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A physics-based approach for simulating future extreme design storms to assess flood risks

Nadav Peleg[1] and Francesco Marra[2,3]

[1]Institute of Earth Surface Dynamics, University of Lausanne, Lausanne, Switzerland

[2]Department of Geosciences, University of Padova, Padua, Italy

[3]Institute of Atmospheric Sciences and Climate, National Research Council, Bologna, Italy

Sharing is encouraged

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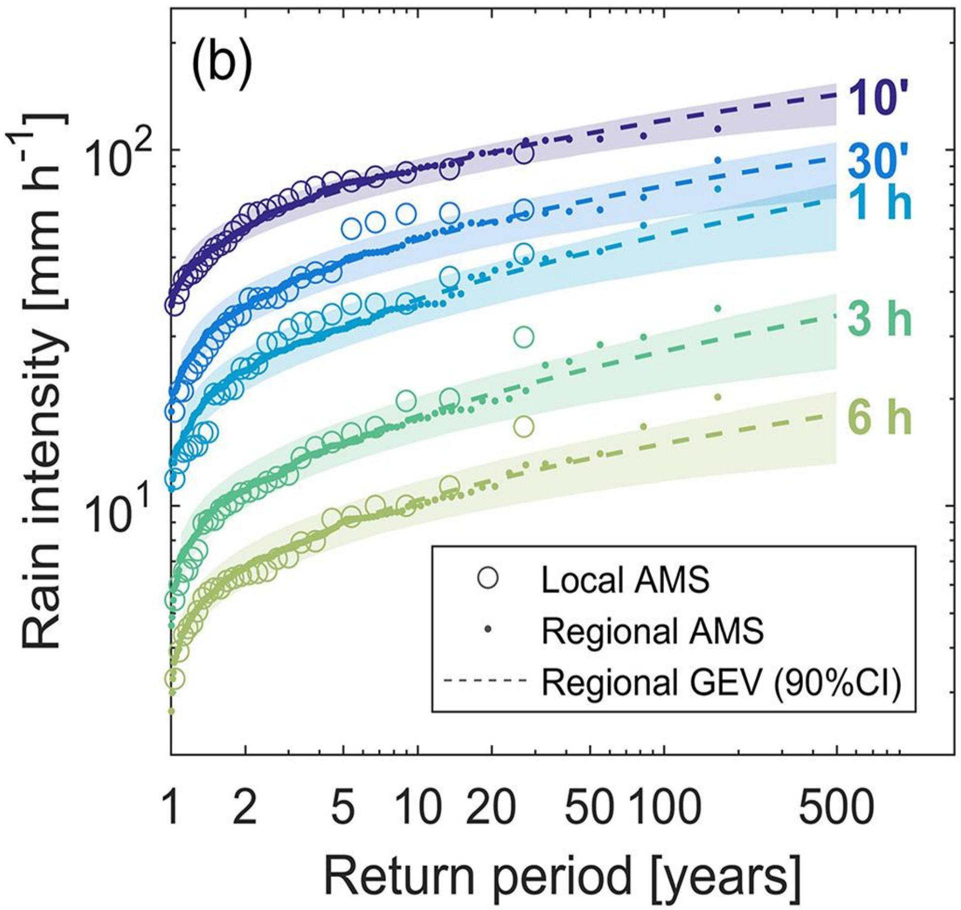
Motivation

- **Extreme sub-hourly precipitation** can lead to natural disasters such as flash floods, urban pluvial floods, and debris flows
- Quantification of the change in their statistics is essential in the context of climate change
- In hydrology – most applications are considered using **Intensity-Duration-Frequency (IDF) curves**

Motivation

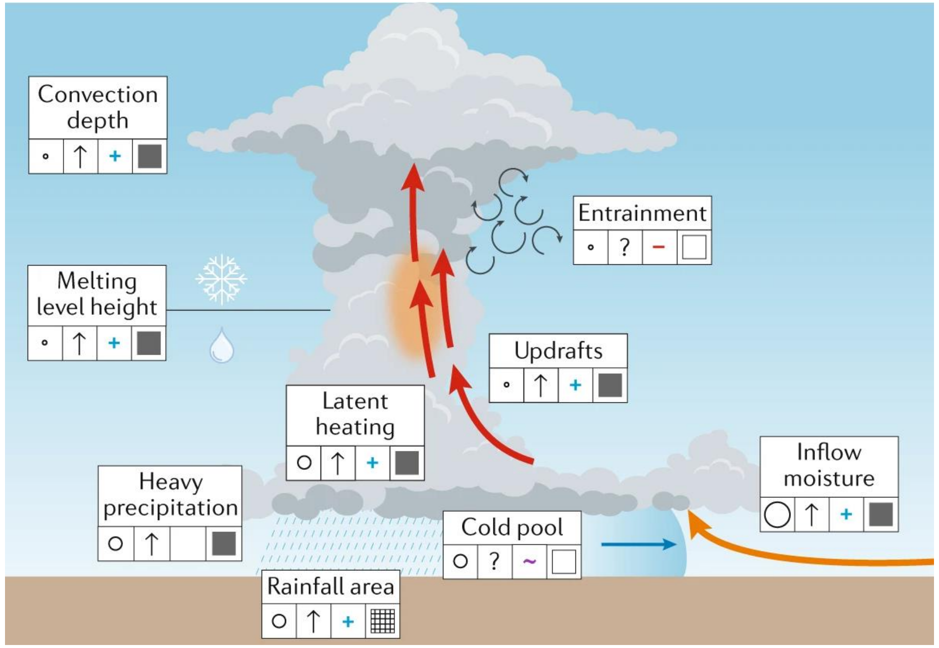
- Often, future IDF curves are derived from climate model data
- Statistical limitations: the bias-correction and downscaling procedures introduce uncertainties
- Physical limitations: climate models do not explicitly simulate convective precipitation, the most common sub-daily extreme rainfall event



