Proc. IAHS, 385, 485–487, 2024
https://doi.org/10.5194/piahs-385-485-2024

Open Access PIAHS

IAHS2022 – Past and future of open, inclusive, innovative, and society-interfacing approaches

Return periods in current and future climate

Dan Rosbjerg

Department of Environmental and Resource Engineering, Technical University of Denmark, Kongens Lyngby, 2800, Denmark

Correspondence: Dan Rosbjerg (daro@dtu.dk)

Published: 19 April 2024

Abstract. For Danish conditions, discrete rain intensity climate factors for a 100-year time horizon are generalized to continuous curves as functions of the return period. Assuming the tails of the distribution functions for T-year events to be approximately exponential, a general formula for projecting current return periods into future return periods is developed. Moreover, the uncertainty of the future T-values due to uncertainty in the climate factor is approximately assessed using first order analysis.

Keywords. UPH 21; SDG 13; Modelling; Urban drainage design; Prediction uncertainty

1 Introduction

In Denmark, recommended climate factors for design rain intensities looking 100 years ahead are given as discrete values for return periods T equal to, respectively, 2, 10 and 100 years (SVK, 2014). Multiplication of the current T-year event with the climate factor results in an estimate of the future T-year event. The recommended Danish climate factor values are based on simulations with climate models (Christensen et al., 1998; Gregersen et al., 2013) and therefore not exact values, but nevertheless useful for design of urban drainage structures. To account for the uncertainty, they are provided both as standard climate factors and as high climate factors. To facilitate design efforts, continuous curves are presented below. Climate factors are telling how much a given T_c-year event in current climate will increase in the future climate. Another, but related question is which future return period, T_f, corresponds to a T_c-year event in the current climate. Below a convenient, general formula for the future return period as function of the climate factor and the current return period is developed. In addition, by means of first analysis the uncertainty of T_f is assessed talking into account the uncertainty in the climate factor.

Table 1. Climate factors as function of return periods.

Return period, T_c	Standard climate factor	High climate factor
2	1.2	1.45
10	1.3	1.70
100	1.4	2.00

2 Continuous climate factor curves

If $x_{T,c}$ denotes the T-year event in the current climate, and $x_{T,f}$ denotes the T-year event in the future climate, the climate factor, k, is defined as the ratio between the events. Thus

$$k = \frac{x_{T,f}}{x_{T,c}} \quad \Rightarrow \quad x_{T,f} = k\, x_{T,c} \tag{1}$$

The climate factor depends on several different other factors, where the return period T by far is the most important one. The dependence of T is shown in Table 1 both for standard climate factors and for high climate factors.

A generalisation of the discrete values into a continuous curve might be done using a simple log-linear approximation. Here, however, it is chosen to use a second order polynomium approximation, which exactly corresponds to the three given climate factor values in Table 1. The relation for the Danish standard climate factor is found to be

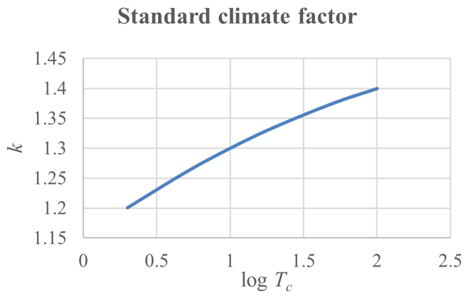

Figure 1. Standard climate factor as function of return period.

