

Multivariate Bias Correction (MBC) Package Help

1. Overview

The Multivariate Bias Correction (MBC) package is a complete package designed to deal with the distribution and, auto and cross dependence biases in a multivariate time series at multiple time steps. It provides the flexibility of applying a simple single time scale univariate bias correction to a comprehensive multivariate multi-time scale bias correction, depending upon the requirement of a particular task. Thus, the package allows the user to frame the structure of their own bias correction model by choosing the type of bias correction, number of time nesting and type of cross nesting required. MBC is a comprehensive package that offers users a wide variety of options by including several variants of standard quantile matching and other routinely used bias correction approaches in a time and cross dependence nesting.

In MBC, distribution behavior of a time series is represented either as a function of both mean and variance or by its empirical distribution. Auto dependence is represented by LAG1 autocorrelation function while cross-dependence is assumed to be a function of LAG0 and LAG1 correlations. The package allows time nesting at daily, monthly, seasonal, annual and tri-annual time scales.

The package allows the user to pick the bias correction for mean only, mean and variance or for distribution only at selected predefined time scales. Similarly, there is flexibility to pick the dependence correction in combinations of LAG1 auto, LAG0 cross and LAG1 cross distributions. User can pick time nesting starting from single to all time scales.

2. Features

Both multivariate bias correction approaches, namely, Multivariate Recursive Nested Bias Correction (MRNBC) and the Multivariate Recursive Quantile-matching Nested Bias

Correction (MRQNBC) also including their variants, in the form of an R package are included here.

MBC is compiled in R and allows applying variants of MRNBC and MRQNBC bias correction approaches in a fairly simple manner. The package requires all essential information to be provided in the 'basic.dat' file. In addition, four data files are to be prepared and included before running the package. These include observed and raw data files for calibration as well as verification period. It is not necessary to have equal length of data for raw and observed file either for calibration or verification periods. Also, depending upon the requirement, same file can be used for both calibration and verification periods. As the package considers across the variables dependence, it can also be used to maintain observed spatial dependence across multiple locations in the simulations. User can first pick their choice of going for either MRNBC or MRQNBC bias correction options and then specify the bias correction statistics and time nesting to be included. Statistics to be used for bias correction include, correction for only mean, mean and SD (or distribution), LAG1 auto, LAG0 and LAG1 cross correlation attributes. The options for time nesting include, daily, monthly, seasonal, annual and tri-annual. The package also allows flexibility of applying bias correction either to daily or to monthly time series. Users are allowed to define their own seasons. Also, there is an option of averaging or aggregating the data as one move from daily to higher time scales (monthly, seasonal and annual). The option of data aggregation is useful when dealing with variables for example, rainfall. In addition to the name of four data files, the 'basic.dat' file also requires information about the number of years of data, number of variables, width of moving window, number of repeats in the recursive procedure, physical lower and upper limits on the variables, whether data consider leap years or not and distribution of calendar months in the seasons specified. All the information is provided in a free format, separated by spaces. At present, the package allows use of a maximum of 150 years of daily data, 25 variables, 6 seasons and 31 days wide moving window.

Upon successful completion of the program, 6 output files are generated, two files containing bias corrected time series for calibration and verification periods and four statistics results files, containing important statistics of 1) Observed and Raw data for calibration; 2) observed and raw data for verification; 3) observed and bias corrected data for calibration; and 4) observed

and bias corrected data for verification time periods. Some of the important statistics calculated include means, standard deviations, skewness, LAG1 and LAG2 auto correlations, and distribution plots at daily, monthly, seasonal and annual time scales. In case of multiple variables, auto and LAG1 cross correlations are also computed. The package allows the users to look at a few raw and bias corrected statistics either in the form of a table or as plots at multiple time scales of interest. Package also provides plots of empirical distribution of raw and bias corrected time series.

2.1 Presentation of Results

The applicability of the package is demonstrated on three sample datasets, included with the package. These datasets are expected to cover a variety of options included in the package. The first dataset considers unequal lengths of time series for calibration and verification periods. It considers synthetically generated daily time series 6 variables look very similar to typical atmospheric variables used in downscaling and applies MRQNBC bias correction approach. The second dataset considers equal lengths of observed and GCM data for calibration (current) and verification time periods. It considers 7 atmospheric variables and uses MRNBC as the bias correction approach. The third datasets considers observed and AR1 model simulated monthly rainfall at 15 locations over Sydney region and uses MRQNBC approach to induce observed spatio-temporal dependence in the rainfall simulations.

2.2 First dataset

The first dataset consists of synthetic (mimicking reanalysis (observed) and raw GCM) daily time series of 6 (climate variables) with unequal data lengths. 66 years of daily data (from 1881 to 1946) is used for model calibration whereas another subset of 70 years (from 1947 to 2016) is used for model verification. Likewise, a subset of 63 years of raw GCM data (from 1891 to 1953) is used for model calibration and of 61 years (from 1954 to 2014) is used for model verification. Please note that the specification of start and end years are arbitrary and are specified only to account for leap years in the data. Cumulative distribution matching multivariate bias correction MRQNBC model with the options of bias correction at daily, monthly, seasonal and annual time scales is picked. Three seasons in a year are considered. In

addition, LAG0 cross and LAG1 auto dependence options are selected. Table 1 presents the details of 'basic.dat' file used for this dataset.

Upon successful completion of the bias correction program, package provides four result files showing the statistics of 1) Observed and Raw data for calibration; 2) Observed and raw data for verification; 3) Observed and bias corrected data for calibration; and 4) observed and bias corrected data for verification. Statistics for the calibration and verification periods are presented in Tables 2 and 3. A few scatter plots of statistics and distribution plots of time series of raw and bias corrected data for calibration and verification periods are presented in Figures 1 and 2, respectively. The bias correction approach performs well in reproducing the statistics of the reanalysis data in the GCM simulations at all time scales during calibration period (Table 2 and Figure 1). It also reproduces well the time distribution of variable at all selected time scales (Figure 2). Some biases in the statistics during verification period are noted. Although, LAG1-cross correlations and SKEW are not modelled explicitly, the bias correction does improve their representation the corrected time series (Table 2 and Figure 2).

2.3 Second dataset

The second dataset includes four files of equal lengths with daily records of 7 atmospheric variables averaged over Sydney, Australia, obtained from NCEP-reanalysis and CSIRO data bases. A subset of 30 years of records from 1950 to 1979 is considered for model calibration while remaining 30 years from 1980 to 2009 is used for the model verification. The basic information about the data start and end years, number of years of data, file names, number of variables and type of bias correction model are given in 'basic.dat' file in a simple text format. The bias correction model selected is a multivariate recursive nested bias correction (MRNBC) model with the option of bias correction in mean, standard deviation, LAG1 auto and LAG0 cross correlations at daily, monthly and annual time scales. Four seasons in a year are considered. Daily GCM data is considered to have fixed 28 days in each February and thus activating the option of fixed days in a month format for GCM calibration and verification datasets. Observed (reanalysis) data sets for calibration and verification periods still follow standard leap year format. More details on the information included in the 'basic.dat' file are

provided in the Table 4.

Upon successful completion of the bias correction package, four result files containing a few important statistics of the raw and bias corrected data are created. Tables 5 and 6 provide the snapshots of a part of these files for raw and bias corrected data for mean, standard deviation and auto correlation statistics for calibration and verification periods, respectively. Raw data (Tables 5a and 5a) exhibits some biases in these statistics. Bias correction model provides near perfect fit for the calibration period and a reasonably good fit for the verification period. Similarly, Figure 3 provides scatter plots of scaled means, standard deviations, LAG1 autocorrelation, LAG0 cross correlations and LAG1 cross correlations of raw and bias corrected time series for these two periods. For a good match all points should lie close to diagonal. Model does a good job in reproducing these statistics during verification period albeit some scatter for some variables.

Figure 4 presents empirical distribution plots of daily, monthly, seasonal and annual time series of reanalysis and raw and bias corrected GCM data for calibration and verification time periods for a selected variable-Temperature depression at 700hPa. Temperature depression is the difference of dewpoint and air temperature at that particular pressure level. Here again, the model performs well at all time scales during calibration, however, exhibits some biases at higher time scales during verification.

The biases noted during verification period are a function of the differences in the behaviour of the observed and raw time series during calibration and verification time periods. MRNBC like any other bias correction model works on the assumption that the biases are stationary and corrects the verification time series for the biases observed in the calibration time period.

2.4 Third dataset

The third dataset consists of observed and model simulated monthly rainfall time series. 70 years of observed rainfall records from 1921 to 1990 at 15 locations around Sydney is used for rainfall generation using AR1 model. As generated rainfall comes from a univariate model with order-one dependence, it is not expected to reproduce the observed spatio-temporal dependence in the simulations. Two sample realisations of monthly rainfall, each 70 years in length, are

generated from the rainfall generation model. One realisation is used for the calibration of the bias correction model, whereas the second one is used for model verification. The bias correction model selected is a multivariate recursive nested bias correction (MRNBC) model with the option of bias correction in mean, standard deviation, LAG1 auto and LAG0 cross correlations at monthly, seasonal and annual time scales. Two seasons in a year are considered and being rainfall, the time aggregation option is also activated. The structure of 'basic.dat' file used in this example is presented in Table 7 while a few basic statistics of the observed, raw and bias corrected data for the calibration and verification periods are presented in Tables 8 and 9. A few scatter plots of statistics of raw and bias corrected data for calibration and verification periods are presented in Figure 5 whereas empirical distribution plots of monthly, seasonal and annual rainfall are presented in Figure 6. As raw data comes from a model which is calibrated using the observed data, there is a good match between means and standard deviations of observed and simulated raw data for calibration and verification time periods (Tables 8a and 9a and Figure 5) and empirical distributions (Figure 6). However, as expected, auto and cross dependence attributes are not simulated well by the univariate rainfall generation model. The bias correction model improves the representation of these observed attributes in the bias corrected time series.

3.1 Input parameters

In addition to observed and raw data files, user is required to provide other basic information in the 'basic.dat' file in a simple free text format with spaces in between them. Each entry in the file is supported by a heading to provide a short description of that entry.

3. Technical specifications

Operating system:

Windows 7

Essential applications:

R 3.0.2 (download from <http://cran.r-project.org/bin/windows/base/>)

Running the programme:

Running the programme is simple. In RGui, open the RGui screen and change the working directory to the folder where all files including the mbc.r script, are located. Select 'mbc.r' file

and double click on it in order to run it. Alternatively, open the R-Studio and open the ‘mbc.r’ file. Now run the file by selecting it and clicking on the run command.