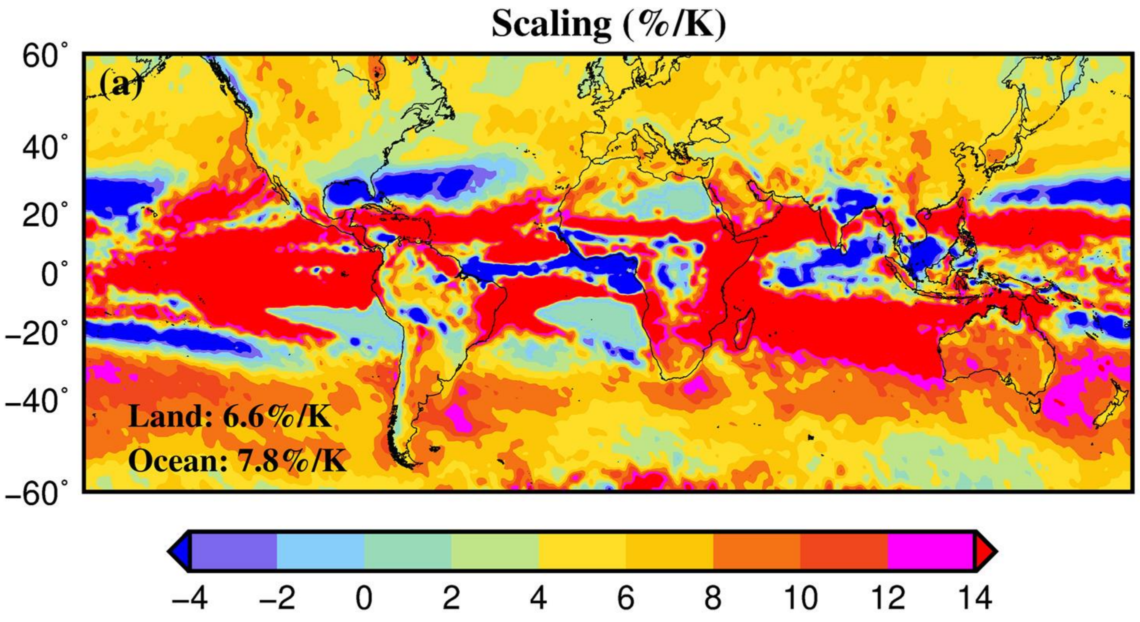
Marra et al. *GRL* **2020**

Extreme rainfall intensification

- We do know that extreme sub-daily rainfall intensity should follow intensification at the rate of 7% °C^{-1} on a global average (following the Clausius–Clapeyron relation)



