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GENERALIZED TOOL FOR UPDATING INTENSITY-DURATION-FREQUENCY CURVES UNDER CLIMATE CHANGE

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ABSTRACT: This paper presents a web based tool that integrates an user interface (UI) with an efficient methodology to update the intensity duration frequency curves (IDF) considering the impact of climate change. IDF curves are frequently used for design of urban drainage, road drainage, flood control structures. It is an expedient method to obtain design ietographs and does not require specific knowledge. The assumption is that the IDF used, should properly represents the hydrological conditions during the life time of the designed structure. The methodology consists of creating correlation through spatial disaggregation and the use of transfer function from the historical data observed to the historical scenarios from the global circulation models (GCM). In this study the statistical relationship between the observed data and the GCM output is established for the base period. This relationship is applied on future period GCM scenarios to generate the updated IDF curves. The application of proposed methodology and tool is applied at a metrological station located at the city of São Paulo, Brazil. The results obtained from the proposed methodology are compared with an existing IDF curves. The GCM model used in the analysis was the CanESM2 from Canadian Centre for Climate Modelling and Analysis. The results show an increasing trend of extreme precipitation compared to the IDF adjusted to the most recent data available.

Key Words: Climate change, IDF Curves, global circulation models

1. INTRODUCTION

There is a great concern among scientific community to understand adequately and comprehensively the effects of climate change on extreme hydrological events such as precipitation, whose frequency and intensity has admittedly changed in recent decades. The recent increase in frequencies and intensities of catastrophic events such as floods, droughts, hurricanes indicates change in climate. Changes in climate conditions observed over the last decades are considered to be the cause of dramatic modifications of magnitude and frequency of occurrence of extreme events. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013) has indicated a global surface temperature increase of 0.3 to 4.8 °C by the year 2100 compared to the reference period 1986-2005 and with maximum changes in tropics and subtropics than in mid-altitudes. It is expected that the rising temperature will have a major impact on the magnitude and frequency of extreme precipitation events in some regions (Wilcox et al., 2007; Allan et al., 2008, Solaiman et al. 2011).

Application of the methodologies proposed by researchers may be challenging to stakeholders and policymakers. The main reasons are most likely: 1) complex methods based on heavy mathematical equations are difficult to implement; 2) researchers focus on publishing their findings following rigorous peer review requirements and little attention is given to practical application; 3) climate change field is somehow controversial and several models and approaches exist, increasing the level of difficulty in application of climate change to design and decision making. For this reason, the implementation of a generic and simplified tool that easily allows these users to incorporate climate change into the storm water design and management, in for of updated IDFs, seems compelling and necessary. To accomplish this task a tool in form of a Decision Support System (DSS) is proposed, combining a friendly web based user interface with powerful database system and simplified, but efficient, methodology for the updated IDF procedure, also briefly presented. It does not require specific knowledge from user of any of involved mathematical models and procedures applied, i.e., GCM models structure and data extraction, statistical methods, optimization and update procedure itself.

Intensity duration frequency (IDFs) curves are usually developed by fitting a theoretical probability distribution to the annual maximum precipitation (AMP) events. The AMP data is fitted using extreme value distributions like Gumbel, Generalized Extreme Value – GEV, Log Pearson, Log Normal and others. These curves provide precipitation accumulation depths for various return periods (T) and different sub-daily/daily durations, usually, 5, 10, 15, 20 30 minutes, 1, 2, 6, 12, 18 and 24 hours. Longer durations are also used, depending on the use of IDF curves. Hydrologic design of storm sewers, culverts, detention basins and other elements of storm water management systems are typically performed based on specified design storms derived from the IDF curves (Solaiman and Simonovic, 2010). The main assumption in this process is that the historical series are stationary and therefore can be used to represent the future extreme conditions. This assumption is questionable under rapidly changing conditions, and therefore IDF curves that rely only on the historical observations, will misrepresent future conditions (Sugahara et al. 2009, Milly et al. 2008). The Global Circulation Models (GCM) is found to be one of the ways to explicitly incorporate such non-stationarity or the changing climate scenarios for the future periods.