Table 1: Structure of ‘Basic.dat’ file used for dataset 1

```

Information about observed data for calibration
  No of years of data      Start Year
      66                  1881
Observed data file name along with directory path for calibration(if not in the directory where executable is located)
obsC.dat
Information about observed data for validation
  No of years of data      Start Year
      70                  1947
Observed data file name along with directory path for validation(if not in the directory where executable is located)
obsF.dat
Information about raw data used in calibration
  No of years of data      Start Year
      63                  1891
Data file name with directory path (if not in the directory where executable is located)
rawC.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_rawc.dat
Bias corrected data file name with directory path (if not in the directory where executable is located)
BCC.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_bcc.dat
Information about data used for bias correction - validation
  No of years of data      Start Year
      61                  1954
Data file name with directory path (if not in the directory where executable is located)
rawF.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_rawf.dat
Bias corrected data file name with directory path (if not in the directory where executable is located)
bcF.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_bcf.dat
Number of variables
6
Specify time scale of data used 0-daily; 1-monthly
0
Number of iterations
3
missing number identifier (any number equal to or slightly higher than the defined value is ok)
-9000.0
bias correction model (1 - multivariate NBC (MRNBC); 2 - multivariate CDM (MRQNBC))
2
Width of one side of moving window for daily data (in days)
15
option whether data (gcm_cali gcm_vali obs_cali obs_vali) follows a usual leap year (0), or a fixed days in a month format (1)
0 0 0 0
Nesting levels and bias correction options: 1-included and 0-excluded
Time      MEAN      SD/Dist      LAG1 Auto      LAG0 CROSS      LAG1 CROSS
Daily     1           1           1             1             1
Monthly   1           1           1             1             1
Quarterly 1           1           1             1             1
Annual    1           1           1             1             1
Triannual 0           0           0             0             0
Number of seasons in a year
3
Number of months in each season
4 4 4 4
Month numbering assigned to each season (1-Jan, 2-Feb....., 12-Dec)
1 2 3 4
5 6 7 8
9 10 11 12
Option for creation of plots (0:no plots, 1:plots of statistics, 2: plots of empirical distribution as well)
1
Specify physical lower and upper limits on the variables/locations and aggration criteria
variable Lower limit Upper limit higher time scale aggr 0-av, >0 sum threshold indicator threshold
1 500 1000 0 0 0 0
2 2000 4000 0 0 0 0
3 -100 100 0 0 0 0
4 -100 100 0 0 0 0
5 -100 100 0 0 0 0
6 -100 100 0 0 0 0
Information about no of days in a month for obs_cali obs_vali gcm_cali gcm_vali
31 31 31 31
28 28 28 28
31 31 31 31
30 30 30 30
31 31 31 31
30 30 30 30
31 31 31 31
31 31 31 31
30 30 30 30
31 31 31 31
30 30 30 30
31 31 31 31

```

Table 2: A few statistics of raw and bias corrected time series for calibration period:
dataset 1
(a) Raw data

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled
Statistics at Annual Level										
1	799.20	805.57	10.448	7.3822	.62846E-01	-.12855	-.11798E-01	-.22253E-01	-.67715	-.54367
2	3084.5	3073.6	13.129	8.3840	.11057	.50677E-01	.39366E-01	-.14444	-.85170	-.24515
3	14.759	16.190	1.7092	.48531	.76638	.82488E-01	.61275	-.47546E-01	-.13596	-.12687
4	3.7496	13.797	.86558	1.1113	-.48978E-01	-.23691	.63553E-01	.40432E-01	-.41174	.17586
5	-.10001	1.7554	.66718E-01	.32201	-.13884	-.12419	.23474	-.17528	.44326	.11811
6	-6.8031	-9.1646	.49192	.40722	.42392	.47448E-01	.30410	-.41959	-.15264	-.71373
Statistics at Seasonal Level										
1	799.37	805.68	17.426	12.745	.32242E-01	.42296E-01	-.12480	-.65328E-01	-.25461E-01	-.15633
2	3084.8	3073.8	30.422	36.690	-.22757	-.41604	-.30331	-.42272	-.10034	-.19427
3	14.783	16.179	2.0931	.83800	.46685	-.41149E-01	.45663	.99273E-02	.16402	.32335
4	3.7208	13.759	1.8160	3.3506	-.16286	-.32511	-.23692	-.34362	-.40159	-.31949E-01
5	-.97710E-01	1.7453	.19015	2.0889	-.33866	-.46739	-.36098	-.44312	-.20454	.29945
6	-6.7913	-9.1456	1.7953	2.3018	-.39417	-.44114	-.38031	-.44560	-.20932	-.53133
Statistics at Monthly Level										
1	799.47	805.74	26.793	24.581	.42445	.39697	.23918	.72651E-01	-.27993E-01	-.16701
2	3085.0	3073.9	39.298	45.254	.55486	.71761	.32191	.37706	-.36823	-.59163
3	14.799	16.193	2.6910	1.6980	.48682	.12917E-01	.33766	.41850E-01	.28140	.71637E-01
4	3.7083	13.741	2.6835	4.5097	.40958	.51489	.21201	.23403	.14113	.27600
5	-.97100E-01	1.7365	.26001	2.6065	.55018	.71749	.30840	.37586	-.45568	.34304
6	-6.7859	-9.1530	2.4329	3.1767	.62997	.68014	.34904	.36054	.44128	.28678
Statistics at Daily Level										
1	799.44	805.73	53.656	50.349	.80070	.72516	.51084	.37851	-.26639	-.32212
2	3084.8	3073.8	66.003	64.531	.84537	.83991	.61415	.62906	-.57213	-.67297
3	14.796	16.188	7.8462	7.1409	.36527	.31681	.12926	.36447E-01	.64826	.23459
4	3.7251	13.766	5.9557	8.7608	.66244	.69139	.37796	.39625	.19452	.41635
5	-.98535E-01	1.7506	.54697	4.1443	.65919	.67424	.36270	.46985	-.41660	.26120
6	-6.7993	-9.1586	4.8967	5.7433	.62385	.64095	.34523	.36707	.14528	.20863

(b) Bias corrected

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled
Statistics at Annual Level										
1	799.20	800.61	10.448	9.1508	.62846E-01	-.15213E-01	-.11798E-01	.14493	-.67715	-.82360E-01
2	3084.5	3086.1	13.129	11.340	.11057	.15222E-01	.39366E-01	.16785	-.85170	-.86308E-01
3	14.759	14.936	1.7092	1.6561	.76638	.61943	.61275	.49431	-.13596	-.56655E-01
4	3.7496	4.2458	.86558	.89837	-.48978E-01	-.85427E-02	.63553E-01	.47288E-01	-.41174	-.17711
5	-.10001	-.93804E-01	.66718E-01	.62587E-01	-.13884	-.8514E-01	.23474	-.11593	.44326	.30038
6	-6.8031	-6.8426	.49192	.55496	.42392	-.75426E-01	.30410	-.63720E-01	-.15264	-.80283E-01
Statistics at Seasonal Level										
1	799.37	800.57	17.426	16.717	.32242E-01	-.80228E-01	-.12480	-.16172	-.25461E-01	.14549
2	3084.8	3086.3	30.422	29.576	-.22757	-.29358	-.30331	-.34426	-.10034	.26992E-01
3	14.783	14.891	2.0931	2.1605	.46685	.34221	.45663	.29768	.16402	.16374
4	3.7208	4.2594	1.8160	2.1109	-.16286	-.19319	-.23692	-.29717	-.40159	-.82018E-01
5	-.97710E-01	-.94131E-01	.19015	.19957	-.33866	-.32946	-.36098	-.35575	-.20454	-.40953
6	-6.7913	-6.8487	1.7953	1.8398	-.39417	-.39807	-.38031	-.37960	-.20932	-.10412
Statistics at Monthly Level										
1	799.47	800.65	26.793	26.583	.42445	.38935	.23918	.17576	-.27993E-01	.10867
2	3085.0	3086.5	39.298	39.207	.55486	.49461	.32191	.28156	-.36823	-.34765
3	14.799	14.910	2.6910	2.9611	.48682	.41379	.33766	.27821	.28140	.39193
4	3.7083	4.2384	2.6835	3.4017	.40958	.26239	.21201	.15724	.14113	.84087
5	-.97100E-01	-.93838E-01	.26001	.30700	.55018	.43079	.30840	.20648	-.45568	-.28355
6	-6.7859	-6.8379	2.4329	2.4883	.62997	.56056	.34904	.29279	.44128	.66092
Statistics at Daily Level										
1	799.44	800.66	53.656	52.883	.80070	.65112	.51084	.49548	-.26639	-.37756
2	3084.8	3086.3	66.003	79.045	.84537	.70607	.61415	.55334	-.57213	-.21252
3	14.796	14.909	7.8462	5.0754	.36527	.50806	.12926	.39154	.64826	.75325
4	3.7251	4.2560	5.9557	13.646	.66244	.52442	.37796	.35087	.19452	.90091
5	-.98535E-01	-.95198E-01	.54697	.94857	.65919	.53040	.36270	.30282	-.41660	-.25850
6	-6.7993	-6.8457	4.8967	10.535	.62385	.41740	.34523	.29525	.14528	.43510

Table 3: A few statistics of raw and bias corrected time series for verification period: dataset1

(a) Raw data

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled
Statistics at Annual Level										
1	801.82	806.04	10.088	6.9478	.11451	-.13995	-.10173E-01	-.64779E-01	-.71557	-.65369
2	3086.9	3074.1	12.870	7.9432	.18769	.58673E-02	.63191E-01	-.18068	-.92476	-.29490
3	17.221	16.196	1.8552	.46233	.78230	.84004E-01	.59591	-.47490E-01	-.10380	.15783
4	5.5248	13.809	.87038	1.0751	-.82235E-01	-.24325	-.37739E-01	-.92817E-02	-.48842	.11915
5	.72903E-02	1.7680	.67027E-01	.31741	-.15072	-.13929	.14198	-.21220	.61372	-.31653E-01
6	-6.5356	-9.1325	.48310	.40350	.46557	-.12867E-01	.30312	-.35267	-.13219	-.71784
Statistics at Seasonal Level										
1	801.42	805.94	17.057	12.410	-.47479E-01	.16152E-01	-.10981	-.72345E-01	-.66770E-01	-.14882
2	3086.4	3074.2	30.863	36.498	-.21954	-.42116	-.30400	-.43186	-.10926	-.18651
3	17.168	16.194	2.2468	.84498	.52049	-.73784E-01	.50680	-.39728E-01	.27084	-.29662
4	5.5428	13.825	1.8109	3.3713	-.14484	-.33003	-.23752	-.33839	-.41876	-.12344E-01
5	.68201E-02	1.7682	.19122	2.0910	-.33382	-.46307	-.36594	-.44241	-.21797	.29925
6	-6.5293	-9.1307	1.8309	2.3011	-.39882	-.44513	-.38298	-.44317	-.18269	-.52089
Statistics at Monthly Level										
1	801.50	806.00	26.551	24.294	.42304	.38806	.22668	.63796E-01	-.34372E-01	-.85195E-01
2	3086.5	3074.3	39.494	44.841	.56530	.71478	.31857	.37628	-.33033	-.58564
3	17.178	16.194	2.7930	1.6763	.52593	-.23716E-02	.38258	.60228E-01	.38284	.49142E-01
4	5.5268	13.799	2.6827	4.5470	.42110	.51732	.22309	.23025	.16615	.26496
5	.79280E-02	1.7613	.26391	2.6075	.54687	.71583	.30415	.37497	-.48412	.33286
6	-6.5196	-9.1254	2.4804	3.1710	.64084	.68654	.35061	.36307	.42617	.28071
Statistics at Daily Level										
1	801.54	805.96	53.419	50.292	.79868	.72396	.50955	.37664	-.39013	-.32322
2	3086.5	3074.1	65.849	64.419	.81112	.83822	.59079	.62505	-.4.0536	-.68173
3	17.175	16.194	7.6451	7.1433	.38714	.31694	.14715	.33556E-01	.70465	.22336
4	5.5412	13.827	5.8321	8.7871	.69735	.69418	.39974	.40021	-.19845	.42556
5	.67061E-02	1.7748	.54600	4.1436	.67625	.67705	.37616	.47405	-.41554	.26704
6	-6.5321	-9.1301	4.9176	5.7241	.62700	.64248	.35074	.36814	-.16963	.21138

