The following material is based on the work of A Anandhi, 'Examination of Change Factor Methodologies for Climate Change Impact Assessment', published in Water Resources Research, 2011.

CHANGE FACTOR METHOD

Introduction:

Change factor method, also known as Simple scaling method or Delta change factor method is a computationally straight forward method, mostly used in the impact analysis studies. It has wide applications, but it is not a downscaling method. In this section, you will find a detailed description on the different types of Change factor methods and their applications. Looking at the pros and cons of the method:

Pros:

- Simplest method to obtain projection
- Ease and speed of applications
- Direct scaling of local data in line with the changes suggested by the GCMs

Cons:

- Scale issues
- Choice of Change factor is not obvious (no clearly defined guidelines to choose the CF)
- Not useful in the scenarios where changes in event frequency and preceding conditions are important in impact assessment as single CFs does not differentiate temporal sequencing of wet and dry days

Methodologies:

Change factors are of different types, classified by:

1. Temporal scale and temporal resolution
2. Mathematical formulation
3. Number of Change Factors

1. Classification by temporal scale and temporal domain:

The CFM is classified by temporal scale and temporal domain, from which they are estimated. Temporal scales are simply time scales used in the study. Temporal domain represents the time of the year, the starting and the ending dates of historical observed, historical modeled, and future modeled values that have to be incorporated in the analysis. However, more the frequency of the time scales, the lesser the GCM efficiency, i.e. monthly, seasonal, and annual averages gives improved simulations for any variables than daily values.

2. Classification by mathematical formulation

This classification is based on whether the CF used is additive or multiplicative. The mathematical procedures to determine the additive and multiplicative CFs are explained later in this chapter.

Additive CFM:

A GCM variable from a current climate scenario and a future scenario at a single location is taken and their arithmetic difference is calculated. This difference obtained is added to the obtained local values to find out the future simulation values. The method assumes that the GCM gives an acceptable value of the absolute change, no matter how accurate the GCM's current climate simulation is.

Multiplicative CFM:

In multiplicative CFM the ratio between the future and the current GCM simulation is found and then multiplied to the observed values. This is done in the assumption that the relative change in the value of a variable can be determined by the GCM quite judiciously. Multiplicative CFs are generally used for precipitation. To use them for temperature, the unit must be converted to Kelvin scale. Often, a random number is chosen as CF and applied such that temperature is increased to obtained scenarios. The scenarios, however, does not represent reliable changes and are called synthetic scenarios. These scenarios are useful in checking the sensitivity of systems before the implementation of reliable model based scenarios. Apart from temperature and precipitation, for other variables such as wind speed and solar radiation, there are no clear methodologies defined to determine the CFs. These variables are frequently used in hydrological impact assessment studies and it is important to define which method is to be used (additive or multiplicative) and the proper way of execution of the methods.

3. Classification based on the number of Change factors (single and multiple)

The analysis done using CFs can include single CF, multiple CFs or both. The single CF is calculated equally for all the values of a variable irrespective of their magnitude. Whereas multiple CFs calculated are different for different ranges of values of the variables, depending on their magnitude. For example, the CF for percentiles 0-10, 10-20, and so on, can be calculated separately. In this case too, there are no properly defined procedures on the number of CFs to be used.

For CFM analysis the CF chosen should be relevant to the methodology applied for the analysis. For example, for a temporal daily scale of a temporal domain having all January values from 1981-2000, compared to future scenarios of 2046-2065, and an additive single CF, it is mostly preferred to analyze each month of a year. In which case, each monthly analysis is carried out separately. The CFs can be obtained from a single GCM grid point or can be taken as the average of the grid points.