Recently there have been number of studies based on statistical downscaling that have used GCM's and/or RCM's to update the IDF curves (Mailhot et al, 2007; Nguyen et al., 2007; Prodanovic and Simonovic, 2007; Kao and Ganguly, 2011; Mirhosseini et al, 2013; Hassanzadeh et al., 2013). These studies can be characterized into three groups (Walsh, 2011) (i) based on weather generator or delta method which accounts for the change in GCM values (change factors) between the projection period and the baseline period; (ii) Bias-correction method in which the differences between the mean values of the GCM and the observed data are used to modify the future GCM simulations and (iii) Bias-correction-disaggregation method wherein quantile-mapping is used to map the GCM data onto historical data and then disaggregate to sub-daily data.. Some of the drawbacks of these proposed methods are (i) weather generators are complex and computationally intensive; (ii) the change factors obtained on the daily/monthly GCM data and cannot be directly applied to sub-daily data; (iii) the disaggregation procedures are complex and adds additional uncertainty; (iv) quantile-mapping thee statistical downscaling models assume that the relationship between the GCM and the observed data remains the same for the projected time period (i.e., it does not account for the non-stationarity). In general, the updating procedures should be reliable, simple and robust to capture the underlying process in the historical data and the future changes due to climate change.

Li et al., (2010) developed quantile-based mapping method for bias correction of monthly GCM simulations and reported that the method is more efficient than the existing traditional CDF mapping (e.g. Ines and Hansen, 2006; Piani et al., 2010; Wood et al., 2004). Unlike the existing bias correction methods where the cumulative distribution functions are used for the baseline period (assume stationarity), they included an additional step to incorporate and adjust the functions for the changes in the projection period. The quantile-based mapping method suggested by Li et al., (2010) seems to be appropriate one in this context and has motivated us to adopt it as methodology to update the IDF curves under climate change embed in the generalized tool proposed. In this research, we propose equidistant quantile matching method of Li et al., (2013) to update the IDF curves which can capture the distribution changes between the projected time period and the baseline period (temporal downscaling), in addition spatial downscaling the annual maximum precipitation (AMP) derived from the GCM data and the observed sub-daily data.

In the next section of the paper, methodology is presented followed by a case study, results and conclusion.

2. METODOLOGY

This paper presents a generalized tool for updating IDF curves under climate change conditions. The tool is built in form of a Decision Support System (DSS) and aims to assist in the assessment of impacts of climate change on the intensity, duration and frequency of extreme rainfall events through the update of IDF curves. The DSS is built in a generic form and can be used to fit IDF equations for any station with sub-daily maximums available. First, an IDF is fitted to the historical observed data using Extreme Value Type 1, i.e., Gumbel distribution function and/or Generalized Extreme Value, i.e. GEV distribution. Based on the station location, and selected GCM model, the updated IDF is then calculated using the method described. For the update procedure an equidistant quantile-matching (EQM) method, proposed by Srivastav et al. (2014) is used. The method integrates two components: (i) a cumulative distribution function based quantile-quantile relationship is established between the GCM daily maximum and the historical sub-daily maximum for the baseline period (spatial downscaling); and (ii) cumulative distribution function based quantile-quantile relationship is established for the projection period between the GCM daily maximum and the future GCM simulations (RCP) daily maximum (temporal downscaling).

2.1 Tool description

The web based tool developed for IDF updated has the usual components of a DSS as presented in Figure 1. The user interface rallies on a GIS (geographic information system) component that is responsible for presenting stations on the map. User information, station's data, GCM models outputs are stored on the tool's database system and netCDF repository. Mathematical models and algorithms assist in IDF fitting and update process. The main objective of the tool is to automate and facilitate the IDF update procedure using as input historical observed data at local stations and precipitation data from GCM model output. The update procedure requires historical sub-daily maximum of observed precipitation data to be provided by the user. In case of Canada, a repository of stations from the Environmental Canada (the country's official environmental agency) is available through the user interface with sub-daily historical records.