(b) Bias corrected

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled	observed	Modelled
Statistics at Annual Level										
1	801.82	798.12	10.083	13.990	.11099	-.21783	-.65382E-02	.23407	-.69517	-.13701
2	3086.9	3082.9	12.864	16.931	.17644	-.59755E-01	.64053E-01	.20023	-.86576	-.67442E-01
3	17.221	14.244	1.8551	2.4087	.78197	.71024	.59589	.60163	-.97252E-01	-.41261
4	5.5251	3.9069	.87693	.94466	-.89292E-01	-.14092	-.32674E-01	-.17071	-.48679	-.27356E-01
5	.72851E-02	-.11404	.67246E-01	.66111E-01	-.15099	-.14107E-01	.13900	-.22140	.61315	-.71342
6	-6.5359	-6.7664	.48335	.72863	.46180	.43184	.30362	.85907E-01	-.15479	.17959
Statistics at Seasonal Level										
1	801.45	798.13	16.925	20.359	.51852E-01	.11166	-.11423	-.17434	-.21154E-01	-.14194
2	3086.5	3083.2	30.643	33.039	-.22738	-.14871	-.30500	-.28057	-.72058E-01	-.94697E-01
3	17.168	14.345	2.2510	2.7875	.51509	.63953	.50498	.56783	.29061	-.23185
4	5.5431	3.9382	1.8173	2.1811	-.14495	-.66859E-01	-.23686	-.26813	-.41844	-.33508
5	.68235E-02	-.11462	.19146	.25174	-.33339	-.37216	-.36605	-.35594	-.18635	-.22585
6	-6.5294	-6.7468	1.8400	1.8909	-.40062	-.27145	-.38330	-.30886	-.16383	-.28630E-01
Statistics at Monthly Level										
1	801.53	798.18	26.499	30.735	.41758	.41738	.22792	.23955	-.24776E-01	.24548
2	3086.7	3083.2	39.338	43.159	.56321	.53474	.31905	.30024	-.12370	-.12347
3	17.179	14.336	2.7979	3.4242	.52305	.63630	.38123	.47923	.39953	.48605E-01
4	5.5276	3.9248	2.6863	3.4753	.41863	.30393	.22372	.73721E-01	.20237	.14362
5	.78925E-02	-.11328	.26454	.36386	.54483	.30077	.30429	.88378E-01	-.50771	-.16768
6	-6.5197	-6.7484	2.4789	2.5752	.64100	.60095	.35253	.33087	.42071	.32590
Statistics at Daily Level										
1	801.54	798.10	53.422	56.117	.80206	.82122	.51171	.58746	-.26489	-.38896E-02
2	3086.5	3083.0	65.850	68.826	.84729	.85862	.61719	.65997	-.56514	-.29067
3	17.175	14.327	7.6451	8.0002	.38718	.42016	.14717	.20751	.70504	.48185
4	5.5414	3.9560	5.8321	9.4714	.69733	.66860	.39974	.37278	-.19833	.46145
5	.67030E-02	-.11542	.54600	1.1287	.67625	.54587	.37616	.26662	-.41558	-.10048
6	-6.5326	-6.7615	4.9170	4.9937	.62697	.64541	.35066	.37200	.16968	-.86017E-01

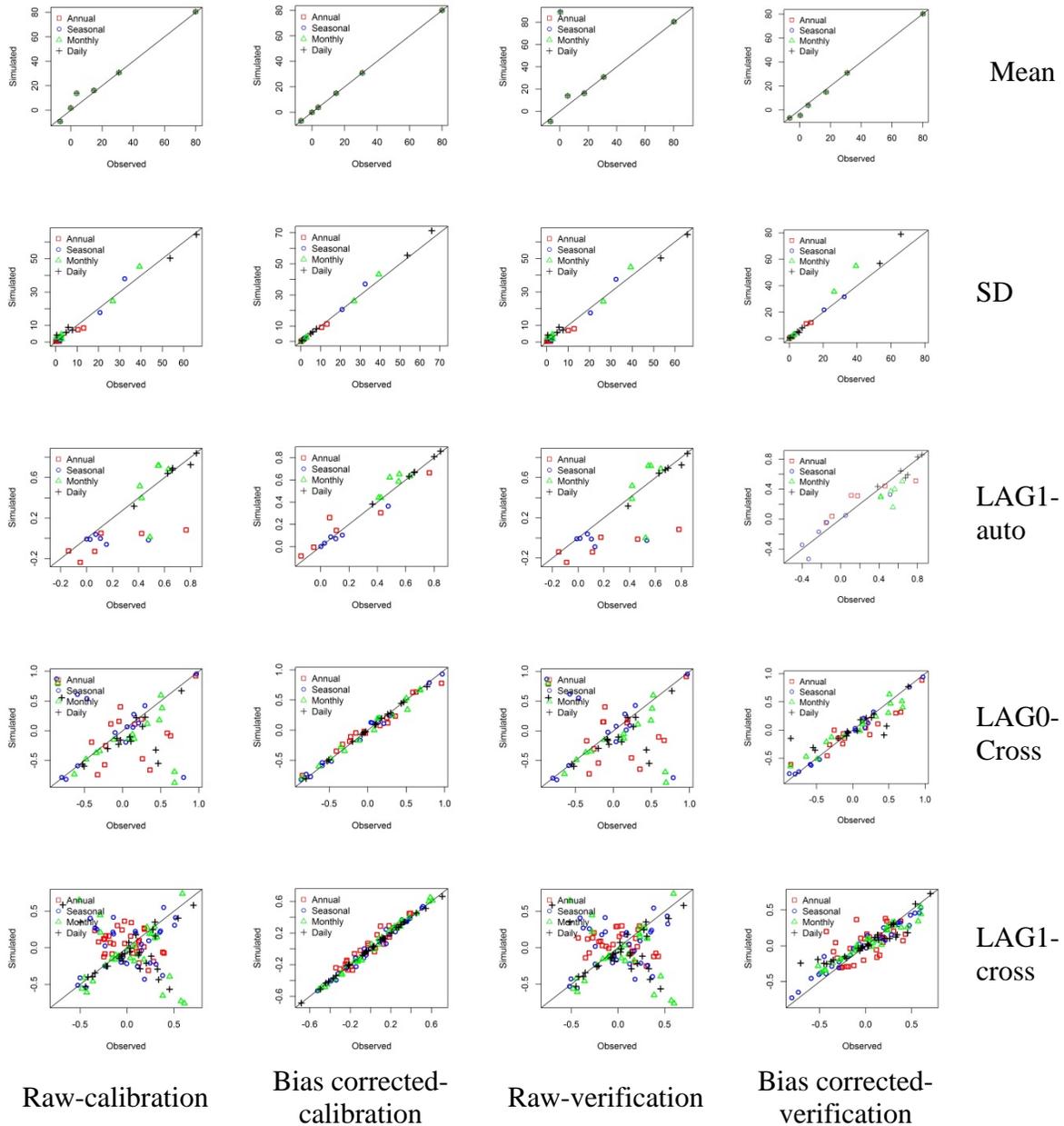


Figure 1: Scatter plots of daily, monthly, seasonal and annual means, standard deviations and LAG0 and LAG1 auto and cross correlations of reanalysis and raw and bias corrected GCM data for calibration and verification periods using MRQNBC bias correction approach and dataset 1. Points on the plots denote variables. Mean and standard deviation (SD) values of all variables are rescaled to lie between -100 to 100.

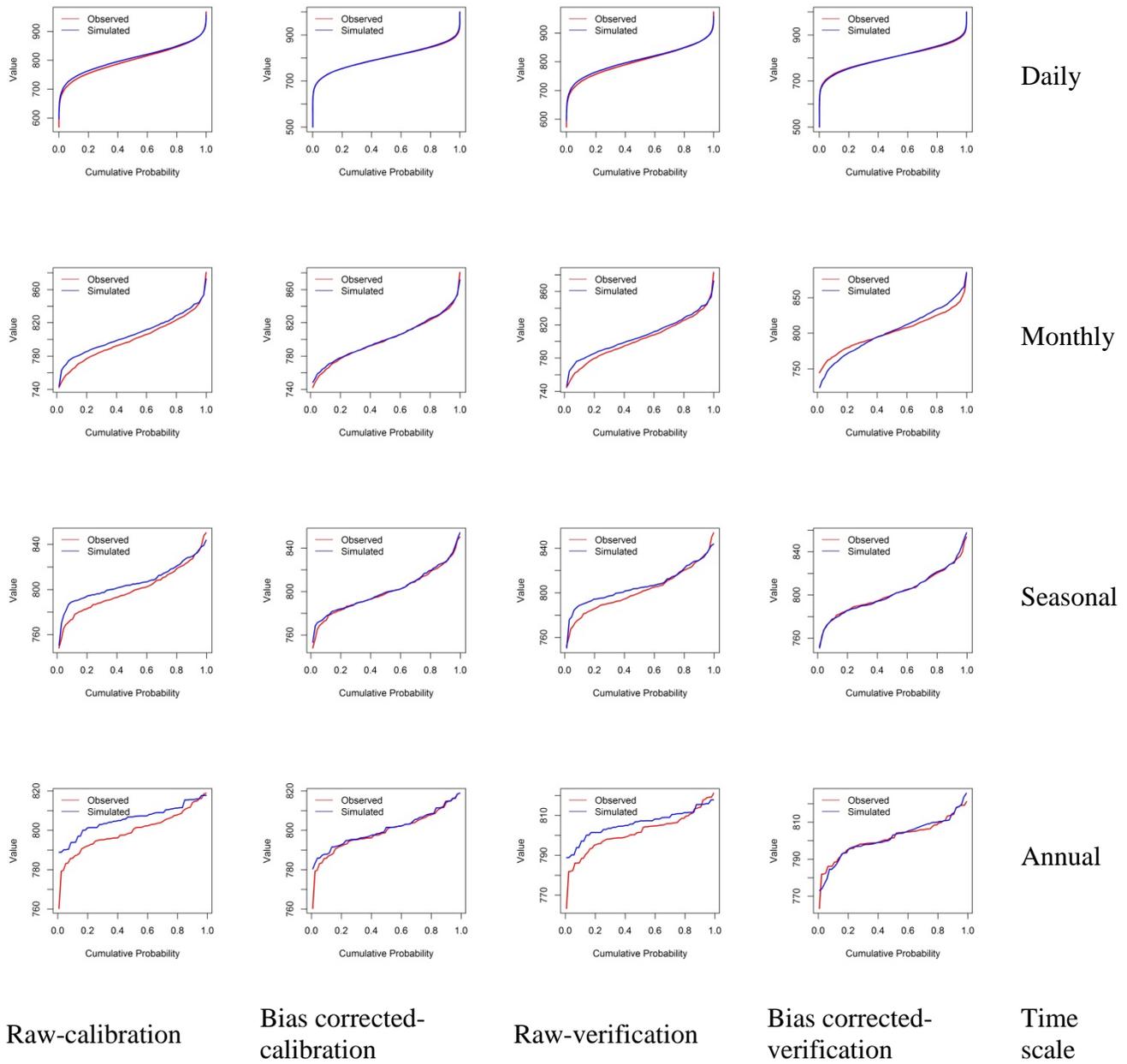


Figure 2: Distribution plots of daily, monthly, seasonal and annual time series of reanalysis and raw and bias corrected GCM data for calibration and verification time periods for a selected variable-1 and dataset 1.

