On the Remapping Procedure of Daily Precipitation Statistics and Indices Used in Regional Climate Model Evaluation

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ABSTRACT

Gridded estimates of precipitation using both satellite and observational station data are regularly used as reference products in the evaluation of basic climate fields and derived indices as simulated by regional climate models (RCMs) over the current period. One of the issues encountered in RCM evaluation is the fact that RCMs and reference fields are usually on different grids and often at different horizontal resolutions. A proper RCM evaluation requires remapping on a common grid. For the climate indices or other derived fields, the remapping can be done in two ways: either as a first-step operation on the original field with the derived index computed on the final/common grid in a second step, or to compute first the climate index on the original grid before remapping or regridding it as a last-step operation on the final/common grid. The purpose of this paper is to illustrate how the two approaches affect the final field, thus contributing to one of the Coordinated Regional Climate Downscaling Experiment (CORDEX) in Africa (CORDEX-Africa) goals of providing a benchmark framework for RCM evaluation over the West Africa monsoon area, using several daily precipitation indices. The results indicate the advantage of using the last-step remapping procedure, regardless of the mathematical method chosen for the remapping, in order to minimize errors in the indices under evaluation.

1. Introduction

International projects, such as the Coordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi et al. 2009), use ensembles of regional climate model (RCMs) simulations with the primary objective of producing climate change projections at high resolution. Before using these models for climate change studies, a first assessment is required to evaluate their skill at reproducing the observed present climate. Lately, an increasing number of studies have been dedicated to evaluate the model ability to simulate not

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only the climatic mean, but also temporal variability and climate extremes. This is usually done by comparing simulated fields against gridded datasets of observations from stations or satellite estimates, and this requires remapping the fields on a common grid. The method employed to bring the observational products and the model on the same grid can affect the resulting fields and may therefore alter the evaluation process.

Two questions are related to the remapping procedure:

- Which mathematical method constitutes the most appropriate procedure to be used in remapping observations and models on a common grid?
- How must the selected method be applied in the process of computation of derived products such as temporal standard deviation and climate indices?

Most of the recent studies focus on the first question, and those mainly concern the precipitation field (e.g., Osborn and Hulme 1997; Booij 2002; Fowler et al. 2005; Haylock et al. 2008; Hofstra et al. 2010; Booij and de Wit 2010). The precipitation remapping constitutes a problematic issue because of the difference in the scales of the model-simulated precipitation and the local station measurements, referred to as the scale issue: station precipitation corresponds to a point value, while simulated precipitation represents an area-average value over a grid box (Zhang et al. 2011). Several studies have evaluated the optimum method to aggregate daily precipitation characteristics from station to area (e.g., Osborn and Hulme 1997; Booij 2002; Fowler et al. 2005). The gridbox area average of station observations is often suggested as the best procedure. To help with the evaluation effort of climate model simulations, several centers now provide gridded datasets of observed daily precipitation from gauge measurements, made available on different regular spatial grids (e.g., Haylock et al. 2008). On the other hand, for regions with a sparse network of stations, such as in central West Africa (CWA), the evaluation is usually done using satellite estimates (e.g., Sylla et al. 2013; Diaconescu et al. 2015). Here, the concern is also that observations and models must have the same spatial scales. This is usually resolved by remapping the finer-grid dataset on the coarser-resolution grid using an aggregation remapping method (e.g., gridbox average, conservative remapping). For remapping on grids with a similar spatial resolution, most studies use bilinear interpolation (e.g., Kalognomou et al. 2013; Nikulin et al. 2012; Gbobaniyi et al. 2014) and distance-weighted-average remapping (e.g., Eum et al. 2012).

No matter what mathematical method is used for remapping the fields, for derived fields such as the daily precipitation temporal standard deviation and other indices, the remapping can be done using two different procedures:

- the last-step procedure, where the statistics and climate indices are computed from the fields directly on the native grid and then interpolated on the destination grid, and
- the first-step procedure, where the fields are first interpolated on the destination grid, and then the statistics and climate indices are calculated.