Single CF:

Procedure to determine a single CF (additively/multiplicatively) is explained in the following steps:

Step 1: Calculate the mean values of GCM simulated baseline and future climate scenarios.

$$\overline{GCMb} = \sum_{i=1}^{Nb} \frac{GCMb_i}{Nb} \quad (1)$$

$$\overline{GCMf} = \sum_{i=1}^{Nf} \frac{GCMf_i}{Nf} \quad (2)$$

Where,

$GCMb$: Values from GCM baseline for a temporal domain

$GCMf$: Values from GCM future scenarios for the same temporal domain

$\overline{GCMb}$: Mean values of a GCM baseline for a temporal domain

$\overline{GCMf}$: Mean values of future scenarios for the same temporal domain

Nb: No. of values in the temporal domain of the GCM baseline

Nf: No. of values in the temporal domain of the GCM future scenario

Example:

For a temporal domain, January 1981-2000, the number of values in the temporal domain of the GCM baseline, consider:

- Nb at daily temporal scale:
  Nb = No. of days in all the January months in the temporal domain
  i.e. Nb = 20*31

- Nb at monthly temporal scale:
  Nb = No. January months in the temporal domain (between 1981-2000)
  i.e. Nb = 20

Similarly, for the future domain, January 2046-2065, consider:

- Nf at daily temporal scale:
  Nf = No. of days in all the January months in the temporal domain
  i.e. Nf = 20*31

- Nf at monthly temporal scale:
  Nf = No. January months in the temporal domain (between 2046-2065)
  i.e. Nf = 20

Step 2: Calculate additive and multiplicative CFs (CF_{add} and CF_{mul})

$$CF_{add} = \overline{GCMf} - \overline{GCMb} \quad (3)$$

$$CF_{mul} = \frac{\overline{GCMf}}{\overline{GCMb}} \quad (4)$$

Step 3: Determine the local scaled future values.

Local scaled future values ($LSf_{add,i}$ and $LSf_{mul,i}$) are determined by applying CF_{add} and CF_{mul}.

$$LSf_{add,i} = LOb_i + CF_{add} \quad (5)$$

$$LSf_{mul,i} = LOb_i * CF_{mul} \quad (6)$$

Where,

LOb_i: Observed values of the meteorological variable, at the i^{th} time step at an individual meteorological station or, the averaged meteorological time series for a watershed for the specified temporal domain

$LSf_{add,i}$ and $LSf_{mul,i}$: Future scenario values of the variables obtained using additive and multiplicative CFMs.

Figure 1 shows the graphical representation of the Single CF calculation procedure for both additive and multiplicative CF.

Multiple (Magnitude dependent) CFs:

Procedure to determine multiple CF (additively/multiplicatively) is explained in the following steps:

Step 1: Estimation of empirical cumulative distribution functions (CDFs) for $GCMb$ and $GCMf$.

Step 2: This step includes (i) Ascertaining the number of sets/bins (n) required and (ii) Fixing the resolution of percentiles (r) in each bin.

The size of the bin can be uniform or non-uniform. In the case of multiple CFs, calculations have to be performed in each bin to find out corresponding CF. The calculations are similar to the calculations for determining single CF. Note that equations 1-6 and 7-12 are similar.