Table 4: Structure of 'Basic.dat' file for dataset 2

```

Information about observed data for calibration
No of years of data      Start Year
30                       1950
Observed data file name along with directory path for calibration(if not in the directory where executable is located)
obs_cali.dat
Information about observed data for validation
No of years of data      Start Year
30                       1980
Observed data file name along with directory path for validation(if not in the directory where executable is located)
obs_vali.dat
Information about raw data used in calibration
No of years of data      Start Year
30                       1950
Data file name with directory path (if not in the directory where executable is located)
gcm_raw_cali.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_raw_cali.dat
Bias corrected data file name with directory path (if not in the directory where executable is located)
gcm_bc_cali.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_bc_cali.dat
Information about data used for bias correction - validation
No of years of data      Start Year
30                       1980
Data file name with directory path (if not in the directory where executable is located)
gcm_raw_vali.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_raw_vali.dat
Bias corrected data file name with directory path (if not in the directory where executable is located)
gcm_bc_vali.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
stat_bc_vali.dat
Number of variables
7
Specify time scale of data used 0-daily; 1-monthly
0
Number of iterations
3
missing number identifier (any number equal to or slightly higher than the defined value is ok)
-9000.0
bias correction model (1 - multivariate NBC (MRNBC); 2 - multivariate CDM (MRQNBC))
1
Width of one side of moving window for daily data (in days)
15
option whether data (gcm_cali gcm_vali obs_cali obs_vali) follows a usual leap year format(0), or fixed days in a month format (1)
1 1 0 0
Nesting levels and bias correction options: 1-included and 0-excluded
Time MEAN SD/Dist LAG1 Auto LAG0 CROSS LAG1 CROSS
Daily 1 1 1 1 1 0
Monthly 1 1 1 1 1 0
Quarterly 1 1 1 1 1 0
Annual 1 1 1 1 1 0
Triannual 0 0 0 0 0 0
Number of seasons in a year
4
Number of months in each season
3 3 3 3
Month numbering assigned to each season (1-Jan, 2-Feb....., 12-Dec)
1 2 3
4 5 6
7 8 9
10 11 12
Option for creation of plots (0:no plots, 1:plots of statistics, 2: plots of empirical distribution as well)
2
Specify physical lower and upper limits on the variables/locations and aggration criteria
variable Lower limit Upper limit higher time scale aggr 0-av, >0 sum threshold indicator threshold
1 500 1000 0 0 0
2 -100 100 0 0 0
3 -100 100 0 0 0
4 200 500 0 0 0
5 -100 100 0 0 0
6 -100 100 0 0 0
7 -100 100 0 0 0
Information about no of days in a month for Obs_cali Obs_vali GCM_cali GCM_vali
31 31 31 31
28 28 28 28
31 31 31 31
30 30 30 30
31 31 31 31
30 30 30 30
31 31 31 31
31 31 31 31
30 30 30 30
31 31 31 31
30 30 30 30
31 31 31 31

```

Table 5: A few statistics of raw and bias corrected time series for calibration period:
dataset 2

(a) Raw data

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	794.81260	801.81570	11.07615	6.48417	-.00992	.00670	-.11382	-.11062	-.96318	-.15844
2	11.85767	19.59069	.92815	1.57433	.33265	-.08557	.19667	-.07736	-.00982	-.31654
3	13.17055	28.01361	.87910	1.99338	.54293	.11176	.29168	-.29251	-.66259	-.23973
4	314.49210	318.78520	.59719	.55259	-.03634	-.15974	-.10205	.08584	.62379	.15254
5	10.83555	12.29951	1.47997	1.71984	-.27599	-.20689	.11715	.18380	.10133	.24343
6	1.36723	2.71904	.84796	.68802	.00964	-.12859	.29021	.33753	-.09025	-.42543
7	-.07574	.44324	.07759	.04170	-.32606	.03260	.20014	-.15016	.06629	-.05898
Statistics at Seasonal Level										
1	795.31300	802.34440	20.39622	26.76151	.16184	.02511	-.20461	-.84657	-.09733	-.13673
2	11.94472	19.60793	1.44061	3.05961	.26435	.14247	.08148	-.23969	.06576	.52357
3	13.19893	28.02888	1.44355	4.66459	.15866	.04267	.17951	-.38841	.11390	.45719
4	314.46650	318.79400	5.41005	3.12094	.00131	-.01643	-.95212	-.84869	.15663	.49516
5	10.86561	12.30282	3.30714	6.27838	.04932	.03517	-.25427	-.80170	.04717	.07051
6	1.38987	2.72258	1.33818	1.28204	.22178	.17406	.02164	-.19118	.20634	-.05164
7	-.07832	.44153	.22043	.10947	.04917	.10276	-.66237	-.56617	-.10211	-.17734
Statistics at Monthly Level										
1	795.29950	802.07310	25.93666	30.31085	.39917	.75037	.25618	.42919	.00706	-.26131
2	11.92105	19.56870	2.04052	5.10792	.27180	.13886	.15533	.00673	.25562	.38378
3	13.20546	27.98813	2.01489	6.58438	.33338	.34646	.11978	.10906	.31916	.27268
4	314.52950	318.82780	5.95683	3.52441	.81329	.75298	.46613	.39676	.07677	.34216
5	10.84255	12.26371	4.30935	7.30355	.35642	.66190	.17210	.38298	.18946	.20722
6	1.37122	2.70800	2.11019	2.08538	.13949	.18166	.12983	-.01590	-.10573	.21800
7	-.07569	.44227	.26207	.14550	.54396	.35136	.31928	.18341	-.36481	-.23738
Statistics at Daily Level										
1	795.17030	802.06520	52.98769	39.46332	.80411	.90695	.51485	.76023	-.20804	-.36580
2	11.91415	19.56943	6.59131	15.23799	.45394	.59810	.15635	.23381	.91426	.92997
3	13.18867	27.99234	6.77156	15.49419	.37049	.60772	.10879	.31517	.78014	.29194
4	314.50670	318.81500	7.09389	4.56450	.88540	.85917	.78182	.71003	.03398	-.01541
5	10.87214	12.29071	9.04825	10.58193	.74194	.83024	.46237	.65293	.20257	.24931
6	1.37059	2.71886	7.45185	6.31226	.49701	.54580	.11775	.20096	-.05463	-.03304
7	-.07706	.44197	.53425	.42655	.68808	.60496	.39610	.28090	-.37952	-.12088

(b) Bias corrected

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	794.81260	794.86710	11.07615	11.16529	-.00992	-.05133	-.11382	-.32373	-.96318	.01470
2	11.85767	11.86766	.92815	.94597	.33265	.39437	.19667	-.07100	-.00982	-.05171
3	13.17055	13.13451	.87910	.83307	.54293	.49152	.29168	.08660	-.66259	.08282
4	314.49210	314.48560	.59719	.59883	-.03634	-.20138	-.10205	-.16912	.62379	-.24125
5	10.83555	10.92036	1.47997	1.46962	-.27599	-.47146	.11715	.33583	.10133	-.43802
6	1.36723	1.42869	.84796	.79020	.00964	-.14182	.29021	-.25470	-.09025	-.26434
7	-.07574	-.07870	.07759	.05853	-.32606	-.37542	.20014	.15540	.06629	.01055
Statistics at Seasonal Level										
1	795.31300	795.16720	20.39622	21.08561	.16184	.19712	-.20461	-.38065	-.09733	.23563
2	11.94472	11.91183	1.44061	1.52436	.26435	.28275	.08148	.05913	.06576	.14392
3	13.19893	13.19351	1.44355	1.46060	.15866	.15818	.17951	.12761	.11390	.16260
4	314.46650	314.48220	5.41005	5.43949	.00131	.00127	-.95212	-.95464	.15663	.15666
5	10.86561	10.85673	3.30714	3.34034	.04932	.06599	-.25427	-.43147	.04717	-.01518
6	1.38987	1.42073	1.33818	1.67237	.22178	.06338	.02164	.05329	.20634	-.55632
7	-.07832	-.07938	.22043	.21869	.04917	.04331	-.66237	-.75692	-.10211	-.15411
Statistics at Monthly Level										
1	795.29950	795.23550	25.93666	26.38590	.39917	.46636	.25618	.27020	.00706	.12762
2	11.92105	11.91298	2.04052	2.03824	.27180	.32809	.15533	.19350	.25562	.07908
3	13.20546	13.20029	2.01489	2.05523	.33338	.33755	.11978	.17490	.31916	.05784
4	314.52950	314.53020	5.95683	5.95555	.81329	.82064	.46613	.46189	.07677	.05963
5	10.84255	10.84168	4.30935	4.27305	.35642	.36175	.17210	.16807	.18946	.19738
6	1.37122	1.41444	2.11019	3.36184	.13949	-.18106	.12983	.05468	-.10573	-.15222
7	-.07569	-.07696	.26207	.26550	.54396	.53398	.31928	.30353	-.36481	-.48814
Statistics at Daily Level										
1	795.17030	795.16840	52.98769	51.59780	.80411	.80424	.51485	.52761	-.20804	-.20950
2	11.91415	11.91384	6.59131	6.47504	.45394	.45868	.15635	.06678	.91426	1.01251
3	13.18867	13.18787	6.77156	6.74781	.37049	.37163	.10879	.04924	.78014	.05474
4	314.50670	314.50580	7.09389	7.02371	.88540	.89197	.78182	.78533	.03398	-.03787
5	10.87214	10.87398	9.04825	9.10082	.74194	.73363	.46237	.47245	.20257	.07922
6	1.37059	1.41322	7.45185	13.24969	.49701	.44494	.11775	.17359	-.05463	-.23840
7	-.07706	-.07798	.53425	.68388	.68808	.63612	.39610	.36097	-.37952	-.58673

Table 6: A few statistics of raw and bias corrected time series for verification period:
dataset 2