Currently, there is no consensus about which procedure is the most appropriate in the evaluation of model climate indices. It may seem obvious that the remapping should be done as a last-step operation, after computing the derived field. On the other hand, in practice it is appealing to first interpolate all the fields on a common grid before calculating the statistics and the climate indices (the first-step procedure), especially in intercomparison studies of simulations from several models with different computational grids (e.g., Loikith et al. 2015; Mehran et al. 2014). Some studies have adopted the first-step procedure in evaluating climate indices (e.g., Chen and Knutson 2008; Bootsma et al. 2005; DeAngelis et al. 2013), while others have chosen the last-step procedure (e.g., Sillmann et al. 2013; Bhowmik and Costa 2014; Sunyer et al. 2013; Diaconescu et al. 2015). Other studies do not even mention the procedure used (e.g., Tencer et al. 2014; Sylla et al. 2013).

The main objective of our study is to evaluate the effect of first- versus last-step remapping procedures on daily precipitation statistics and indices over CWA. This study aims to contribute to one of the CORDEX in Africa (CORDEX-Africa) project goals to provide a benchmark framework for RCM evaluation and assessment. In the following, section 2 presents the datasets and methods, and section 3 presents the results. Concluding remarks are included in section 4.

2. Datasets and methods

This paper analyzes the effect of the remapping procedure on daily precipitation statistics and indices over CWA, a region spanning from 10°S to 30°N and from 20°W to 20°E (see Fig. 1), using three sets of satellite estimates that also integrate observations from rain gauge stations and are often employed in evaluation studies over this region (e.g., Nikulin et al. 2012; Sylla et al. 2013; Kalognomou et al. 2013; Diaconescu et al. 2015):

- The Africa Rainfall Climatology, version 2 (ARC2; Novella and Thiaw 2013), daily precipitation estimates from the Climate Prediction Center provide daily data from 1983 to present on a 0.1° horizontal grid mesh.