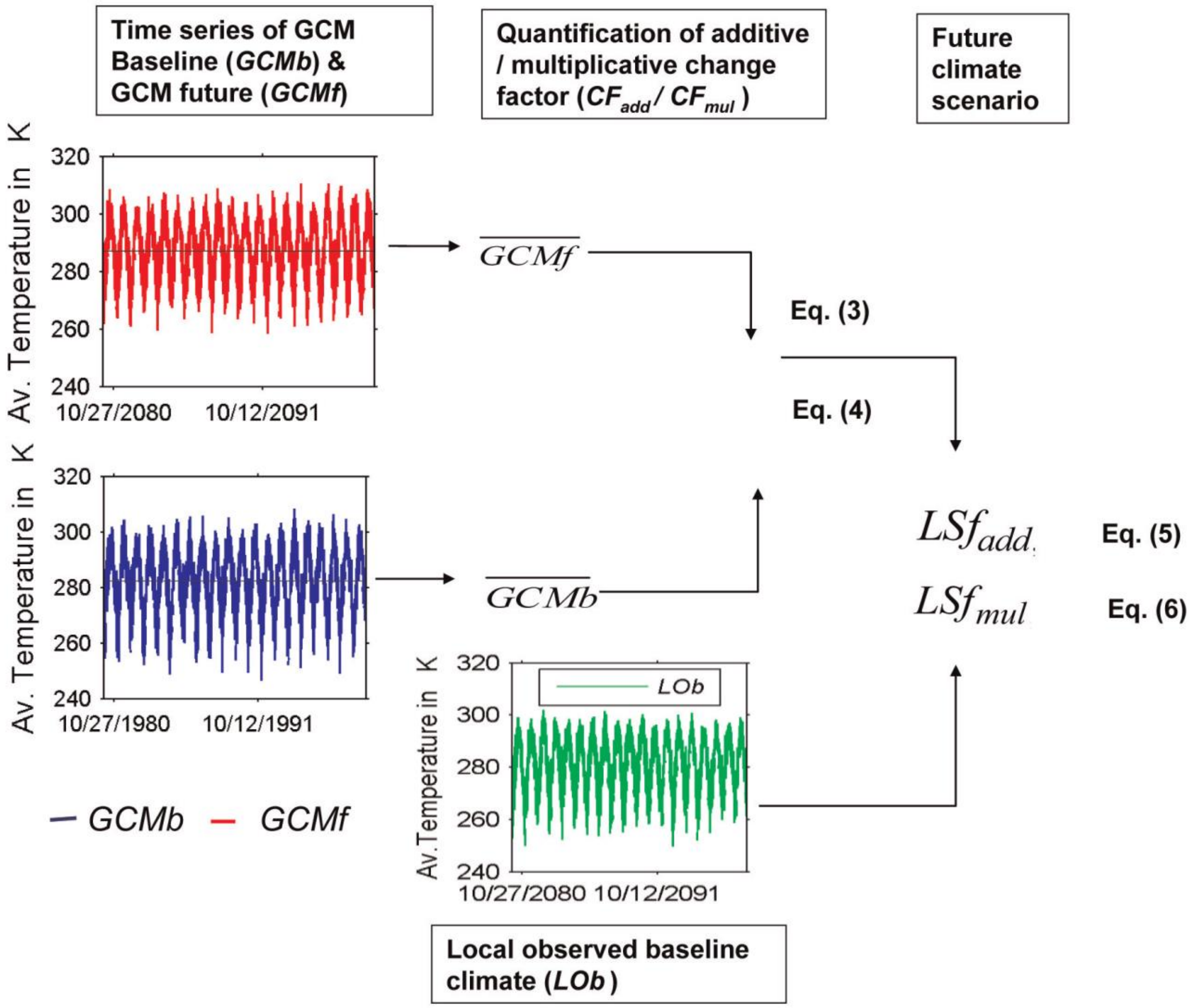


Figure 1: Procedure to determine future scenarios using ‘‘Single additive’’ and ‘‘Single multiplicative’’ Change Factors (Source: Anandhi et al., 2011)

Step 3: For each bin, $GCMb$ and $GCMf$ are estimated.

$$\overline{GCMb_n} = \sum_{i=1}^{Nb} \frac{GCMb_{i,n}}{Nb} \quad 7$$

$$\overline{GCMf_n} = \sum_{i=1}^{Nf} \frac{GCMf_{i,n}}{Nf} \quad 8$$

Here, n represents the corresponding bin.

Step 4: Estimating additive and multiplicative CFs ($CF_{add,n}$ and $CF_{mul,n}$) for each bin

$$CF_{add,n} = \overline{GCMf_n} - \overline{GCMb_n} \quad 9$$

$$CF_{mul,n} = \frac{\overline{GCMf_n}}{\overline{GCMb_n}} \quad 10$$

Step 5: Calculating the CDF for LOb and then dividing LOb into the same bin and percentile classes.