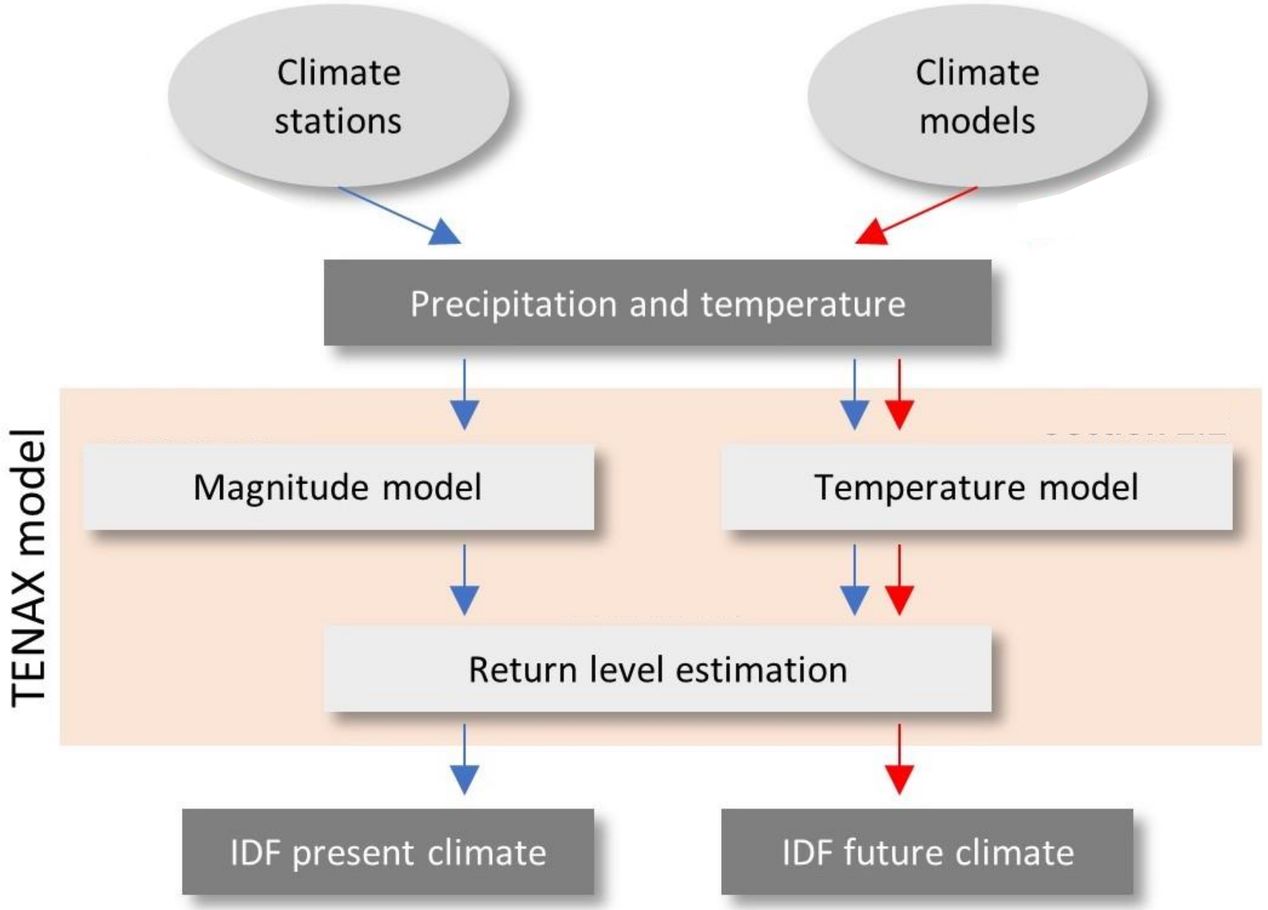
Fowler et al., *Nature Rev.* **2021**



Ali et al. *GRL* **2021**

The TENAX model

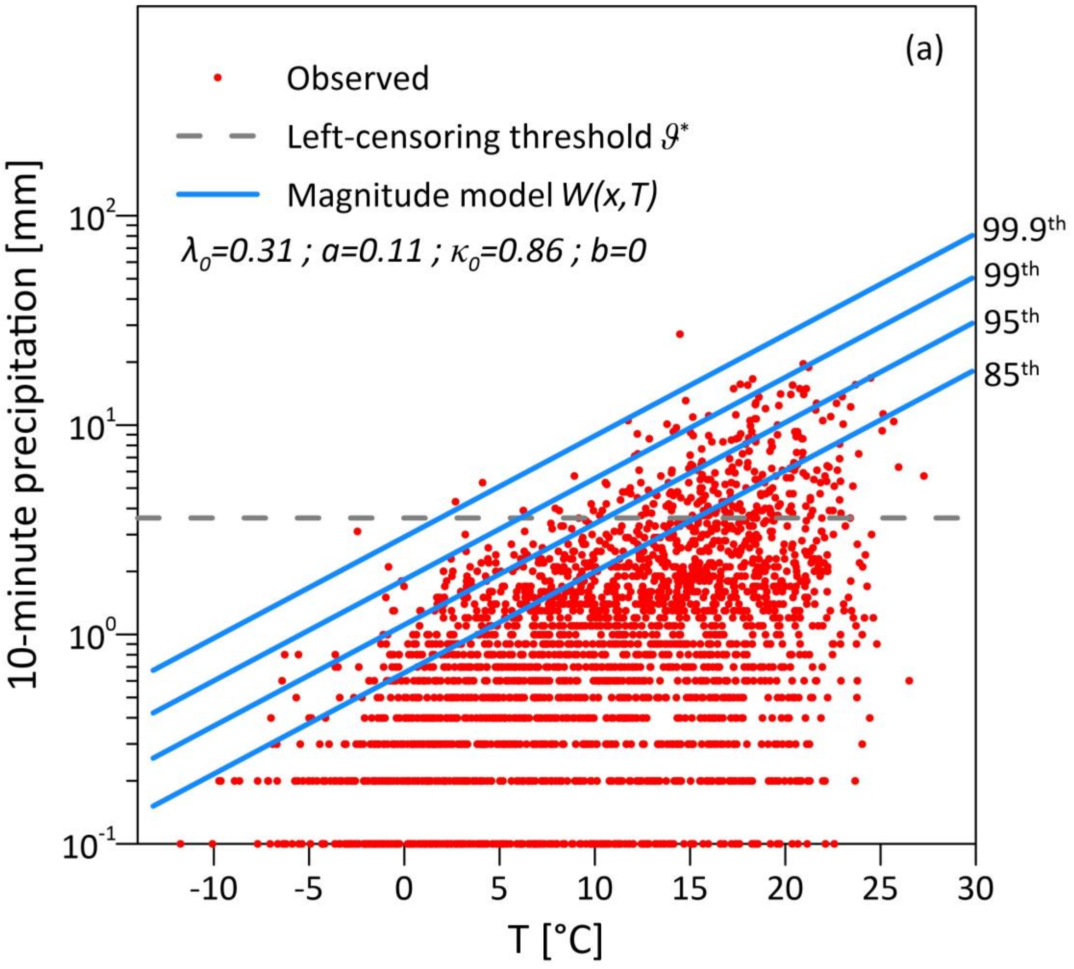
- We developed the **TE**mperature-dependent **N**on-**A**symptotic statistical model for e**X**treme return levels (**TENAX**)
- A **parsimonious** non-stationary and non-asymptotic theoretical framework that incorporates **temperature as a covariate** in a physically consistent manner



Marra et al. *HESS* **2024**

TENAX: Precipitation event magnitude model

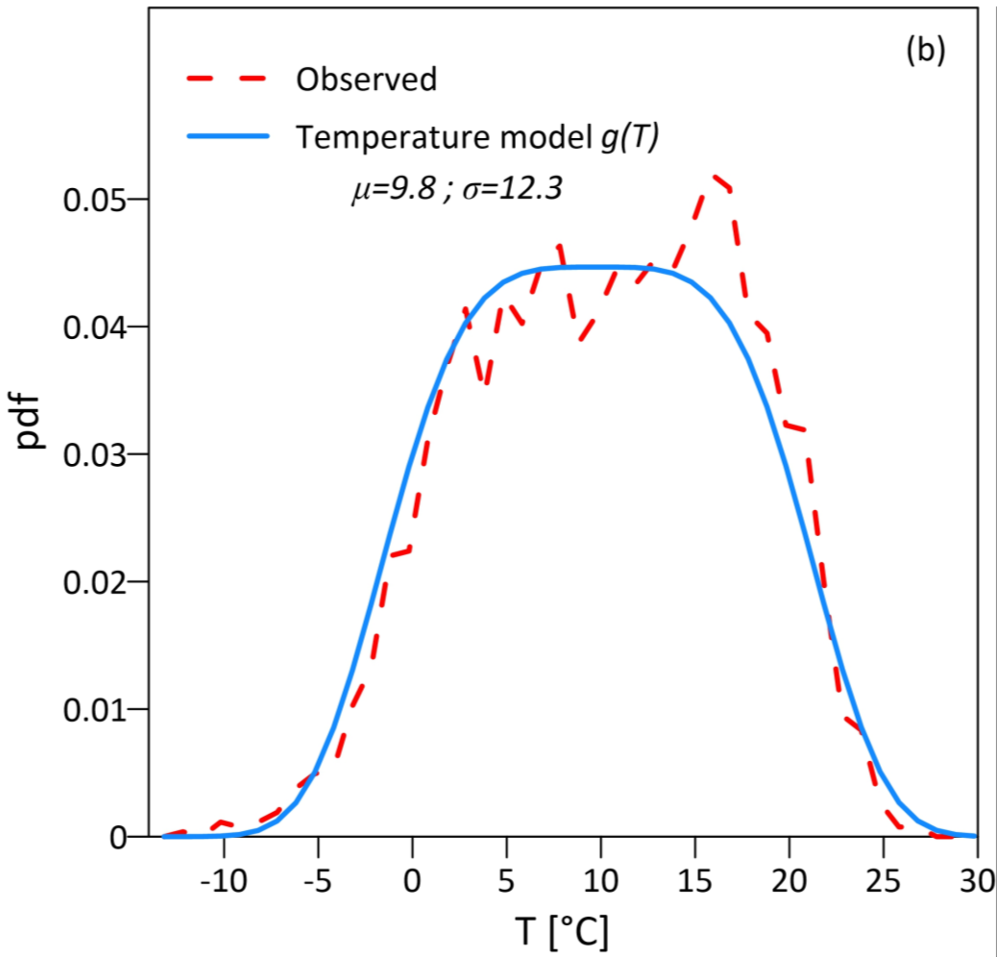
- We use the Weibull distribution to model the magnitudes of sub-hourly ordinary precipitation events
- **The Weibull parameters are explicitly dependent on near-surface air temperature as covariate**
- An exponential dependence of the scale parameter on temperature is introduced following the Clausius–Clapeyron relation