Based on the precipitation series, either provided by user or from official sources, the IDF curve is first fitted to historical observed data by using Gumbel and GEV distribution. With the IDF fitted, the possible changes for the future are calculated from the selected GCM model using EQM method. The tool is built such a way that with only a few click through the UI, the user is able obtain updated IDF for future condition based on the GCM model selected. Results are presented in form of tables and interactive graphs. As mention, GCM models for IPCC AR 5 provide scenarios for the future, the so called RCPs, and each RCP have usually several different runs associated. For this reason, a range of possible future IDFs is generated with the application of the EQM method. Results of the future IDF is available as an average from each RCP in form of tables and interactive graphs. The uncertainty relate to the different ensembles (runs) available for each RCP is presented as a range with lower and upper bounds limits, by applying the same procedure to each run.

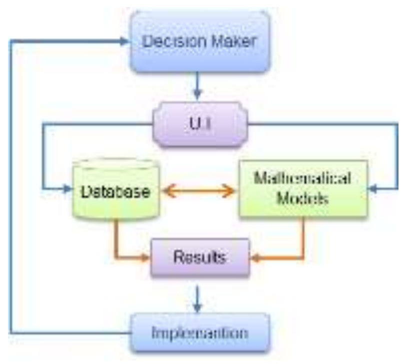

Figure 1: Usual Decision Support System components

2.2 IDF Update algorithm

The following section presents the EQM method for updating the IDF curves developed by Srivastav et al. (2014) and is used by the Tool for the updated IDFs. The steps involved are as follows:

(i) Extract daily maximums from the historical run from the selected GCM model

(ii) Extract sub-daily maximums from the observed data at a given location (i.e., maximums of 5min, 10min, 15min, 1hr, 2hr, 6hr, 12hr, 24hr precipitation data)

(iii) Extract daily maximums from the RCP Scenarios (i.e., RCP26, RCP45, RCP85) for the selected GCM model

(iv) Fit a probability distribution to the daily maximums from GCM model (each of the sub-daily maximum series for the observed data and daily maximums for the future scenarios)

(v) Using the principle of quantile based mapping, wherein the cumulative probability distribution of the GCM and the sub-daily series are equated to establish a statistical relationship between them to obtain GCM modeled sub-daily series $Y_{\max,j}^{GCM}$. This is spatial downscaling of the data from the GCM daily maximums to observed sub-daily maximums.

(vi) Next establish a similar quantile-mapping statistical relationship which models the change between the current GCM maximums and future GCM scenario maximums. This is temporal downscaling of the data from the projected GCM simulations of daily maximum to baseline GCM daily maximums.

(vii) Find an appropriate function to relate $Y_{\max,j}^{STN}$ and $X_{\max}^{GCM}$. Piani et al. (2010) suggest that in most of the cases the relation is observed to be linear. In this study it was observed that the first order linear equation is sufficient to build this relationship. Further, it is evident from the Gumbel CDF that it results in a linear equation when equating the two CDF's. It is worth to be noted that it is not guaranteed that the other distribution functions would lead to the linear first order equations.

$$Y_{\max,j}^{STN} = f\left(X_{\max}^{GCM}\right) \quad [1]$$

$$Y_{\max,j}^{STN} = a_1 \times X_{\max}^{GCM} + b_1 \quad [2]$$

(viii) Similarly, find an appropriate function to relate $Y_{\max}^{GCM,Fut}$ and $X_{\max}^{GCM}$.