(a) Raw data

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	802.54400	804.88480	8.24078	5.55648	.00062	.05787	-.31081	-.38833	.45871	.50423
2	14.55578	19.81402	.83537	1.37419	.41963	.06397	.34520	.00765	-.02783	-.14958
3	16.16421	27.97035	.97117	1.93598	.56657	.32962	.16865	.30374	-.20598	-.24923
4	315.15110	319.94120	.72180	.53326	.35424	.43394	.29407	.38857	-.17430	-.77996
5	10.96024	12.42488	1.21249	1.08545	.11899	-.16061	-.00739	.03346	-.18692	-.59432
6	1.52278	2.55975	.52059	.66482	.06427	-.21438	.11530	-.05695	-.23976	.10915
7	-.11541	.41118	.04796	.03516	.02007	.14855	.11886	.13805	.54829	.34961
Statistics at Seasonal Level										
1	802.59940	804.85860	20.05032	27.33052	.07819	.03557	-.46944	-.83651	.15219	-.07411
2	14.53467	19.78944	1.44952	3.19703	.10807	-.08414	.13201	-.23378	-.21674	.29251
3	16.16446	27.97396	1.69983	5.33887	.04073	-.00407	.15855	-.47863	.20454	-.02461
4	315.13170	319.93530	5.10300	3.09277	.00206	-.03517	-.93845	-.76784	.14859	.57867
5	10.93281	12.47173	2.99045	5.81299	.04733	-.00282	-.48093	-.85598	.28448	.09663
6	1.49193	2.51583	1.08435	1.32642	-.00811	.16169	-.01940	.12712	-.35661	-.08748
7	-.11580	.40908	.21283	.11503	-.02865	-.07848	-.79011	-.46049	-.52749	-.37545
Statistics at Monthly Level										
1	802.49550	804.61990	26.73181	31.76105	.41975	.70961	.19440	.39799	-.09576	-.34779
2	14.53987	19.78832	2.37383	5.20840	.10715	.19273	.04492	-.01734	.08453	.25392
3	16.16158	27.95698	2.40473	6.99345	.24609	.41466	.05646	.21161	.20854	.03739
4	315.18540	319.96960	5.71912	3.58860	.78996	.72501	.44904	.37146	.08743	.50494
5	10.94025	12.40907	4.05373	7.05531	.36997	.61111	.17676	.31739	.43950	.22839
6	1.50217	2.52657	1.98726	2.11904	-.02357	.09428	.02616	.13217	-.06715	-.06799
7	-.11443	.40979	.25800	.16639	.56403	.25743	.30329	.15947	-.56034	-.26756
Statistics at Daily Level										
1	802.37460	804.72200	53.75423	40.20984	.79841	.91255	.50453	.77637	-.30850	-.36210
2	14.53335	19.80636	8.48021	15.72155	.42558	.61204	.10318	.25116	.77109	.91383
3	16.14070	27.99209	8.03056	15.69899	.35078	.61569	.10014	.32783	.55773	-.09223
4	315.16410	319.95370	6.96778	4.71903	.86444	.86262	.75042	.71139	.07565	-.04180
5	10.97513	12.43323	9.12886	10.61447	.70597	.82706	.39794	.63863	.25012	.25439
6	1.50283	2.52533	7.76968	6.55768	.44950	.56036	.07829	.19700	-.11677	-.02167
7	-.11551	.40945	.54737	.44334	.65908	.62168	.34904	.29279	-.46302	-.09431

(b) Bias corrected

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	802.54400	795.22650	8.24078	21.92270	.00062	-.09499	-.31081	-.31326	.45871	.10020
2	14.55578	12.05820	.83537	1.78626	.41963	.50901	.34520	.08637	-.02783	-.55250
3	16.16421	13.42455	.97117	1.61021	.56657	.66521	.16865	.34864	-.20598	-.05712
4	315.15110	315.79980	.72180	1.01295	.35424	-.25698	.29407	.01759	-.17430	-.58076
5	10.96024	10.95207	1.21249	2.10807	.11899	-.64418	-.00739	.54558	-.18692	-.28611
6	1.52278	2.15749	.52059	2.09602	.06427	-.05134	.11530	-.05970	-.23976	-.47139
7	-.11541	-.03031	.04796	.12596	.02007	-.21893	.11886	.12148	.54829	.31803
Statistics at Seasonal Level										
1	802.59940	795.52940	20.05032	30.22545	.07819	.35779	-.46944	-.05973	.15219	.11849
2	14.53467	12.08982	1.44952	2.78201	.10807	.29662	.13201	.17142	-.21674	.03662
3	16.16446	13.43418	1.69983	2.34861	.04073	.26992	.15855	.44729	.20454	.10799
4	315.13170	315.73960	5.10300	5.68765	.00206	.00607	-.93845	-.88709	.14859	.28347
5	10.93281	10.94511	2.99045	4.42997	.04733	.19815	-.48093	-.20066	.28448	-.03957
6	1.49193	2.29039	1.08435	4.41053	-.00811	.19535	-.01940	.01289	-.35661	-.57781
7	-.11580	-.03692	.21283	.47097	-.02865	-.01057	-.79011	-.68952	-.52749	-.43102
Statistics at Monthly Level										
1	802.49550	795.56270	26.73181	37.40029	.41975	.49192	.19440	.33224	-.09576	.18595
2	14.53987	12.09915	2.37383	3.47858	.10715	.45350	.04492	.28433	.08453	.33955
3	16.16158	13.44677	2.40473	2.98510	.24609	.36647	.05646	.29502	.20854	.05801
4	315.18540	315.80830	5.71912	6.33463	.78996	.79571	.44904	.45967	.08743	.21766
5	10.94025	10.90896	4.05373	6.68757	.36997	.16963	.17676	.09930	.43950	-.56138
6	1.50217	2.31432	1.98726	6.68988	-.02357	.12241	.02616	.12506	-.06715	.13263
7	-.11443	-.03299	.25800	.57199	.56403	.44814	.30329	.24939	-.56034	-.39040
Statistics at Daily Level										
1	802.37460	795.57010	53.75423	58.55110	.79841	.84268	.50453	.62483	-.30850	-.03637
2	14.53335	12.10999	8.48021	7.43642	.42558	.54092	.10318	.20149	.77109	1.18872
3	16.14070	13.45868	8.03056	7.23877	.35078	.42961	.10014	.13498	.55773	.21964
4	315.16410	315.78670	6.96778	7.44669	.86444	.89924	.75042	.79306	.07565	.02940
5	10.97513	10.92419	9.12886	12.42447	.70597	.75603	.39794	.54303	.25012	.17602
6	1.50283	2.33505	7.76968	18.35575	.44950	.47759	.07829	.20063	-.11677	-.03906
7	-.11551	-.03431	.54737	1.24896	.65908	.69495	.34904	.45146	-.46302	-.03645

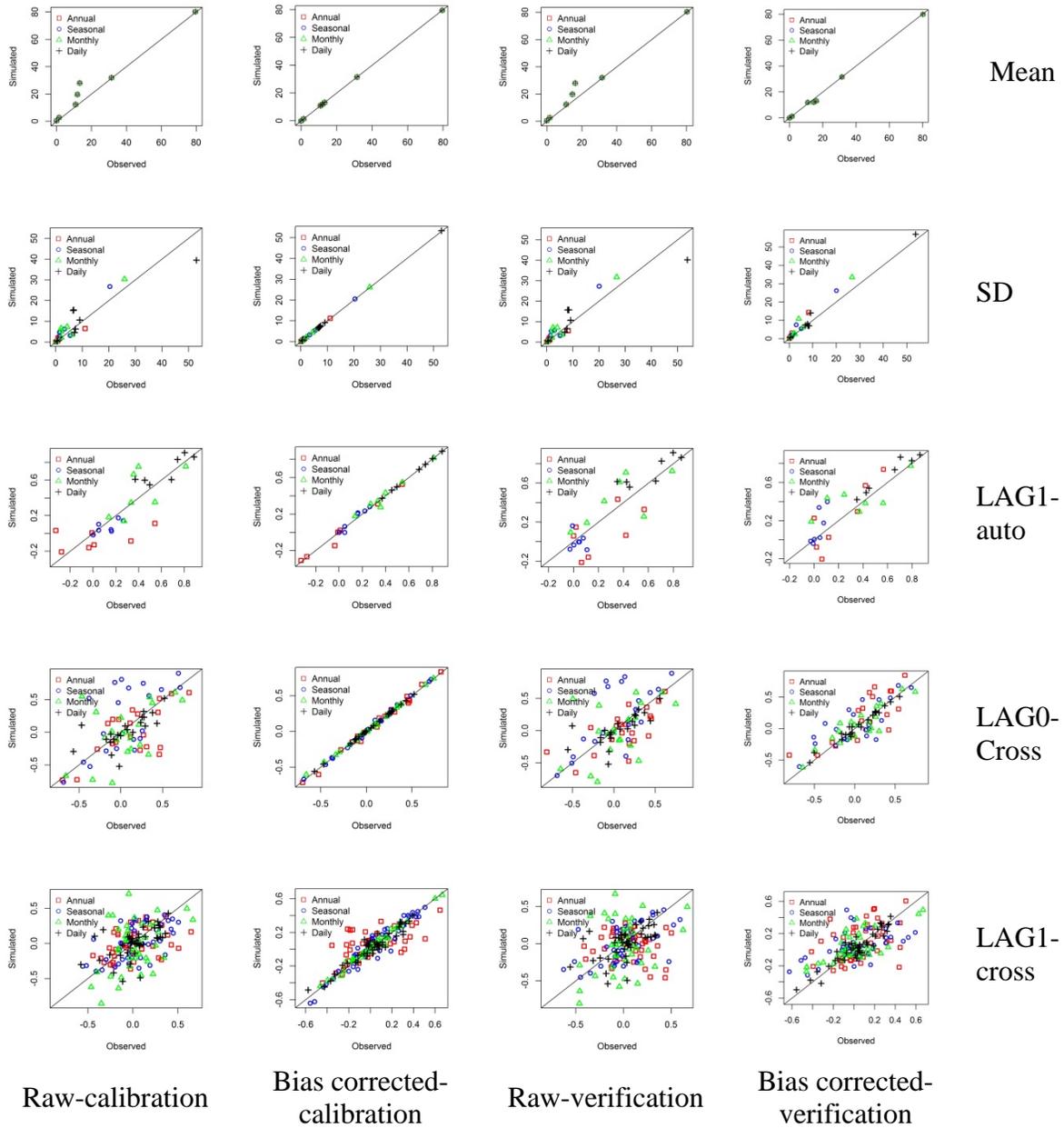


Figure 3: Same as Figure 1 for dataset 2 except that the Lag1 cross correlations are not modelled.