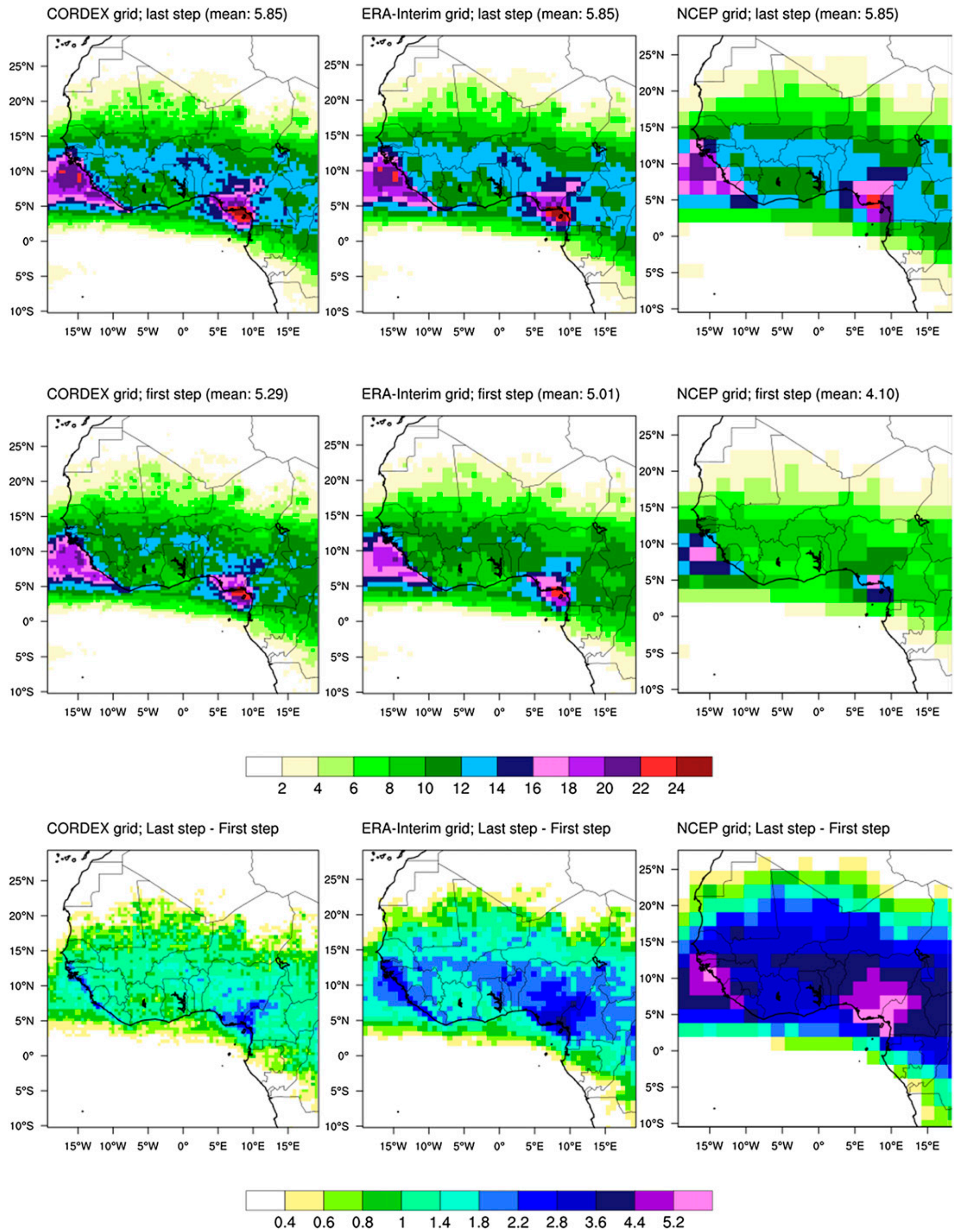

FIG. 1. Comparison of the JJAS 1998–2008 daily precipitation temporal std dev (mm day^{-1}) for TRMM remapped on the (left) 0.44° CORDEX-Africa, (middle) ERA-Interim, and (right) NCEP grids using the first-order conservative remapping methods. Shown are (from top to bottom) the fields obtained with the last- and first-step remapping procedures and the differences between the last- and first-step procedures.

- The Tropical Rainfall Measuring Mission (TRMM) 3B42, version 6 (Huffman et al. 2007), dataset provides 3-hourly precipitation data since 1998 on a 0.25° horizontal grid mesh.
- The Global Precipitation Climatology Project (GPCP) daily precipitation dataset (GPCP-1DD, version 1.2; Huffman et al. 2001) is available from late 1996 to present on a 1° horizontal grid mesh.

TABLE 1. CWA spatial mean and variance of the TRMM temporal std dev field of daily precipitation on the original grid and remapped using the conservative method on the 0.44° CORDEX-Africa, 0.75° ERA-Interim, and T62 Gaussian (~2°) NCEP grid, from the first- and last-step procedures.

		Last-step procedure			First-step procedure		
TRMM	Original	CORDEX-Africa grid	ERA-Interim grid	NCEP grid	CORDEX-Africa grid	ERA-Interim grid	NCEP grid
Spatial mean (mm day^{-1})	5.91	5.94	5.94	5.93	5.37	5.09	4.16
Spatial variance (mm day^{-1})^2	32.94	32.64	32.48	31.68	27.21	24.46	16.58

The ARC2 and TRMM datasets have spatial grids much finer than the 0.44° CORDEX-Africa grid. Consequently, they are remapped on the 0.44° CORDEX-Africa grid with the first-order conservative remapping method, using Climate Data Operators (https://code.zmaw.de/projects/cdo), as used in recent CORDEX-Africa analyses (e.g., Nikulin et al. 2012; Kalognomou et al. 2013). Because reanalysis datasets are also regularly used in RCM evaluations, the ARC2 and TRMM datasets are also interpolated on the ECMWF interim reanalysis (ERA-Interim; Dee et al. 2011) grid (0.75°) and on the NCEP–DOE AMIP-II reanalysis (hereafter referred to as NCEP; Kanamitsu et al. 2002) grid (~2°). This will also allow for analyzing whether the resolution of the destination grid has an impact on the results and will bring important information for studies where the interpolation on global climate model (GCM) grids is also required. Because GPCP data have a coarse spatial resolution, they will only be interpolated on the NCEP grid (the GPCP–RCM comparison is usually done by remapping the finer-resolution RCM on the coarser-resolution GPCP grid). The analysis is made over the Sahel rainy season [June–September (JJAS)] within the CWA region and over the common period 1998–2008. Some examples with the bilinear and distance-weighted-average approaches are also presented, along with the conservative remapping technique to evaluate the influence of the interpolation methods.