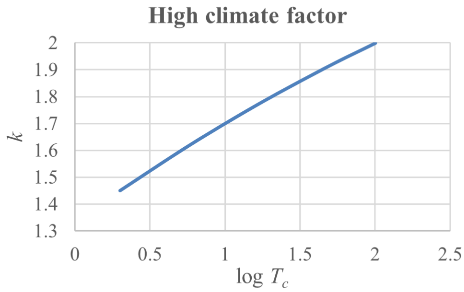

Figure 2. High climate factor as function of return period.

$$k = -0.0253\,(\log T_\mathrm{c})^2 + 0.175 \log T_\mathrm{c} + 1.150 \quad (2)$$

which is shown in Fig. 1. The corresponding formula for the high climate factor is

$$k = -0.0341\,(\log T_\mathrm{c})^2 + 0.402 \log T_\mathrm{c} + 1.332 \quad (3)$$

which is shown in Fig. 2. Both the relations are developed for $2 \le T_\mathrm{c} \le 100$, but can be assumed valid also for values of T_c greater than 100.

3 Projection of the current return period into a future return period

A wide class of distribution functions possesses exponential tails, and it is here assumed plausible that this is also the case for the distributions of $x_{T,\mathrm{c}}$ and $x_{T,\mathrm{f}}$. Thus for the extreme value regions we get for $x_{T,\mathrm{c}}$

$$F(x) = 1 - \exp\left(-\frac{x}{a}\right) = 1 - \frac{1}{T_\mathrm{c}} \quad \Rightarrow \quad T_\mathrm{c} = \exp\left(\frac{x}{a}\right) \quad (4)$$

and for $x_{T,\mathrm{f}}$

$$G(x) = 1 - \exp\left(-\frac{x}{b}\right) = 1 - \frac{1}{T_\mathrm{f}} \quad \Rightarrow \quad T_\mathrm{f} = \exp\left(\frac{x}{b}\right) \quad (5)$$

From Eq. (1) we have

$$P\left\{x_{T,\mathrm{f}} \le x\right\} = P\left\{k\,x_{T,\mathrm{c}} \le x\right\} = P\left\{x_{T,\mathrm{c}} \le \frac{x}{k}\right\} \Rightarrow \quad G(x) = F\left(\frac{x}{k}\right) \quad (6)$$

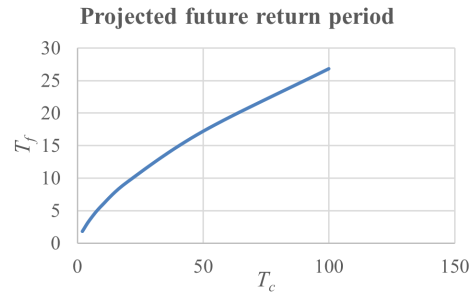

Figure 3. Projected future return period as function of current return period using standard climate factors.

Table 2. Current return periods, corresponding climate factors and projected future return periods.

T_{2017} (MST, 2021)	1	3	68	220	515
T_{2100} (MST, 2021)	1.2	1.6	20	50	100
k_{standard} Eq. (2)	1.15	1.23	1.39	1.42	1.44
T_{2100} Eq. (9)	1	2.5	20.1	44.3	76.3
k_{high} Eq. (3)	1.3	1.5	2.0	2.1	2.2
T_{2100} Eq. (9)	1	2.1	8.7	13.3	17.7

Combining with Eqs. (4) and (5) we get

$$\exp\left(-\frac{x}{b}\right) = \exp\left(-\frac{x}{k\,a}\right) \quad \Rightarrow \quad b = k\,a \quad (7)$$

By insertion into Eq. (5) we then obtain

$$T_\mathrm{f} = \exp\left(\frac{x}{b}\right) = \exp\left(\frac{x}{k\,a}\right) = \left[\exp\left(\frac{x}{a}\right)\right]^{\frac{1}{k}} \quad (8)$$

leading to the below general relation between T_f and T_c

$$T_\mathrm{f} = T_\mathrm{c}^{\frac{1}{k}} \quad (9)$$

The relation is exemplified in Fig. 3 using Danish standard climate factors. It is, e.g., seen that a 100-year value in the current Danish climate becomes a 27-year event in the future climate.

In Table 2, the values obtained using Eq. (9) are compared to values published in MST (2021) obtained by using results from climate models. The correspondence is found reasonable. Moreover, it can be seen from the table that the use of high climate factors gives rise to a dramatic change in the assessment of future return periods.

