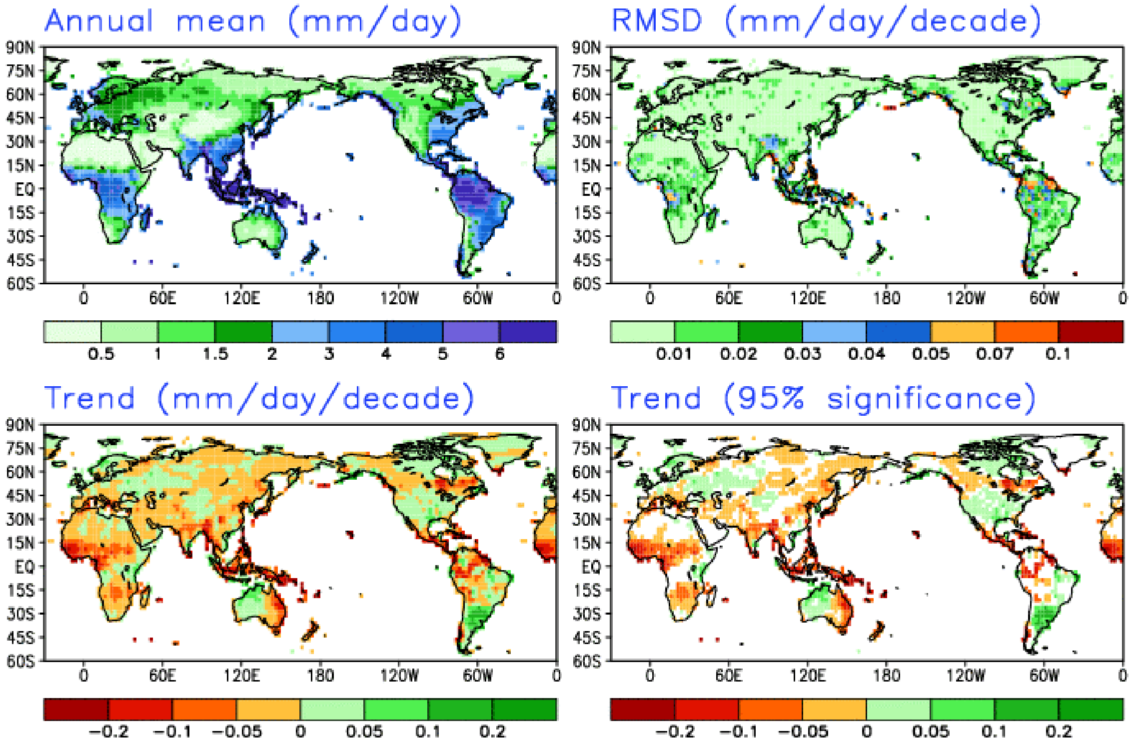

FIG. 6. Spatial distributions of annual mean precipitation for a 56-year period of 1948 – 2003 as calculated from the PREC/L (top left); linear trend over the 56-year period (bottom left); RMSD of the trends (top right); and linear trend significant at 95% confidence level based on a simple F-test (bottom right).

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