$$Y_{\max}^{GCM,\mathrm{Fut}} = f\left(X_{\max}^{GCM}\right) \quad [3]$$

$$Y_{\max}^{GCM,Fut} = a_2 \times X_{\max}^{GCM} + b_2 \quad [4]$$

(ix) To generate future maximum sub-daily data, combine equations (2) and (4) by replacing $X_{\max}^{GCM}$ to $Y_{\max}^{GCM,Fut}$ in equation (3)

$$X_{\max,j}^{STN,\,future} = a_1 \times \left[\frac{X_{\max}^{GCM,\,future} - b_2}{a_2} \right] + b_1 \qquad [5]$$

(x) Generate IDF curves for the future sub-daily data and compare the same with the historically observed IDF curves to obtain the change in the intensities.

In case of spatial downscaling the number of equations required to map the sub-daily historical AMP from the GCM AMPs would be equal to the number of sub-daily time intervals. On the other hand the temporal downscaling would have only one mapping function between the baseline period and projected period GCM AMPs. In this study we adopt extreme value –Type 1 distribution, i.e., Gumbel distribution to fit the maximum daily/sub-daily series as it is very commonly used for such analysis.

3. CASE STUDY

The proposed tool and methodology (EQM method) is tested using data from one station location in the city of São Paulo, SP – Brazil. The location of the station if presented in Figure 2. The sub-daily daily maximums from observed data was obtained from DAEE (*Departamento de Águas e Energia Elétrica*) and IAG USP (*Instituto de Astronomia, Geofísica e Ciências*) from University of Sao Paulo. The sub-daily annual maximums for 0, 20, 30 minutes, 1, 2, 3, 6, 12, 18 and 24 hours were available from 1933 to 1998 (66 years of data). The station E3-035 (IAG-USP) is located at 23º39''S and 46º37''W.

In this study the GCM model selected was CanESM2 (the Second Generation Earth System Model) from CCCma (Canadian Centre for Climate Modelling and Analysis). For the selected GCM model three future RCP scenarios (RCP-26, RCP-45 and RCP-85) were available and each of these scenarios has five ensembles.

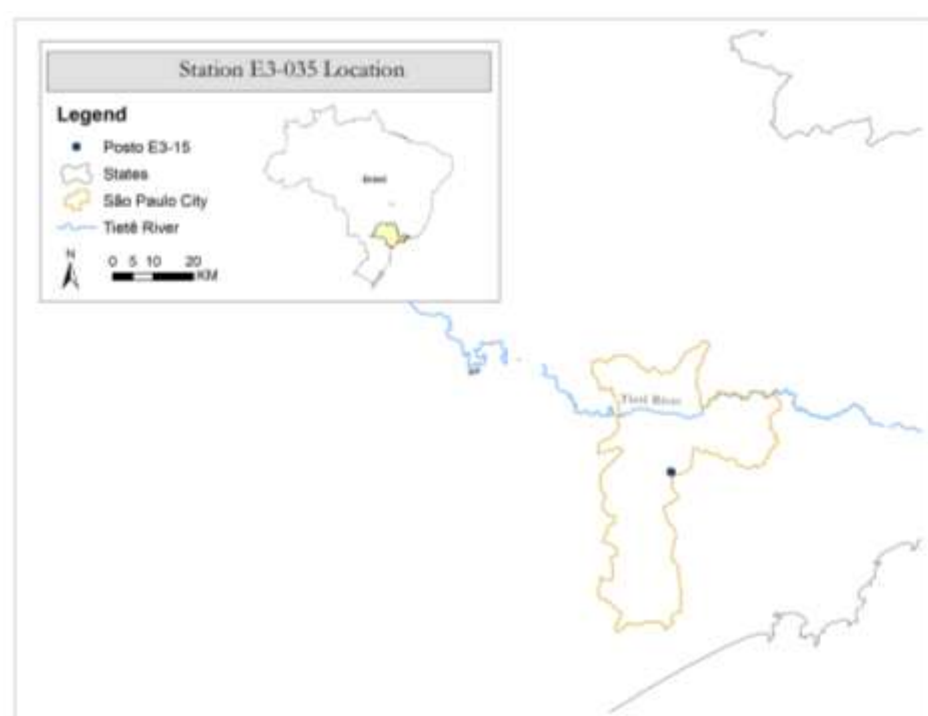

Figure 2: Location of Station E3-035 used in case study.