Step 6: Determining future scaled climate values

Future scaled climate values ($LSf_{add,n,j}$ and $LSf_{mul,n,j}$) are determined by applying $CF_{add,n}$ and $CF_{mul,n}$ to the corresponding observed values (j) in each bin in the baseline period, LOb using the following equations, 11 and 12.

$$LSf_{add,n,j} = LOb_{n,j} + CF_{add,n} \quad (11)$$

$$LSf_{mul,n,j} = LOb_{n,j} * CF_{mul,n} \quad (12)$$

Exercise 1: Bangalore City Temperature using Change Factor Method

Objective: To obtain projected average daily temperature for Bangalore city during 2021-2050 using Delta change (Change factor) method.

- Historical data is available at Bangalore city meteorological station located at 12.97°N, 77.58°E for the period 1971- 2000
- Use CMIP5 GCM : MIROC-ESM (scenario RCP 4.5)

Solution:

Step 1:

i. Download the GCM data for variable "Near-Surface Air Temperature" (tas) for "historical" and "future run RCP 4.5 scenario"

ii. The data are available at https://esgf-node.llnl.gov/search/esgf-llnl/

iii. Select a CMIP5 under "Project" and "MIROC-ESM" under "Model" and search for the variable "Near-Surface Air Temperature"

iv. Choose the appropriate file from the search results and download by clicking "HTTP Download"

v. Log in (Registration for a login may be done by filling up simple details) is required to download the data set.

Step 2:

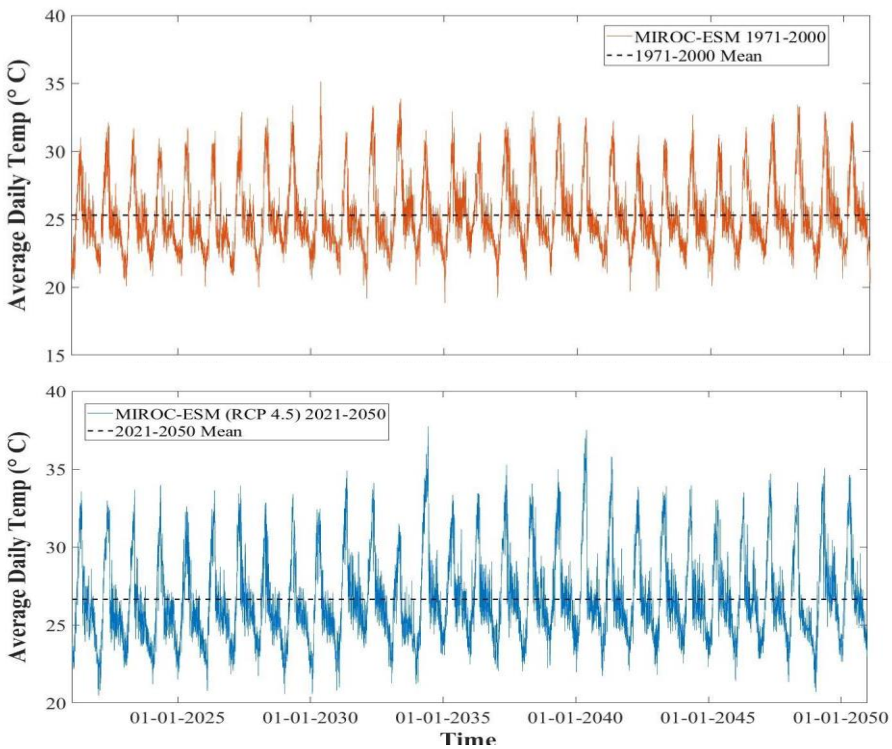
i. The data format is normally in NetCDF (.nc) format. MATLAB can be used to read and process the GCM datasets.