4 Uncertainty of projected future return periods

Due to uncertainty in the climate factor, the projection of a return period into the future will become uncertain as well. For fixed values of T_c, the uncertainty of T_f is assessed in terms of coefficient of variations. Interpreting Eq. (9) as $T_\mathrm{f} = f(k)$ and applying first order analysis lead to the general equation

$$\mathrm{CV}\{T_\mathrm{f}\} \cong \frac{k}{f(k)}\left|\frac{\mathrm{d}f(k)}{\mathrm{d}k}\right|\mathrm{CV}\{k\} = \frac{\ln T_\mathrm{c}}{k}\mathrm{CV}\{k\} \quad (10)$$

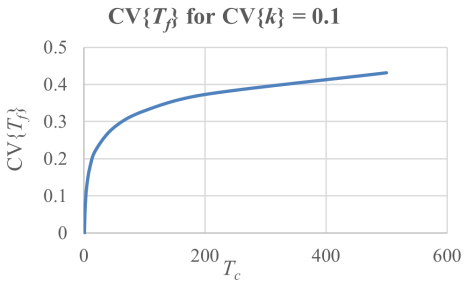

Figure 4. Coefficient of variation of the future return period as function of the current return period assuming the coefficient of variation of the climate factor equal to 10 %.

The relation is shown in Fig. 4. It can, e.g., be seen that a 10 % uncertainty in the climate factor implies a 33 % uncertainty in the future projection of a 100-year return period.

5 Conclusions

Discrete climate factors are for Danish conditions generalized to continuous functions of the return period for both standard and high climate factors. Using exponential tail approximations for the distribution function of current and future T-year events, a general analytical expression for projecting the current return period into the future return period as function of the climate factor is developed and evaluated. Finally, the uncertainty of the projected future return period due to uncertainty in the climate factor is assessed revealing a notable uncertainty even in case of a moderate uncertainty in the climate factor.

Code availability. The code is not publicly available.

Data availability. The applied data are available in MST (2021, https://www2.mst.dk/Udgiv/publikationer/2018/manual.pdf).

Competing interests. The author has declared that there are no competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors.

Special issue statement. This article is part of the special issue "IAHS2022 – Hydrological sciences in the Anthropocene: Past and future of open, inclusive, innovative, and society-interfacing approaches". It is a result of the XIth Scientific Assembly of the International Association of Hydrological Sciences (IAHS 2022), Montpellier, France, 29 May–3 June 2022.

Acknowledgements. The editor Christophe Cudennec is acknowledged for his great efforts in handling the paper.

Review statement. This paper was edited by Christophe Cudennec.

References

Christensen, O. B, Christensen, J. H., Machenauer, B., and Botzet, M.: Very-high resolution regional climate simulations over Scandinavia – present climate, J. Climate, 11, 3204–3229, https://doi.org/10.1175/1520-0442(1998)011<3204:VHRRCS>2.0.CO;2, 1998.

Gregersen, I. B., Sørup, H. J. D., Madsen, H., Rosbjerg, D., Mikkelsen, P. S., and Arnbjerg-Nielsen, K.: Assessing future climatic changes of precipitation extremes at small spatio-temporal scales, Clim. Change, 118, 783–797, https://doi.org/10.1007/s10584-012-0669-0, 2013.

MST: Manual for application of Report no. 31 by IDA, Spildevandskomitéen, Ramboell to Miljoestyrelsen, https://www2.mst.dk/Udgiv/publikationer/2018/manual.pdf (last access: 21 January 2023), 2021 (in Danish).

SVK: Updated climate factors and design rain intensities, Report no. 30, IDA Spildevandskomitéen, https://ida.dk/media/2994/svk_skrift30_0.pdf (last access: 21 January 2023), 2014 (in Danish).