Marra et al. *HESS* **2024**

TENAX: Temperature model

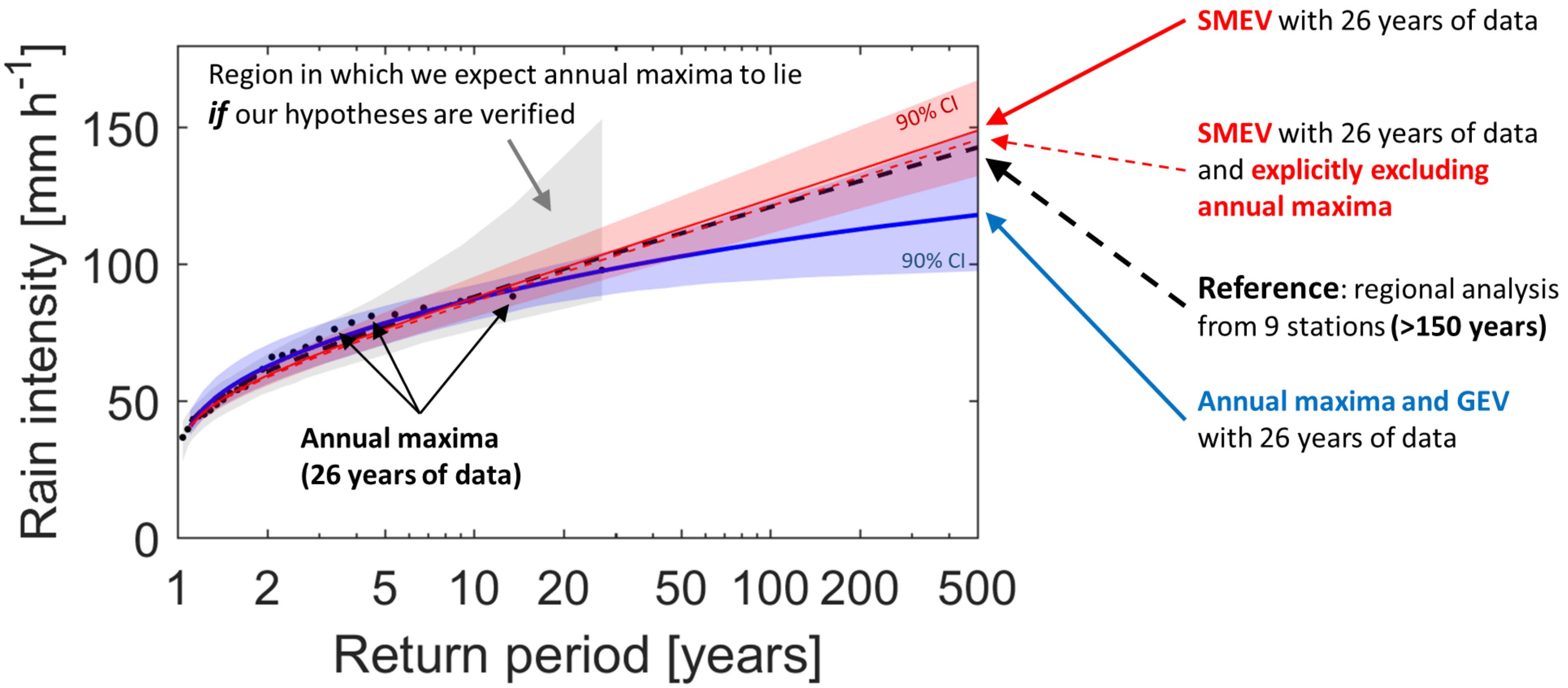
- The average **temperatures observed during 24 hours preceding the peak intensities** are well described by a Generalized Gaussian distribution