4. RESULTS AND DISCUSSION

In this paper a generalized web base tool is presented and used to generate IDF for historical observed data and the updated IDF for the future using GCM models with the presented methodology. The tool fits IDF using data provided by the user, process GCM's data by extracting series form nearest grid points based on the location of the station (geographic coordinates) and applies the EQM algorithm.

For the selected station E3-035 (IAG-USP) the IDF fitted for historical observed data (from 1933 to 1998) is presented on Table 1. Total precipitation for a return period of 100 years and 24 hour duration is 165.2 mm. The IDF was fitted using Gumbel distribution with method of moments. The tool presents the result to user in tables and interactive graphs. User can also select the type of information (intensity/total precipitation) for graphs and tables, as well as equations fitted to IDF points. A screenshot of the user interface that presents the results is shown on Figure 3.

Table 1: IDF (total precipitation in mm) for historical observed data of station E3-035

TR (years)	2	5	10	25	50	100
10 min	15.56	20.08	23.07	26.85	29.66	32.44
20 min	25	31.95	36.55	42.37	46.69	50.97
30 min	30.6	39.38	45.19	52.53	57.98	63.39
1 h	42.23	54.38	62.42	72.58	80.12	87.61
2 h	49.67	63.17	72.1	83.39	91.77	100.08
3 h	53.29	67.75	77.32	89.41	98.39	107.29
6 h	59.31	75.87	86.84	100.69	110.97	121.17
12 h	66.94	85.06	97.05	112.21	123.45	134.61
24 h	79.41	102.37	117.58	136.79	151.05	165.2

Table 2: Average IDF (total precipitation in mm) for future under RCP 8.5 scenario from CGM model CanEMS2. Average of all ensembles

TR (years)	2	5	10	25	50	100
10 min	17.1	23.98	28.53	34.28	38.55	42.78
20 min	27.36	37.94	44.95	53.8	60.37	66.89
30 min	33.58	46.94	55.79	66.96	75.26	83.48
1 h	46.35	64.84	77.09	92.56	104.03	115.42
2 h	54.25	74.79	88.4	105.58	118.33	130.99
3 h	58.2	80.2	94.77	113.18	126.83	140.39
6 h	64.93	90.14	106.83	127.91	143.55	159.08
12 h	73.09	100.67	118.92	141.99	159.1	176.09
24 h	87.2	122.16	145.31	174.55	196.25	217.78