ii. The gridpoints of the GCM do not match with the station location. Here, the data at the GCM gridpoint nearest to the station at which historical data is available is considered.

iii. Data is extracted for the nearest Lat-Lon from 12.97°N, 77.58°E and the temporal domain required i.e. for historical: 1971-2000 and for future RCP 4.5 scenario: 2021-2050

iv. Units are converted from “Kelvin” to “°C ”

Step 3: Calculate mean values of GCM simulated baseline (1971-2000) and future climates (2021-2050)



$\overline{GCMb}$ = 25.29 °C

$\overline{GCMf}$ = 26.64 ℃

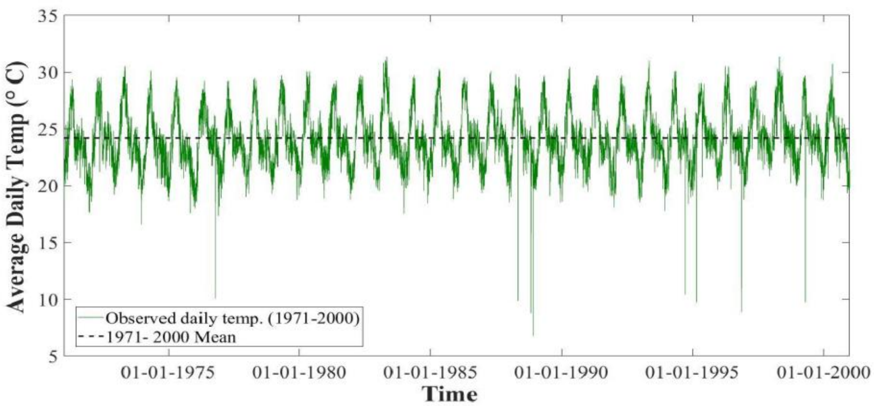
Step 4: Calculate additive change factor (CF_{add})

$$CF_{add} = GCMf - GCMb$$

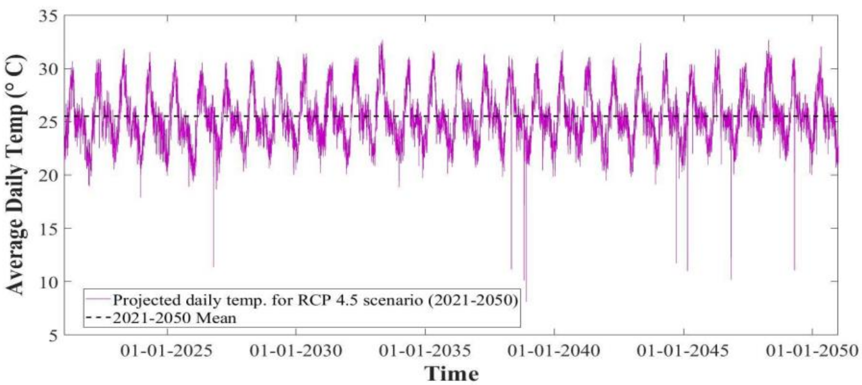
$$CF_{add} = 26.64 - 25.29 = 1.35°C$$

Step 5: Obtain local scaled future values ($\boldsymbol{LSf}_{add,}$) by applying CF_{add} to the observed values of the average daily temperature at the meteorological station ($\boldsymbol{LOb}_i$)

$$\boldsymbol{LSf}_{add,i} = \boldsymbol{LOb}_i + CF_{add}$$



Local observed baseline climate (*LOb*)
Mean: 24.16 °C



Local scaled future climate (*LSf*)
for RCP 4.5 scenario
Mean: 25.51 °C

REFERENCES:

Anandhi, A., Frei, A., Pierson, D. C., Schneiderman, E. M., Zion, M. S., Lounsbury, D., & Matonse, A. H. (2011). Examination of change factor methodologies for climate change impact assessment. *Water Resources Research*, *47*(3). https://doi.org/10.1029/2010WR009104