3. Results

First, we present the effect of the two remapping procedures on daily precipitation statistics. For the 1998–2008 seasonal means, the two remapping procedures must give the same results because the remapping methods rely on spatial means, and the temporal and spatial operations can commute. The results are different for the temporal standard deviation (std dev) field, which involves nonlinear operations. Figure 1 illustrates the case of TRMM std dev of daily rainfall, computed for the 1998–2008 JJAS period and remapped on the 0.44° CORDEX-Africa, ERA-Interim, and NCEP grids using the first- and last-step procedures, along with the differences between the two procedures. The remapping is done over the entire Africa domain using the conservative method. Differences between the std dev fields depend on the destination-grid resolution. For the NCEP grid, the differences between the two procedures are larger than 5.2 mm day^{-1} where maximum std dev values occur. While for the last-step procedure, the field presents similar maxima for the three grids, the first-step procedure reduces them, the reduction being more pronounced for the NCEP grid.

To find out which of the two procedures gives results most suitable for the RCM evaluation, we analyze which of them best preserves the distribution of the nonremapped field. This means that the remapped std dev field over the region of interest must be similar to the case when the std dev is computed on the original grid. Table 1 presents the comparison of the spatial mean and variance between the original-grid std dev and the ones from the remapped two-step procedures (using the conservative remapping method). The fields remapped at the last step present very similar mean and variance values with respect to the original field for all destination-grid resolutions. However, if the conservative remapping is done as a first-step procedure on the daily precipitation field, the std dev fields present smaller variances and spatial means, the differences increasing with coarsening of the destination grid. On the other hand, the std dev field obtained with the first-step remapping on the NCEP grid lost half of the original field spatial variance. Thus, care must be taken when GCM climate fields, with a similar or coarser resolution than NCEP, are compared to very high–resolution gridded observations or at the scale of RCM grids (0.44° or finer).

Similar results are also obtained when other observational datasets are used. An example is presented in Fig. 2 (left) in terms of quantile–quantile (Q–Q) plots using all grid points located over CWA for the ARC2, TRMM, and GPCP std dev field. The diagrams compare the remapped std dev with the two procedures, the last-step procedure represented by points in magenta, red, and brown for the CORDEX-Africa, ERA-Interim, and NCEP grids, respectively; and the first-step procedure