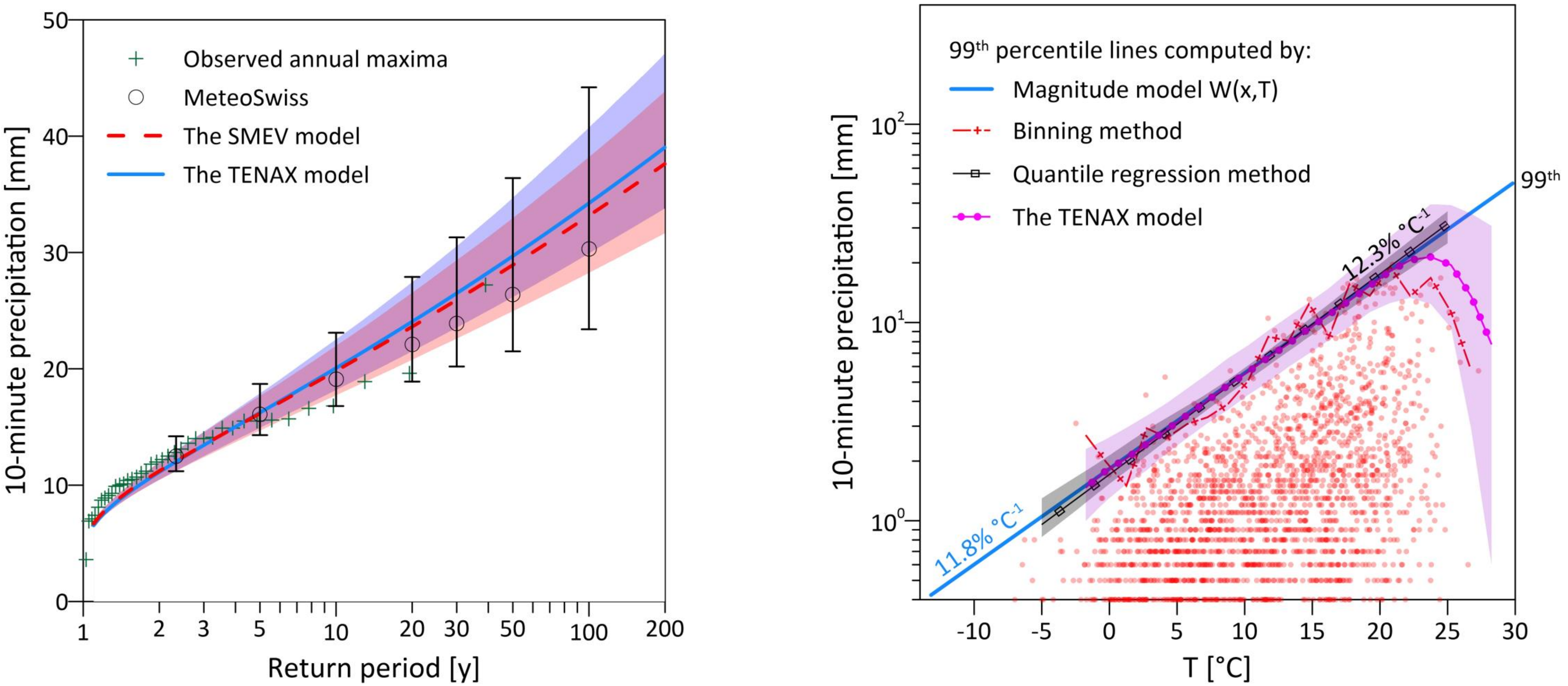
Marra et al. *HESS* **2024**

TENAX: Return level estimation

- The distribution of annual maxima is obtained with the Simplified Metastatistical Extreme Value (SMEV) formulation (Marra el al., *GRL* **2020**)

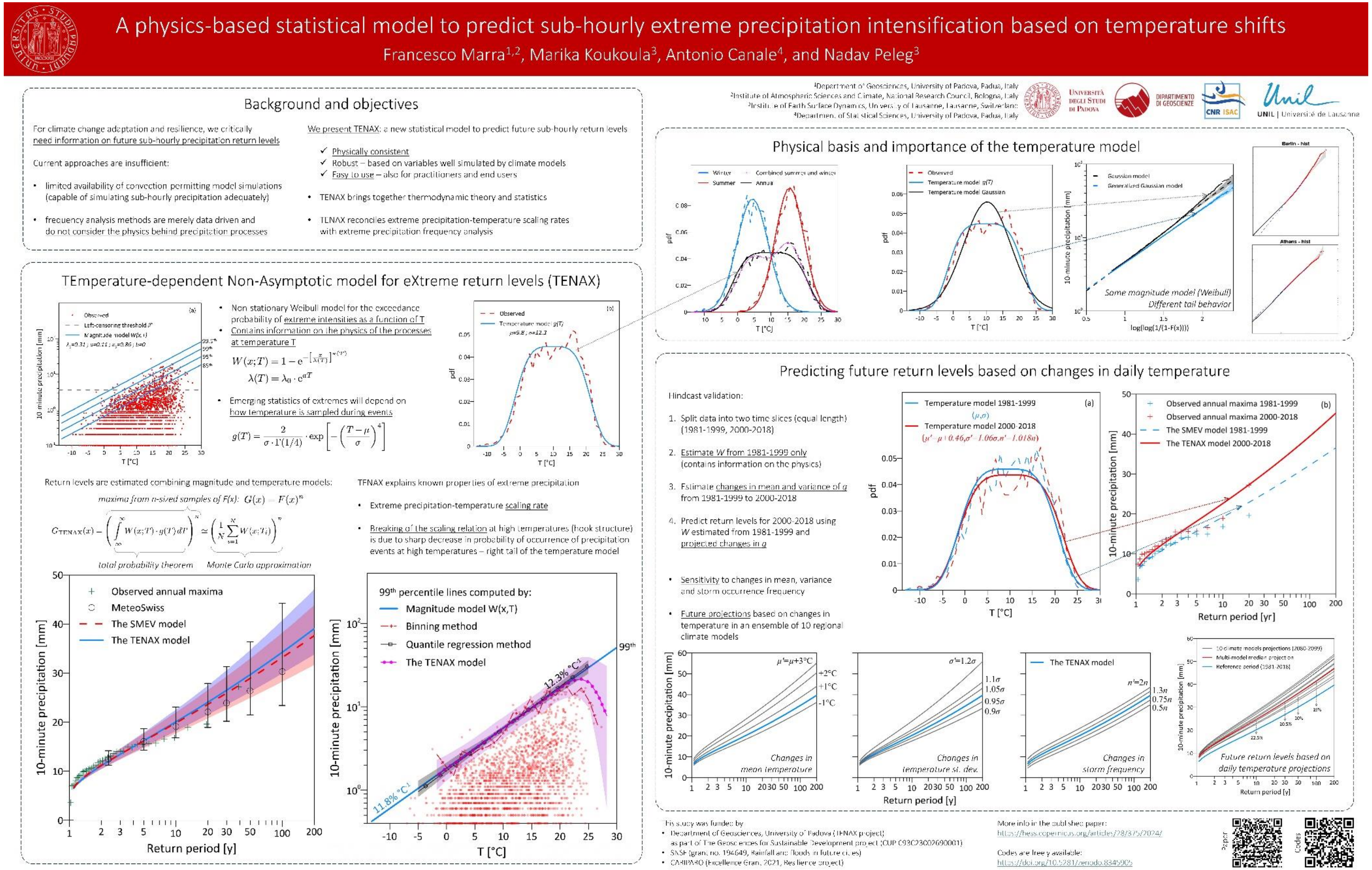


TENAX: evaluation (Aadorf station, 10-min)



Marra et al. *HESS* **2024**

The TENAX model



The TENAX model

- Poster: "A physics-based statistical model to predict sub-hourly extreme precipitation intensification based on temperature shifts" presented by Francesco Marra
- Wednesday, 10:45–12:30
- Hall A | A.42