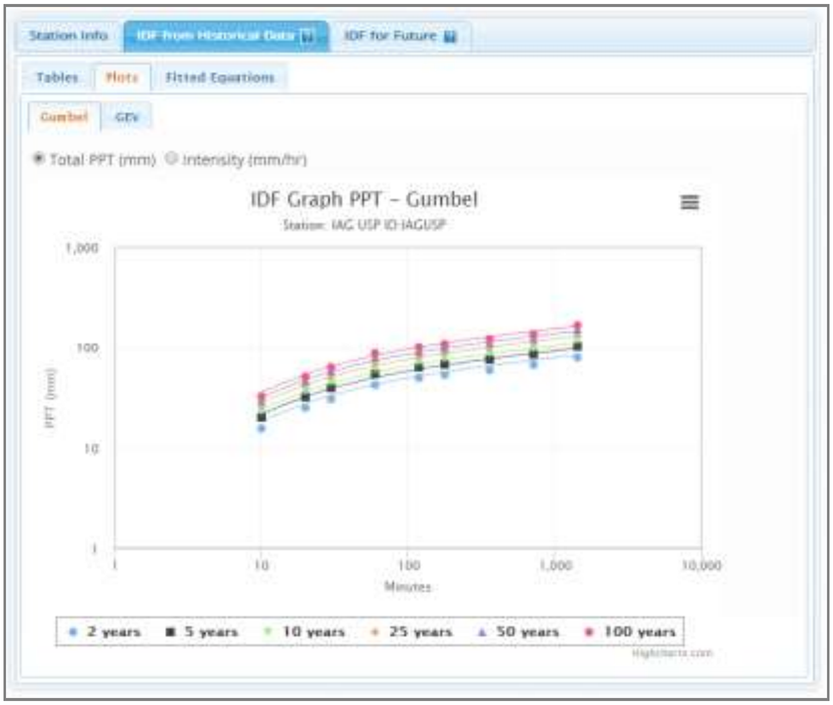

Figure 3: Screenshot showing result screen on user interface. Results are presented in form of interactive tables and graphs for both historical observed period and future.

To generate the updated IDFs for future, the user is only required to a GCM model from and the future time slice, and then a series of calculation steps are triggered on the tool. Among those, one is the application of the update methodology also presented in this paper. As example, Table 2 presents the average updated IDF for scenario RCP 8.5 from CGM model CanEMS2. This model has 5 ensembles (runs) that are automatically processed by the tool. The increase from the historical observed IDF to average from RCP 8.5, ranges from around 9% to 31%. The IDF presented on Table 2 is already an average of the ensembles for RCP 8.5. For this reason, a range of possible lower and upper bounds is presented to the user in form of interactive graphs, as the one presented in Figure 4.

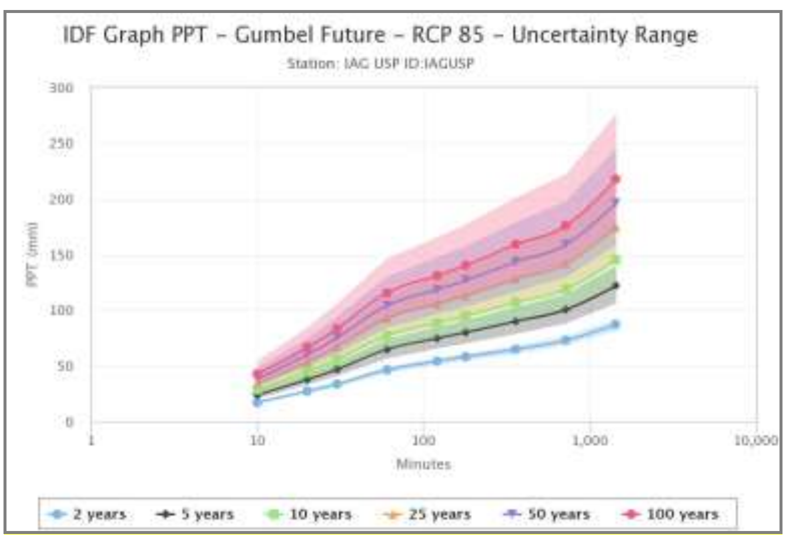

Figure 4: Screenshot showing interactive graph of the possible range for updated IDF under RCP 8.5 scenario using CanEMS2 from CCCma.

5. CONCLUSION

This paper presents a generic web-based tool that aims to assists on IDF update for expected future conditions due to climate change. The implemented tool uses a simplified although very efficient methodology that incorporates the changes in the distributional characteristics of the GCM model between the baseline period and the projection period. The tool is simple to use and computationally very efficient, and dramatically simplifies the IDF update process by automating very demanding procedures. The proposed tool and methodology is carried out to model the sub-daily precipitation series at one location in dense populated city (Sao Paulo) in Brazil. Three future RCP scenarios as per the IPCC fifth assessment report are selected to capture the future change.

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