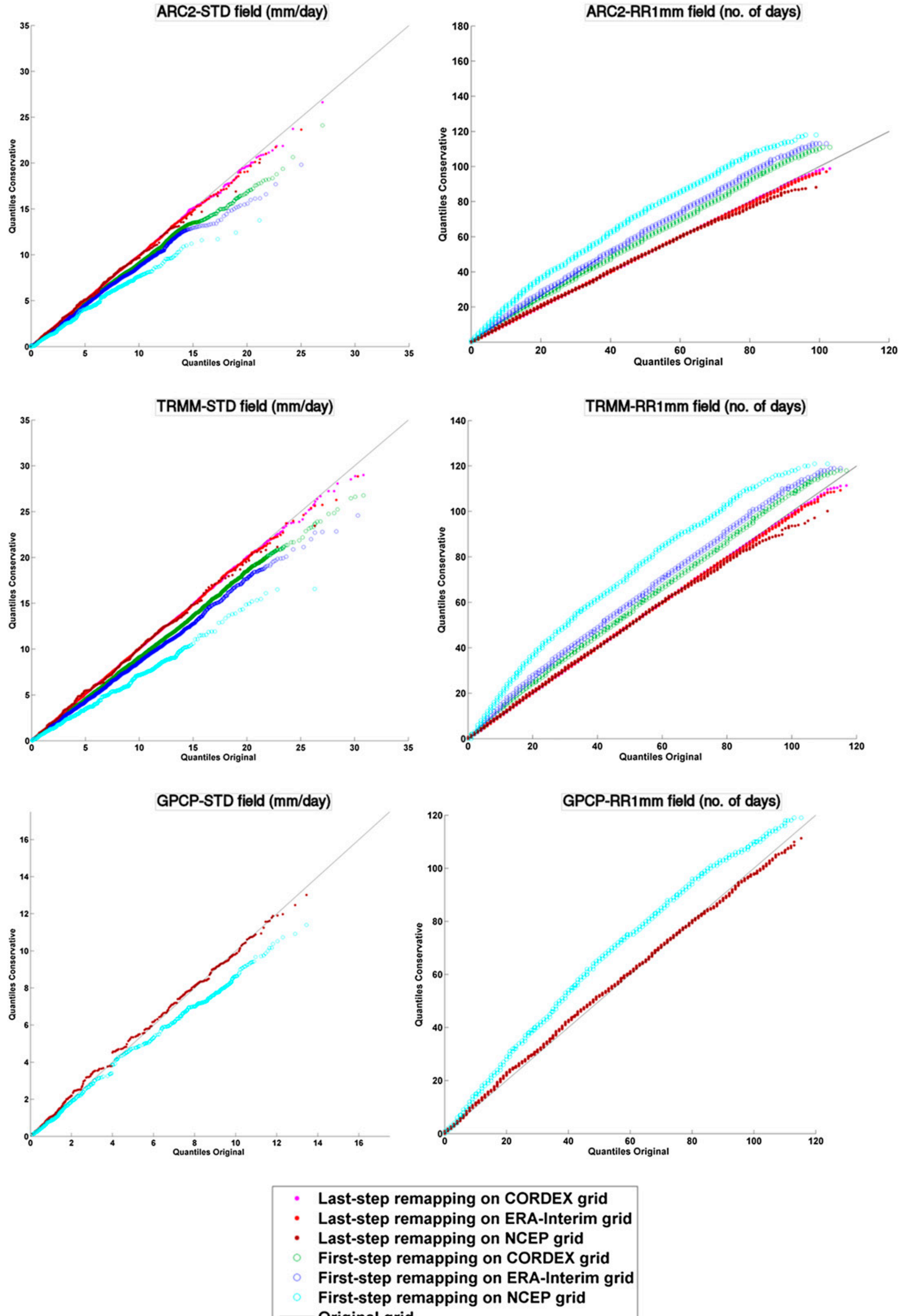

FIG. 2. Quantile–quantile comparison of the JJAS 1998–2008 temporal (left) std dev and (right) RR1mm index of the (from top to bottom) ARC2, TRMM, and GPCP datasets, obtained with the conservative remapping method (on y axis) or with the original ARC2, TRMM, and GPCP fields (on x axis).

represented by green, blue, and cyan circles, all with respect to the original field. If the remapping preserved the original distribution of the field as it should, the quantile values of the remapped field would follow the gray diagonal line. The overall picture shows that for all three datasets, the std dev computed with the last-step procedure best preserves the spatial distribution of the original-grid std dev, while the std dev obtained with the first-step procedure systematically reduces higher-quantile values. If the remapping is done at the final step, the differences between the remapped and the original std dev are relatively small. However, if the field is computed after remapping the daily precipitation, the initially small differences derived from the interpolation of the daily fields will increase with the computation of the std dev on the final grid.

Climate indices are also affected by the order of operations, especially when thresholds are involved. Figure 2 (right) presents the Q–Q plots for the number of wet days defined as days with at least 1 mm day^{-1} of precipitation (RR1mm) during JJAS, remapped using the conservative method. As for the temporal std dev, the last-step remapped RR1mm indices best preserve the spatial distribution of the original-grid values, while the first-step remapped RR1mm indices have higher values for almost all quantiles for all destination grids. There are locations where the differences in the RR1mm indices computed with the two procedures are larger than 15 days when the remapping is done on the CORDEX-Africa grid, 20 days for the ERA-Interim grid, and 30 days for the NCEP grid.