Paper

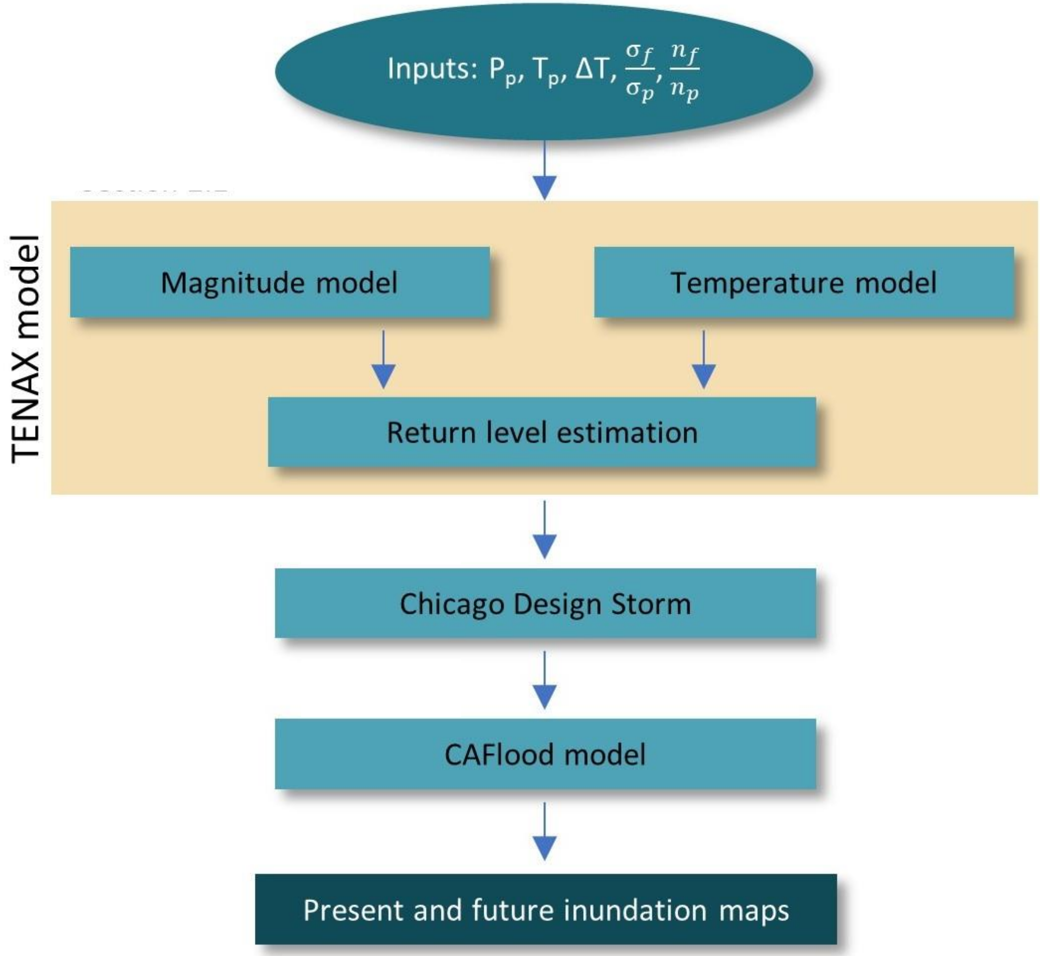
Codes

More info in the published paper:
https://hess.copernicus.org/articles/28/375/2024/

Codes are freely available:
https://doi.org/10.5281/zenodo.8345905

The TENAX-CDS model

- We propose a framework for adjusting IDF curves and design storms to future climate conditions
- **Information from climate models at the daily scale can be used to construct design storms at the sub-hourly**
- Our approach is illustrated through a re-parameterization of the Chicago Design Storm (CDS)