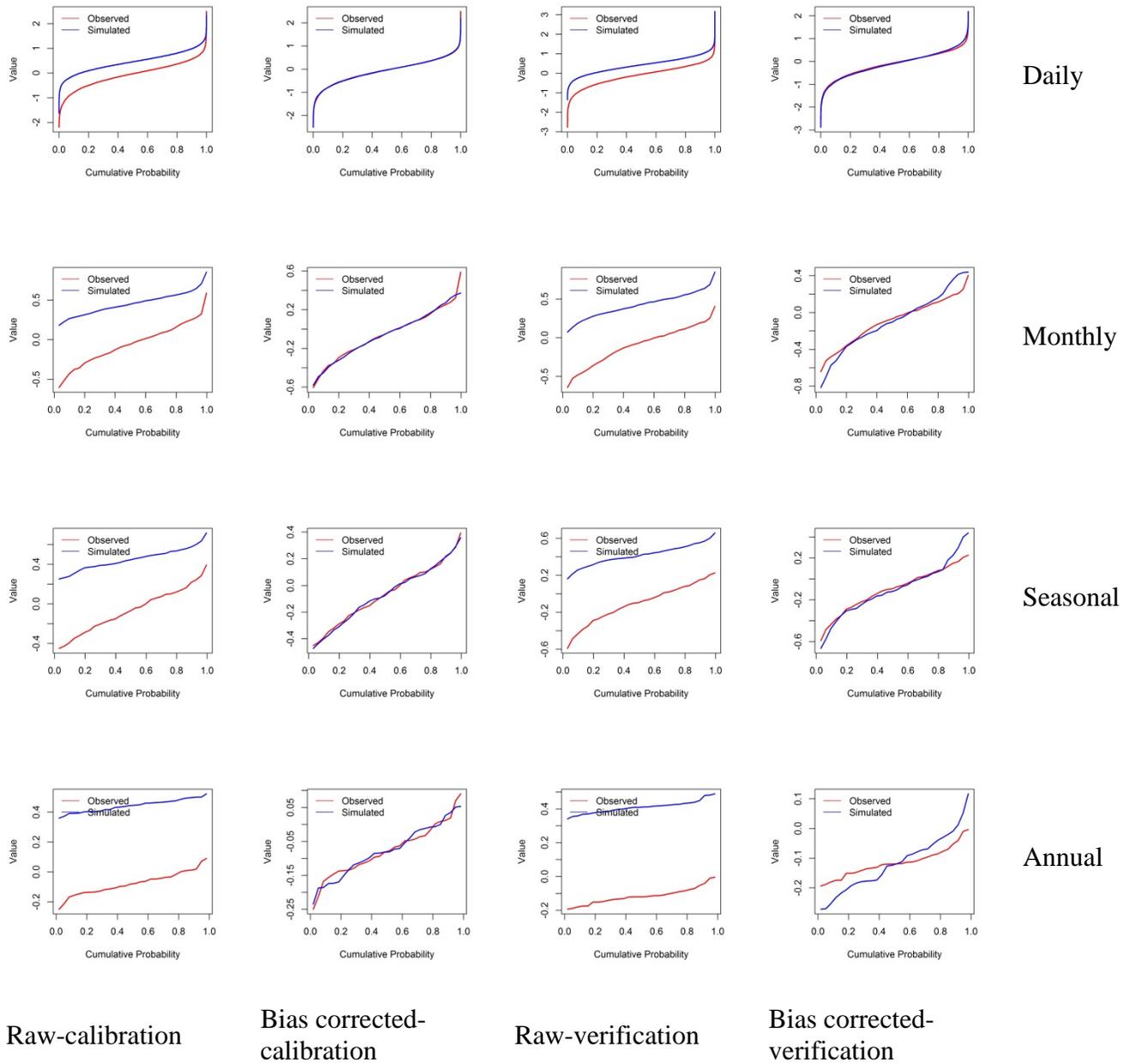


Figure 4: Same as Figure 2, for dataset 2 and variable 7

Table 7: Structure of Basic.dat file used for dataset 3

```

Information about observed data for calibration
  No of years of data      Start Year
    70                    1921
Observed data file name along with directory path for calibration(if not in the directory where executable is located)
  data_obsc.dat
Information about observed data for validation
  No of years of data      Start Year
    70                    1921
Observed data file name along with directory path for validation(if not in the directory where executable is located)
  data_obsc.dat
Information about raw data used in calibration
  No of years of data      Start Year
    70                    1921
Data file name with directory path (if not in the directory where executable is located)
  data_rawc.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
  stat_rawc.dat
Bias corrected data file name with directory path (if not in the directory where executable is located)
  data_bcc.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
  stat_bcc.dat
Information about data used for bias correction - validation
  No of years of data      Start Year
    70                    1921
Data file name with directory path (if not in the directory where executable is located)
  data_rawf.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
  stat_rawf.dat
Bias corrected data file name with directory path (if not in the directory where executable is located)
  data_bcf.dat
Statistics (to be computed and stored) file name with directory path (if not in the directory where executable is located)
  stat_bcf.dat
Number of variables
  15
Specify time scale of data used 0-daily; 1-monthly
  1
Number of iterations
  3
missing number identifier (any number equal to or slightly higher than the defined value is ok)
  -9000.0
bias correction model (1 - multivariate NBC (MRNBC); 2 - multivariate CDM (MRQNBC))
  1
Nesting levels and bias correction options: 1-included and 0-excluded
Time      MEAN  SD/Dist  LAG1 Auto  LAG0 CROSS  LAG1 CROSS
Monthly   1      1        1          1           0
Quarterly 1      1        1          1           0
Annual    1      1        1          1           0
Triannual 0      0        0          0           0
Number of seasons in a year
  2
Number of months in each season
  6
Month numbering assigned to each season (1-Jan, 2-Feb....., 12-dec)
  1 2 3 4 5 6
  7 8 9 10 11 12
Option for creation of plots (0:no plots, 1:plots of statistics, 2: plots of empirical distribution as well)
  2
Specify physical lower and upper limits on the variables/locations and aggregation criteria
variable Lower limit Upper limit higher time scale aggr 0-av, >0 sum threshold indicator threshold
  1      0      1500      1      1      0.3
  2      0      1500      1      1      0.3
  3      0      1500      1      1      0.3
  4      0      1500      1      1      0.3
  5      0      1500      1      1      0.3
  6      0      1500      1      1      0.3
  7      0      1500      1      1      0.3
  8      0      1500      1      1      0.3
  9      0      1500      1      1      0.3
 10     0      1500      1      1      0.3
 11     0      1500      1      1      0.3
 12     0      1500      1      1      0.3
 13     0      1500      1      1      0.3
 14     0      1500      1      1      0.3
 15     0      1500      1      1      0.3

```

Table 8: A few statistics of raw and bias corrected time series for calibration period: dataset3

(a) Raw data

Variable	Mean		SD		LAG1 Corre		LAG2 Corre		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	1014.91000	998.69270	276.98530	213.56840	.20078	-.06654	.11883	-.11346	.41272	.43369
2	1222.26400	1273.17800	336.84520	356.42470	.12894	.16291	.09737	.14804	.58218	.74283
3	770.81590	785.35680	260.94370	284.29270	.16415	.00165	.15104	.16045	.79906	1.33858
4	1485.34500	1450.90700	494.16750	467.85750	.20772	-.03518	.16392	.05803	.68392	.57882
5	998.50010	1012.91200	281.74410	259.37270	.06118	.19398	.10916	.15209	.46197	.66826
6	843.77040	818.82890	279.71960	240.84110	.11363	.15808	.17029	.06192	.59495	.48861
7	1721.69400	1772.73400	574.67100	635.37360	.09287	.27919	.07781	-.02314	.75477	.75706
8	1286.84700	1239.34500	419.29860	332.32720	.23546	.14295	.26223	-.09620	.69044	.78949
9	759.53820	738.59730	248.89610	213.66900	.10013	.18019	-.00696	-.18179	.64455	.59869
10	849.85820	877.70590	235.17760	200.65250	.10367	.27373	.08319	.09383	.75813	.18647
11	660.40690	644.13190	185.78900	190.91150	.13378	.07032	.10124	-.15090	.39915	.80709
12	1026.51300	914.54350	328.80900	230.12700	.12129	.02007	-.01980	-.18458	.55826	.64622
13	723.18730	788.03910	230.43370	240.24220	.20123	.32659	.09923	-.02408	.65003	.31926
14	847.44680	851.33780	228.77530	229.99210	-.00926	.17852	.06211	-.02065	.37807	.23765
15	1168.93300	1206.26200	315.87010	460.32270	.09561	.32721	.11504	.15553	.54859	.41340
Statistics at Seasonal Level										
1	509.67900	504.79430	185.41220	148.34200	.08055	.14810	.24326	-.05664	.94651	.59455
2	617.08910	631.66210	278.01010	242.42150	-.24395	.07557	.37353	.20527	.82174	.68641
3	388.39070	390.98200	195.09760	189.64610	-.08486	.13032	.31414	.09447	1.46655	1.02845
4	746.17050	726.64830	389.00210	347.77930	-.20983	-.14669	.41300	.26356	1.12277	1.01416
5	500.42530	508.30580	211.37760	188.06190	-.18875	.10129	.28589	.16019	1.02178	.92644
6	423.14150	409.60150	207.48430	161.41730	-.10512	.08514	.26796	.14416	1.29010	.44551
7	858.12020	888.69760	433.94820	424.23230	-.19661	.06998	.34260	.21112	1.14690	1.02651
8	648.46200	622.84970	326.94440	259.13650	-.19245	-.08215	.40733	.21670	.97957	.77818
9	380.36450	370.44030	169.45430	141.37170	.00811	.12603	.18110	.11362	1.09650	.91293
10	423.80580	432.51230	153.43390	140.53810	.07658	.06132	.13811	.21540	1.04564	.52666
11	329.93850	322.52740	119.99180	129.88140	.11768	.05842	.09447	.03476	.51620	.80956
12	512.87840	458.30000	237.99350	170.82030	-.12660	.04211	.29012	-.07753	1.05399	.56220
13	362.16080	391.68990	158.31760	149.54870	.00979	.21922	.24026	.20729	1.25875	.58326
14	426.22970	425.08420	151.52410	149.73980	.03220	.17943	.05957	.12176	.85885	.42771
15	589.57150	600.38340	263.10160	305.58980	-.24958	.02911	.35374	.47106	.84178	.91288
Statistics at Monthly Level										
1	84.95329	83.82393	64.02579	59.70914	.11608	.05116	.09257	.07450	1.80151	1.50934
2	102.78070	105.59110	93.96899	84.56216	.06876	.12824	.04001	.00078	1.95858	1.53387
3	64.79573	65.07799	64.96172	67.49122	.11085	.10255	.10407	.08409	1.97466	2.42810
4	124.30450	120.73680	128.47400	110.07030	.08588	.11189	.04349	.03996	2.20356	2.09952
5	83.52116	84.66153	74.29630	67.36945	.05983	.04665	-.00751	.00574	2.11163	1.96996
6	70.64392	68.41918	70.27670	63.89220	.11805	.04019	.08283	.05271	1.93762	1.89646
7	143.11600	147.62900	144.16490	146.36450	.06813	.07683	.04133	.04984	2.15356	2.43037
8	107.98540	103.83800	107.55690	91.60246	.12874	.09667	.06713	.06081	2.00113	1.71663
9	63.48323	61.59699	59.29981	51.45409	.10462	.04188	.02511	.05007	2.90135	1.61397
10	70.84396	72.00192	54.53593	50.49887	.13535	.03547	.02874	.03840	1.70809	1.38453
11	55.14740	53.75957	42.12397	42.73677	.12365	.12830	.04126	.10348	1.44738	1.69669
12	85.59470	86.34666	82.92091	82.92091	.07300	.02735	.02347	.02193	2.61542	1.83434
13	60.56215	65.69021	53.28434	56.16650	.10551	.06267	.05259	.08302	1.96945	1.93545
14	71.03535	70.90096	52.60167	50.07892	.11733	.14219	.06804	.02594	1.70604	1.25938
15	98.23196	100.43120	89.48470	91.61392	.06090	.21205	.04020	.11656	1.98543	2.30286