Other climate indices are affected as well. Figure 3 presents how the two procedures of remapping affect the longest period of consecutive wet days (CWD) in JJAS (where wet days are defined as for the RR1mm index); the highest amount of daily precipitation (RX1day); the RR1mm index; and the total amount of seasonal precipitation exceeding the daily precipitation 99th percentile, computed from the TRMM dataset. The comparison is done in terms of spatial mean and standard deviation over the CWA region, with each panel presenting the values for the nonremapped original field (black solid line) and for the last- (solid lines) and first-step (dotted lines) remapped fields, using conservative, bilinear, and distance-weighted remapping methods. Whatever the remapping method and the four precipitation indices, the last-step remapped fields have spatial means and std dev values over the domain, closer to the original-grid fields than the first-step procedure. The first-step procedure tends to smooth the original field by increasing the minima and decreasing the maxima of the field on which it is applied. When the remapping is applied initially on the daily precipitation field, the average operation increases the number of days with low intensity and diminishes the number of days with large intensity compared to the original field. Therefore, indices that are based on low-intensity thresholds (i.e., RR1mm and CWD) will have increased values compared to the original field, while indices based on high-intensity thresholds (i.e., the 99th percentile) will have reduced values compared to the original field when the first-step procedure is used. If the remapping is applied at the last step, the single effect consists of a small decrease in the spatial variance of the field (Fig. 3, right). The nearest-neighbor remapping method (not shown here) does not use any mean operation. Consequently, for this method, the last- and first-step remapping procedure will give the same results for all climate indices. However, this remapping method is never used in precipitation evaluation because it does not address the spatial-scale issue.

The CWA is known as a region with important differences between the TRMM, GPCP, and ARC2 datasets (see Diaconescu et al. 2015). Our analysis showed that derived fields remapped at the last step on the common grid keep the statistical properties of the original field. Therefore, it is expected that the uncertainty between the last-step-interpolated observational fields will be the same as between the original-grid fields. On the other hand, the first-step procedure can increase or decrease the uncertainty between the original fields. This is exemplified in terms of differences between the CWA spatial means of the TRMM and ARC2 indices, in Fig. 4 (left), and of the TRMM and GPCP indices in Fig. 4 (right). Figure 4 shows the differences between the CWA spatial means of fields on their original grids in black; between the last-step remapped fields in blue, red, and green solid lines; and between the first-step remapped fields in blue, red, and green dotted lines. The remapping is done on the CORDEX-Africa grid for the TRMM–ARC2 comparison and on the ERA-Interim grid for the TRMM–GPCP comparison. As expected, the differences between the last-step remapped fields are similar to that between fields on the original grid. If the field is remapped using the first-step procedure, the CWD and RR1mm indices present increased differences between the spatial means for the bilinear and distance-weighted-average methods, while the differences for the RX1day and seasonal precipitation exceeding the daily precipitation 99th percentile are smaller than in the original fields. In other words, the first-step procedure affects the uncertainty in observations differently, according to the considered index.

4. Concluding remarks

The purpose of this study was to analyze the effect of the last- and first-step remapping procedures on precipitation