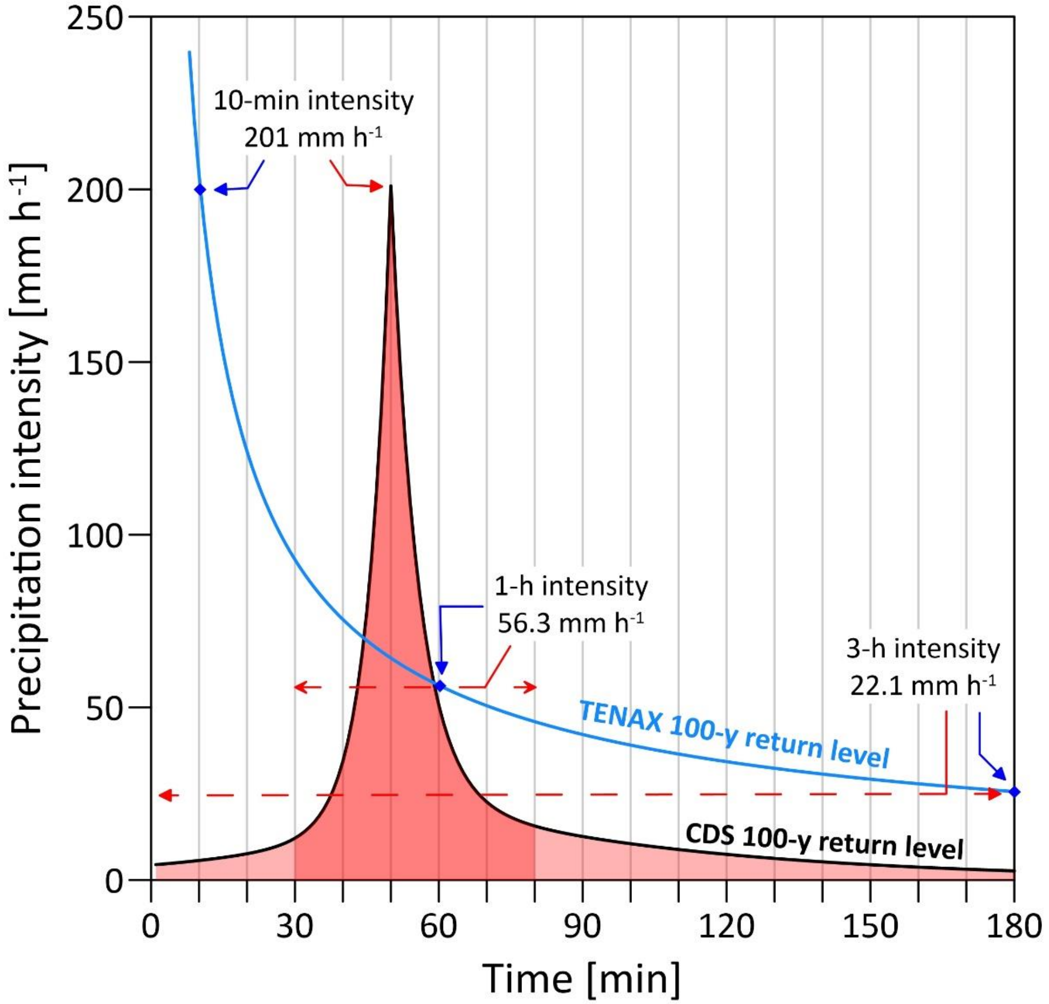
Peleg et al. *ADWR* **under review**

The Chicago Design Storm (CDS)

- The CDS approach enables a single synthetic storm to embed analytically a given precipitation return level for all durations of interest based on an intensity-duration curve

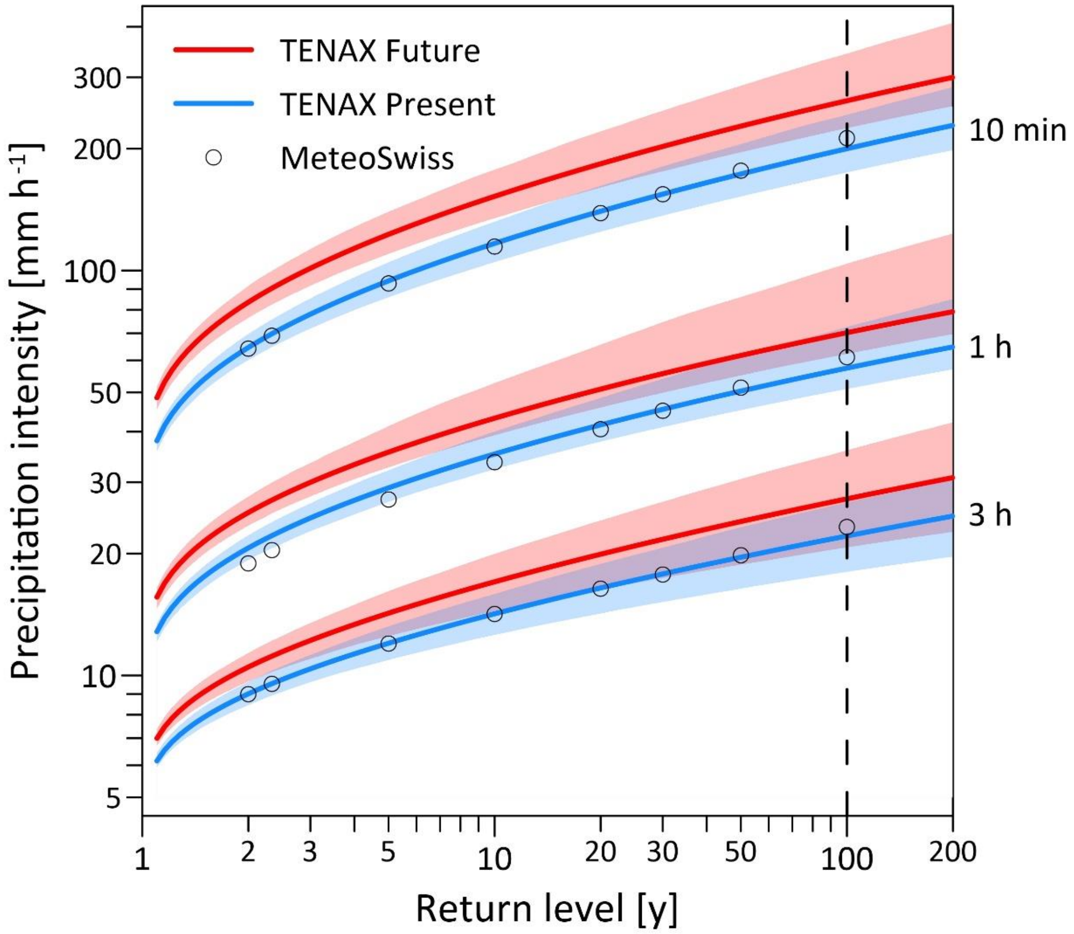
$$I(t_D;\mathcal{T}) = \frac{C_a}{(t_D + C_b)^{C_c}}$$