(b) Bias corrected

Variable	Mean		SD		LAG1 Corre		LAG2 Corre		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	1014.91000	1015.97400	276.98530	281.77700	.20078	.17250	.11883	-.02720	.41272	.40198
2	1222.26400	1226.28900	336.84520	350.79030	.12894	.18697	.09737	.14840	.58218	.57433
3	770.81590	776.83010	260.94370	267.47380	.16415	.13921	.15104	.05887	.79906	.79630
4	1485.34500	1484.34800	494.16750	499.72660	.20772	.22091	.16392	.04971	.68392	.67711
5	998.50010	999.23580	281.74410	286.24220	.06118	.00184	.10916	-.07069	.46197	.44697
6	843.77040	846.31230	279.71960	282.47490	.11363	.09646	.17029	.01131	.59495	.58991
7	1721.69400	1714.73900	574.67100	576.75830	.09287	.13868	.07781	.10424	.75477	.74751
8	1286.84700	1281.00400	419.29860	437.69300	.23546	.23952	.26223	.06046	.69044	.51945
9	759.53820	757.48360	248.89610	250.71120	.10013	.08618	-.00696	.06806	.64455	.62892
10	849.85820	846.34700	235.17760	236.92940	.10367	.09128	.08319	-.07322	.75813	.74732
11	660.40690	660.40510	185.78900	187.48700	.13378	.12770	.10124	.00381	.39915	.38915
12	1026.51300	1022.22900	328.80900	328.95510	.12129	.16235	-.01980	.06116	.55826	.55040
13	723.18730	723.99410	230.43370	233.34730	.20123	.22667	.09923	.13702	.65003	.63667
14	847.44680	848.02560	228.77530	234.88760	-.00926	-.01704	.06211	-.07010	.37807	.36492
15	1168.93300	1170.95000	315.87010	328.26110	.09561	.13312	.11504	.16485	.54859	.55165
Statistics at Seasonal Level										
1	509.67900	508.42200	185.41220	185.63760	.08055	.10566	.24326	.13011	.94651	.73447
2	617.08910	613.39650	278.01010	277.55230	-.24395	-.20134	.37353	.30576	.82174	.68222
3	388.39070	388.34680	195.09760	196.29870	-.08486	-.07705	.31414	.19628	1.46655	1.51618
4	746.17050	742.17720	389.00210	391.47220	-.20983	-.17570	.41300	.27487	1.12277	1.03491
5	500.42530	498.90950	211.37760	212.52220	-.18875	-.15884	.28589	.13335	1.02178	.91578
6	423.14150	422.76430	207.48430	203.26140	-.10512	-.10809	.26796	.17509	1.29010	1.25997
7	858.12020	855.96930	433.94820	437.51010	-.19661	-.17296	.34260	.23011	1.14690	1.16550
8	648.46200	640.42530	326.94440	327.04790	-.19245	-.14435	.40733	.29974	.97957	.93597
9	380.36450	378.66170	169.45430	170.73910	.00811	.02174	.18110	.08496	1.09650	.99295
10	423.80580	423.39010	153.43390	156.41160	.07658	.06093	.13811	.08140	1.04564	1.07988
11	329.93850	330.16340	119.99180	120.19050	.11768	.12687	.09447	.06732	.51620	.42093
12	512.87840	511.47820	237.99350	238.68890	-.12660	-.10572	.29012	.21454	1.05399	1.02338
13	362.16080	362.50890	158.31760	159.55890	.00979	.03713	.24026	.17926	1.25875	1.16284
14	426.22970	423.82760	151.52410	153.00270	.03220	.02164	.05957	-.03053	.85885	.74229
15	589.57150	585.52680	263.10160	262.79890	-.24958	-.21324	.35374	.28024	.84178	.74017
Statistics at Monthly Level										
1	84.95329	84.77444	64.02579	64.83232	.11608	.10519	.09257	.13271	1.80151	1.60532
2	102.78070	102.28940	93.96899	95.81302	.06876	.06718	.04001	.04232	1.95858	1.74147
3	64.79573	64.71867	64.96172	66.13430	.11085	.07944	.10407	.10473	1.97466	1.82531
4	124.30450	123.71570	128.47400	131.96830	.08588	.06953	.04349	.04771	2.20356	1.95682
5	83.52116	83.19615	74.29630	75.98300	.05983	.04299	-.00751	.06535	2.11163	1.77243
6	70.64392	70.47025	70.27670	71.04875	.11805	.07972	.08283	.08763	1.93762	1.67575
7	143.11600	142.77070	144.16490	147.31290	.06813	.04387	.04133	.05595	2.15356	1.87117
8	107.98540	107.14100	107.55690	109.17610	.12874	.08891	.06713	.06710	2.00113	1.81954
9	63.48323	63.20314	59.29981	60.34837	.10462	.09155	.02511	.06344	2.90135	2.34170
10	70.84396	70.60664	54.53593	56.32887	.13535	.09926	.02874	.03830	1.70809	1.67482
11	55.14740	55.04200	42.12397	43.29775	.12365	.11579	.04126	.04225	1.44738	1.32825
12	85.59470	85.39006	82.92091	84.92062	.07300	.06265	.02347	.06158	2.61542	2.24694
13	60.56215	60.45809	53.28434	55.16214	.10551	.10391	.05259	.08186	1.96945	1.80325
14	71.03535	70.72619	52.60167	53.66370	.11733	.10499	.06804	.05554	1.70604	1.37932
15	98.23196	97.56973	89.48470	91.93147	.06090	.03155	.04020	.04282	1.98543	1.81564

Table 9: A few statistics of raw and bias corrected time series for verification period: dataset3

(a) Raw data

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	1014.91000	1024.23200	276.98530	289.79350	.20078	-.00728	.11883	-.14028	.41272	.68209
2	1222.26400	1206.46900	336.84520	366.12300	.12894	-.06862	.09737	-.20475	.58218	.26037
3	770.81590	824.01030	260.94370	245.53540	.16415	-.03887	.15104	-.10877	.79906	.52426
4	1485.34500	1543.59000	494.16750	372.63110	.20772	.22107	.16392	-.29684	.68392	.70558
5	998.50010	1020.99400	281.74410	351.91590	.06118	-.03331	.10916	-.09489	.46197	1.27995
6	843.77040	798.46950	279.71960	235.55940	.11363	-.09665	.17029	-.08797	.59495	.33969
7	1721.69400	1722.62200	574.67100	644.19060	.09287	.04366	.07781	-.09553	.75477	.69640
8	1286.84700	1177.29900	419.29860	428.06370	.23546	.23313	.26223	.12170	.69044	1.00307
9	759.53820	743.82750	248.89610	234.05530	.10013	.21105	-.00696	.08706	.64455	.58042
10	849.85820	864.66370	235.17760	222.10730	.10367	.14455	.00839	.10028	.75813	.29947
11	660.40690	689.02030	185.78900	226.15990	.13378	.37698	.10124	.29106	.39915	.40045
12	1026.51300	993.31860	328.80900	297.63110	.12129	.14271	-.01980	.16268	.55826	.39022
13	723.18730	760.35510	230.43370	199.03780	.20123	.01178	.09923	-.15049	.65003	.47358
14	847.44680	836.21310	228.77530	222.33540	-.00926	.10773	.06211	-.07153	.37807	.13083
15	1168.93300	1241.68000	315.87010	400.90050	.09561	.14260	.11504	.00737	.54859	.21068
Statistics at Seasonal Level										
1	509.67900	511.35420	185.41220	183.29480	.08055	.14575	.24326	-.04346	.94651	.66807
2	617.08910	599.62150	278.01010	252.07210	-.24395	-.03484	.09674	.37353	.82174	.64315
3	388.39070	412.61150	195.09760	177.35280	-.08486	-.14252	.31414	.17733	1.46655	1.10226
4	746.17050	762.44900	389.00210	294.94950	-.20983	-.16445	.41300	.30582	1.12277	.79173
5	500.42530	508.18120	211.37760	253.67600	-.18875	-.03261	.28589	.04740	1.02178	2.43561
6	423.14150	400.82370	207.48430	174.35310	-.10512	-.08883	.26796	.14360	1.29010	1.02004
7	858.12020	863.29580	433.94820	443.05290	-.19661	-.04876	.34260	.12112	1.14690	1.29488
8	648.46200	588.97140	326.94440	301.22290	-.19245	.07309	.40733	.30502	.97957	1.27116
9	380.36450	369.19420	169.45430	156.55140	.00811	.19119	.18110	.12515	1.09650	.85006
10	423.80580	433.84680	153.43390	152.07730	.07658	.15049	.13811	-.02726	1.04564	.84170
11	329.93850	342.62370	119.99180	138.13120	.11768	.31610	.09447	.25288	.51620	.66487
12	512.87840	497.23090	237.99350	195.83530	-.12660	.16604	.29012	.04692	1.05399	.66134
13	362.16080	379.60210	158.31760	135.48320	.00979	.06510	.24026	-.07587	1.25875	.70550
14	426.22970	417.13590	151.52410	137.21540	.03220	.23076	.05957	.06976	.85885	.58081
15	589.57150	622.09340	263.10160	274.47840	-.24958	.03909	.35374	.18354	.84178	.80628
Statistics at Monthly Level										
1	84.95329	85.03928	64.02579	61.13312	.11608	.13843	.09257	.11446	1.80151	1.77067
2	102.78070	100.38660	93.96899	82.97786	.06876	.06834	.04001	.10208	1.95858	1.67817
3	64.79573	68.84090	64.96172	66.56024	.11085	.05060	.10407	.02911	1.97466	2.44994
4	124.30450	128.05340	128.47400	115.54550	.08588	.01626	.04349	-.00287	2.20356	2.15614
5	83.52116	84.54016	74.29630	90.83154	.05983	.08383	-.00751	.07094	2.11163	6.52837
6	70.64392	66.89117	70.27670	62.56224	.11805	.11473	.08283	.05097	1.93762	2.25059
7	143.11600	143.33350	144.16490	152.45250	.06813	.12671	.04133	.07340	2.15356	3.22472
8	107.98540	98.14247	107.55690	97.38316	.12874	.13538	.06713	.13661	2.00113	2.20463
9	63.48323	61.65693	59.29981	54.79449	.10462	.05385	.02511	.01758	2.90135	2.02517
10	70.84396	72.10526	54.53593	53.36875	.13535	.06735	.02874	.07436	1.70809	1.70092
11	55.14740	57.03683	42.23397	44.47588	.07551	.08883	.04126	.10798	1.44738	1.47251
12	85.59470	82.74319	82.92091	74.37447	.05300	.07407	.02347	.05405	2.61542	2.23423
13	60.56215	63.21033	53.28434	50.06249	.10551	.16056	.05259	.02534	1.96945	1.59399
14	71.03535	69.52634	52.60167	48.42537	.11733	.04262	.06804	.01379	1.70604	1.56690
15	98.23196	103.71070	89.48470	87.35123	.06090	.12032	.04020	.06352	1.98543	1.85733