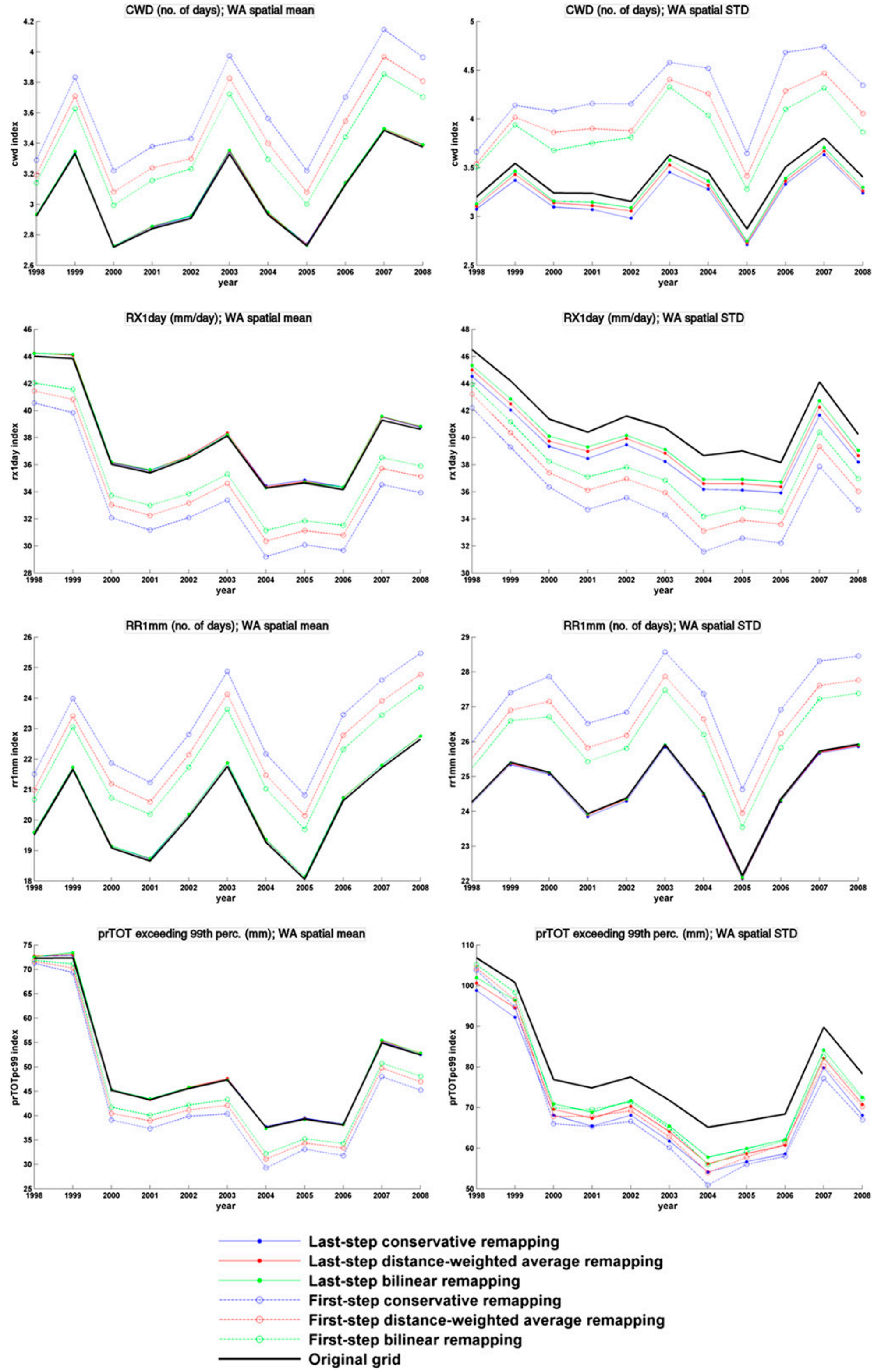

FIG. 3. Interannual variation of the JJAS 1998–2008 spatial (left) mean and (right) std dev CWD, RX1day, RR1mm, and total JJAS precipitation exceeding the 99th percentile indices for the TRMM dataset regridded on the CORDEX-Africa grid using conservative (blue), distance-weighted (red), and bilinear (green) remapping methods, and the corresponding indices computed on the TRMM original grid (black).