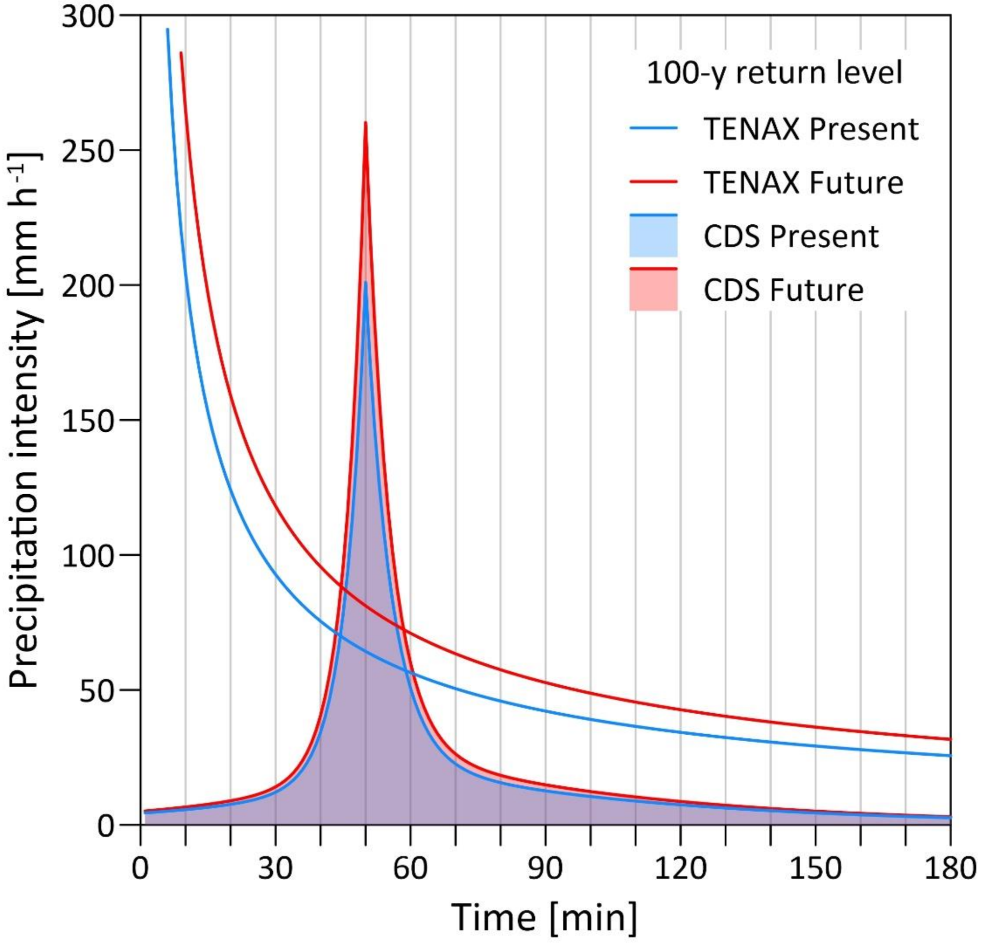
$$I(t_b;\mathcal{T}) = \frac{C_a\left((1-C_c)(\frac{t_b}{r}) + C_b\right)}{\left(\frac{t_b}{r} + C_b\right)^{C_c+1}} \qquad I(t_a;\mathcal{T}) = \frac{C_a\left((1-C_c)(\frac{t_a}{1-r}) + C_b\right)}{\left(\frac{t_a}{1-r} + C_b\right)^{C_c+1}}$$



Peleg et al. *ADWR* **under review**

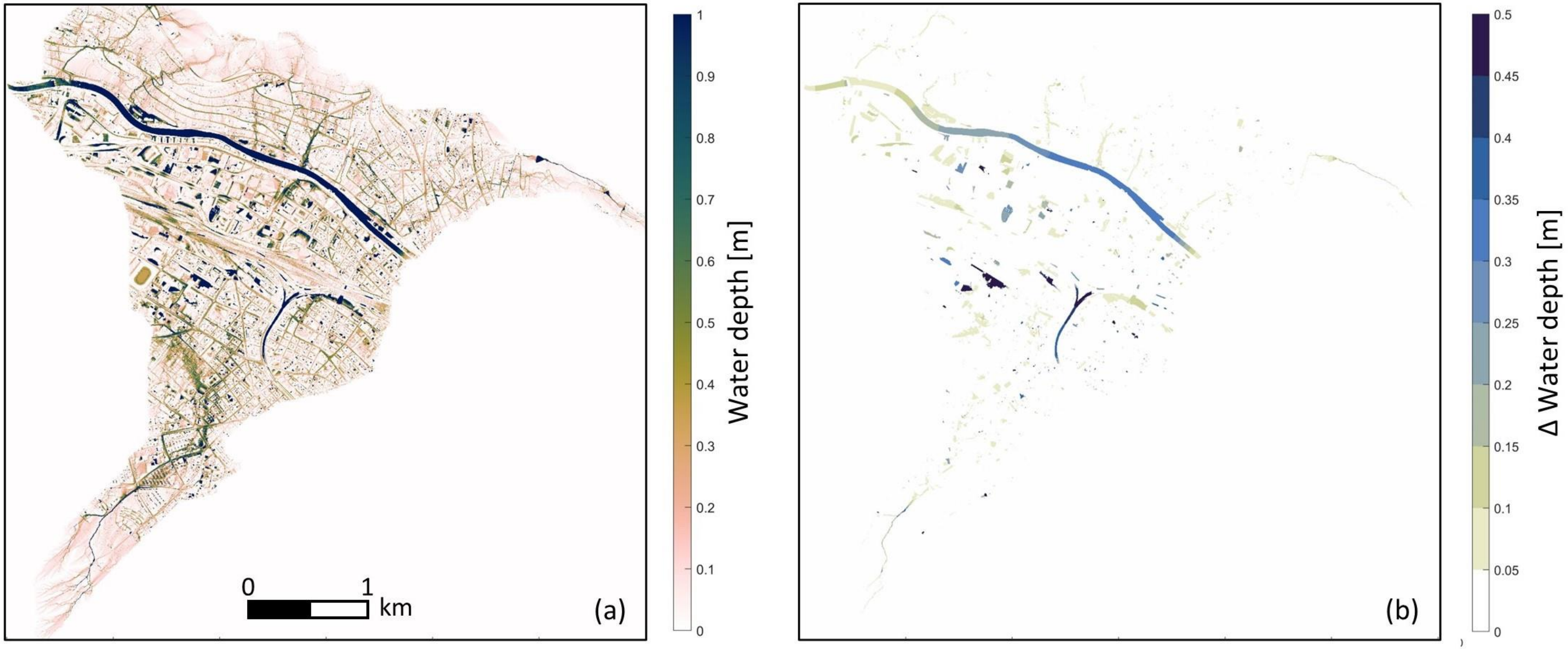
TENAX-CDS: example





Peleg et al. *ADWR* **under review**

TENAX-CDS: example



Peleg et al. *ADWR* **under review**

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Thank You!

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- We have presented a new method for computing short-duration IDF curves and design storms for flash flood assessments under increasing temperatures
- The physically-based TENAX-CDS model considers both thermodynamical and dynamical changes and is highly efficient in terms of its data requirements
- The TENAX-CDS code is freely available: https://zenodo.org/records/10491542

HYDROMETEOROLOGY AND SURFACE PROCESSES

Marra, F., Koukoula, M., Canale, A., and Peleg, N. (2024)
- **Predicting extreme sub-hourly precipitation intensification based on temperature shifts**
Hydrology and Earth System Sciences

Peleg, N., Wright, D.B., Fowler, H.J., Leitao, J.P., Sharma, A., and Marra., F. (under review)
- **A simple and robust approach for adapting design storms to assess climate-induced changes in flash flood hazard**
Advances in Water Resources

nadav.peleg@unil.ch