(b) Bias corrected

Variable	Mean		SD		LAG1 Correl		LAG2 Correl		Skewness	
	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled	Observed	Modelled
Statistics at Annual Level										
1	1014.91000	1033.19900	276.98530	416.88900	.20078	.03274	.11883	-.00815	.41272	1.63146
2	1222.26400	1231.68700	336.84520	415.28020	.12894	-.21761	.09737	.13733	.58218	.77079
3	770.81590	789.70110	260.94370	360.72310	.16415	-.18098	.15104	-.00327	.79906	2.08957
4	1485.34500	1502.13500	494.16750	631.49540	.20772	-.06023	.16392	.10904	.68392	1.15724
5	998.50010	998.57170	281.74410	297.78510	.06118	-.23617	.10916	.25244	.46197	.57923
6	843.77040	862.20170	279.71960	417.40510	.11363	-.28523	.17029	.01543	.59495	2.48514
7	1721.69400	1721.05800	574.67100	674.27100	.09287	.32418	.07781	.15480	.75477	.88706
8	1286.84700	138.97000	419.29860	595.06480	.23546	.23546	.26223	.05607	.69044	3.20947
9	759.53820	761.16750	248.89610	295.23280	.10013	-.16884	-.00696	.15376	.64455	.80264
10	849.85820	844.49520	235.17760	261.29060	.10367	-.21369	.00839	.18583	.75813	.82642
11	660.40690	663.16380	185.78900	210.58640	.13378	.10493	.10124	-.07628	.39915	.99734
12	1026.51300	1030.00200	328.80900	390.12340	.12129	-.29949	-.01980	.18996	.55826	.55798
13	723.18730	725.34530	230.43370	250.62740	.20123	.00682	.09923	.11468	.65003	.43999
14	847.44680	847.78980	228.77530	256.41760	-.00926	.07519	.06211	.03695	.37807	.35002
15	1168.93300	1177.97400	315.87010	393.42170	.09561	-.18161	.11504	.08930	.54859	.76670
Statistics at Seasonal Level										
1	509.67900	517.07320	185.41220	245.68270	.08055	.22239	.24326	.02294	.94651	2.86512
2	617.08910	613.82950	278.01010	288.63280	-.24395	-.18164	.37353	.08453	.82174	.74006
3	388.39070	393.94780	195.09760	228.19730	-.08486	.00404	.31414	-.01372	1.46655	2.94960
4	746.17050	745.92080	389.00210	428.31590	-.20983	-.09458	.41300	.17321	1.12277	1.62411
5	500.42530	498.04450	211.37760	220.94590	-.18875	-.18231	.28589	.02004	1.02178	1.15870
6	423.14150	429.85750	207.48430	257.23390	-.10512	.03552	.26796	-.11980	1.29010	3.61975
7	858.12020	855.74650	433.94820	459.55770	-.19661	-.17042	.34260	.02607	1.14690	1.32975
8	648.46200	651.12960	326.94440	358.64990	-.19245	.11547	.40733	.11547	.97957	1.63324
9	380.36450	379.67500	169.45430	177.02020	.00811	.15254	.18110	-.10601	1.09650	1.04800
10	423.80580	423.18470	153.43390	162.52110	.07658	.12405	.13811	.14552	1.04564	1.40104
11	329.93850	331.58080	119.99180	129.96250	.11768	.27184	.09447	.19141	.51620	1.19201
12	512.87840	513.25530	237.99350	246.20490	-.12660	.01522	.29012	-.10501	1.05399	1.05399
13	362.16080	362.80660	158.31760	158.20650	.00979	.15477	.24026	.03947	1.25875	1.14066
14	426.22970	424.26810	151.52410	158.35310	.03220	.20264	.05957	.02133	.85885	1.09799
15	589.57150	585.18710	263.10160	281.91940	-.24958	-.21840	.35374	.10477	.84178	.91782
Statistics at Monthly Level										
1	84.95329	86.01029	64.02579	83.39093	.11608	.10359	.09257	.09257	1.80151	2.20000
2	102.78070	102.54850	93.96899	117.91510	.06876	-.00613	.04001	-.00710	1.95858	1.98219
3	64.79573	65.68986	64.96172	77.89826	.11085	.04977	.10407	.07808	1.97466	2.30556
4	124.30450	124.53660	128.47400	161.00530	.08588	.00827	.04349	.04859	2.20356	2.46566
5	83.52116	82.88083	74.29630	97.86182	.05983	-.07386	-.00751	.01282	2.11163	2.48973
6	70.64392	71.59128	70.27670	89.76194	.11805	.10659	.08283	.04911	1.93762	2.43394
7	143.11600	142.88150	144.16490	179.32960	.06813	-.02297	.04133	.02251	2.15356	2.15719
8	107.98540	108.53030	107.55690	135.36120	.12874	.08594	.06713	.01946	2.00113	2.02999
9	63.48323	63.21531	59.29981	74.22312	.10462	-.03014	.02511	.03416	2.90135	2.12414
10	70.84396	70.31515	54.53593	72.45659	.13535	-.01152	.02874	-.04300	1.70809	1.87777
11	55.14740	55.03102	42.23397	53.37137	.07551	-.00897	.04126	-.01404	1.44738	1.63800
12	85.59470	85.51060	82.92091	102.00890	.05300	.07300	.02347	.02709	2.61542	2.11072
13	60.56215	60.30075	53.28434	65.49623	.10551	-.02361	.05259	-.03204	1.96945	1.94294
14	71.03535	70.53312	52.60167	66.16062	.11733	-.04793	.06804	.01067	1.70604	1.85110
15	98.23196	97.81871	89.48470	110.30780	.06090	-.01039	.04020	.00077</		

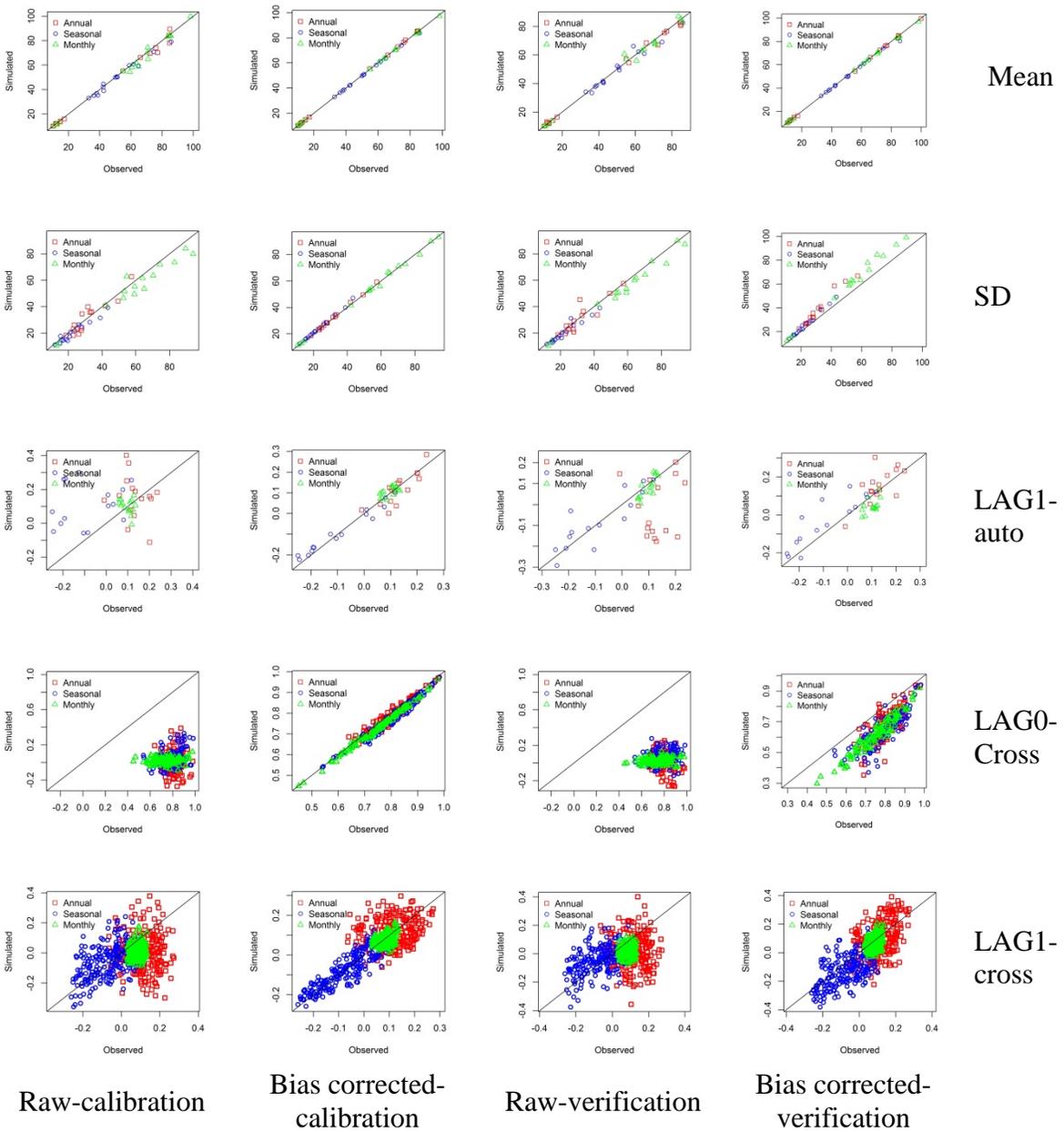


Figure 5: Same as Figure 1 for dataset 3

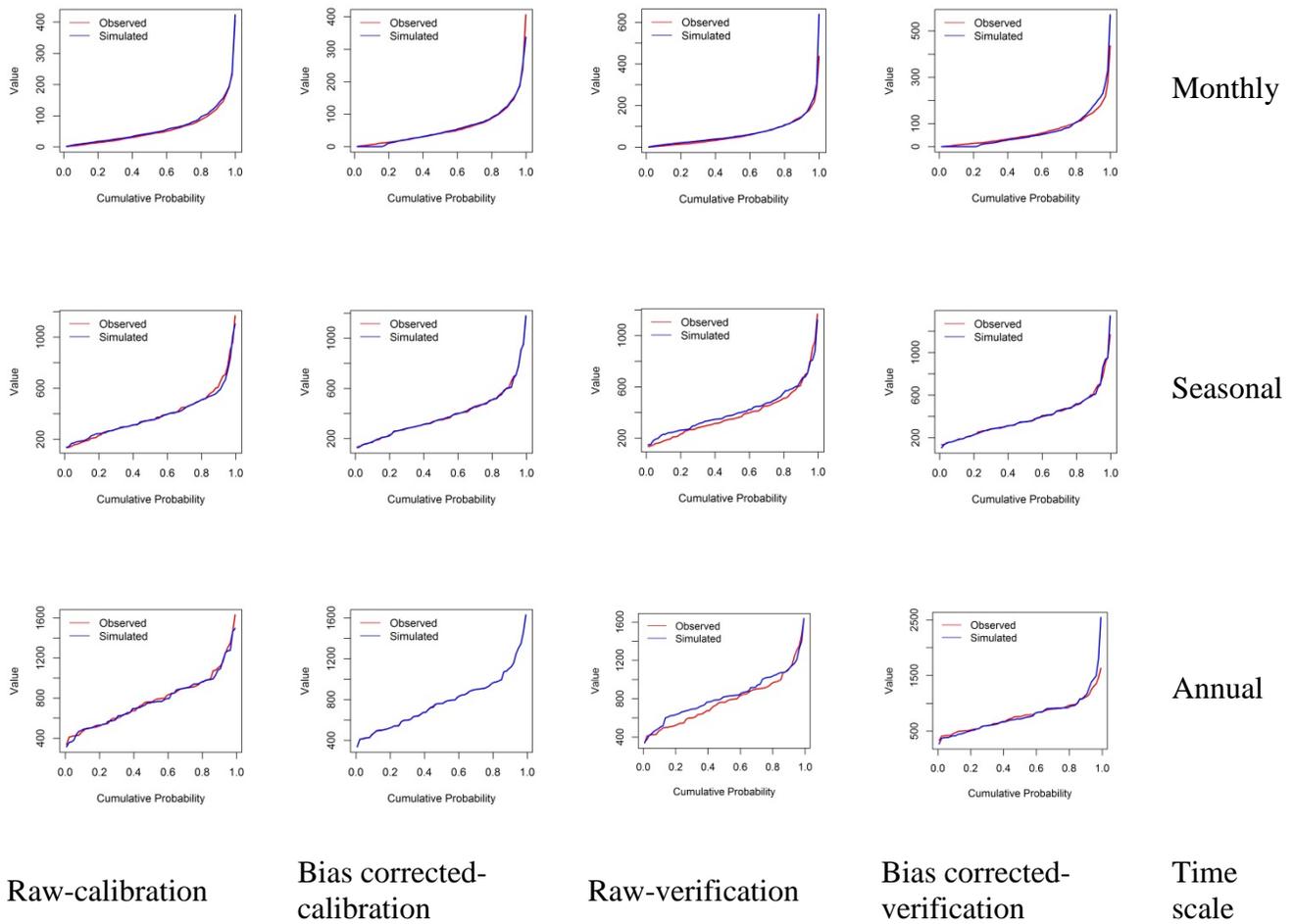


Figure 6: Same as Figure 2, for dataset 3 and station 3