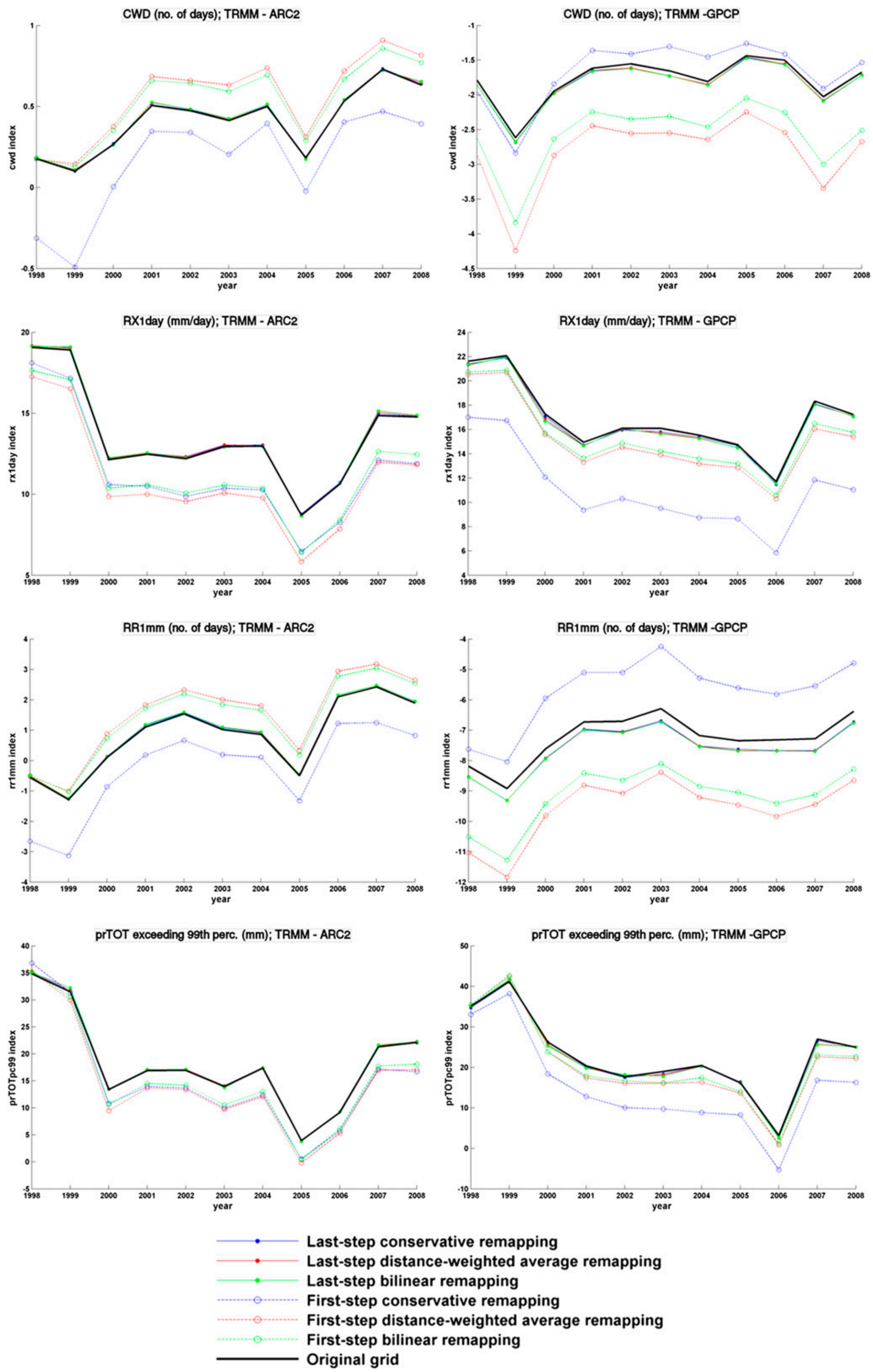

FIG. 4. Time evolution of the differences between TRMM and (left) ARC2 or (right) GPCP CWA spatial mean of JJAS CWD, RX1day, RR1mm, and total JJAS precipitation exceeding the 99th percentile indices regridded on the (left) CORDEX-Africa and (right) ERA-Interim grids using conservative (blue), distance-weighted (red), and bilinear (green) remapping methods, and the corresponding indices computed on the TRMM original grid (black).

statistics and climate indices based on daily rainfall, used in the evaluation of RCM simulations over the CWA region. We find that climate indices and standard deviation fields present more differences when daily precipitation fields are remapped first on the evaluation grid than when the derived fields are first computed on the original grid and then interpolated, regardless of the mathematical method used to do the remapping. The differences between remapped fields increase when the remapping is done on coarse-resolution grids.

The purpose of the remapping is to bring observations and models on the same grid, and at the same spatial scales, but in preserving as much as possible the statistical characteristics of the original field. This condition is satisfied when climate indices are remapped using the last-step procedure. However, if the remapping is done as a first-step operation on the precipitation field and then the indices are computed on the final grid, the derived products have spatial means and variances larger or smaller than the original field.

In summary, our results indicate a clear advantage of using the last-step remapping procedure, regardless of the mathematical remapping method, and suggest care in the evaluation of RCM-derived fields after the first-step remapping of daily precipitation. This can provide a useful benchmark framework for RCM evaluation over the West Africa monsoon area using daily precipitation indices, which are all based on sensitive threshold values, in terms of occurrence, duration, and intensity of rainfall events.

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