# Projection of droughts as multivariate phenomenon in the River Rhine

**Alejandro Chamorro[1], T. Houska[1], Shailesh Kumar Singh[2], L. Breuer[1,3]**

Departamento de Ecosistemas y Medio Ambiente, Pontificia Universidad Católica de Chile, Avenida Vicuña Mackenna 4860, Santiago, Chile

[2] Institute of Landscape Ecology and Resources Management, Justus Liebig University of Giessen, Heinrich-Buff-Ring 26, D-35392 Giessen, Germany; tobias.houska@umwelt.uni-giessen.de (T.H.); Lutz.Breuer@umwelt.uni-giessen.de (L.B.)

[3] National Institute of Water and Atmospheric Research, Christchurch, New Zealand; Shailesh.Singh@niwa.co.nz

[4] Centre for International Development and Environmental Research, Justus Liebig University Giessen, Senckenbergstrasse 3, D-35390 Giessen, Germany

# Supplementary information

**Supplementary Table S1**: HBV model parameters and their meaning.

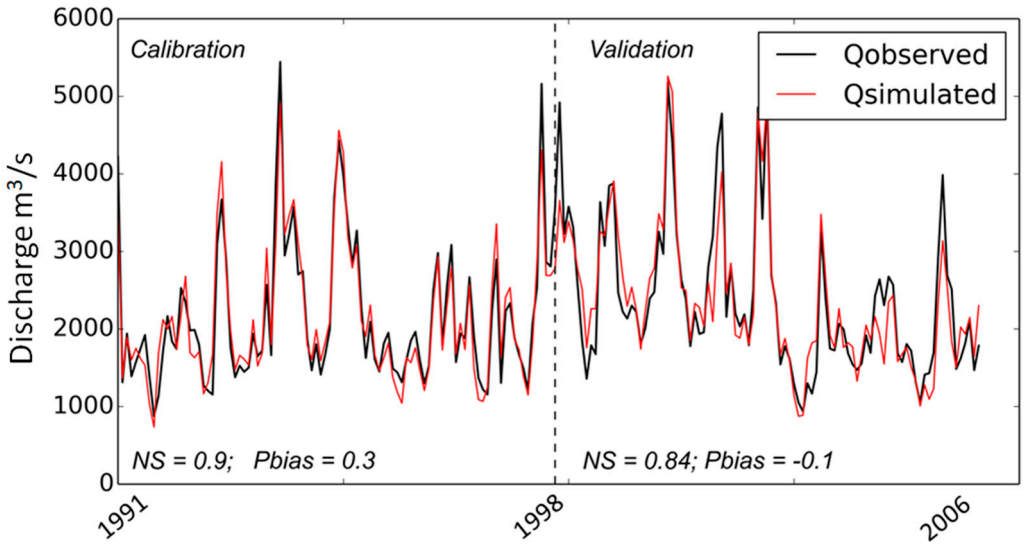
| No | Parameter | | Unit |
|---|---|---|---|
| 1 | L | Depth of upper reservoir | mm |
| 2 | K0 | Surface flow storage constant | L/day |
| 3 | K1 | Interflow storage constant | L/day |
| 4 | K2 | Baseflow storage constant | L/day |
| 5 | KPER | Percolation storage constant | L/day |
| 6 | TT | Threshold temperature | $^0$C |
| 7 | DD | Degree day factor | mm/$^0$C day |
| 8 | BETA | Model parameter | - |

**Supplementary Table S2:** Statistics of drought events associated with the observation period 1971–2000.

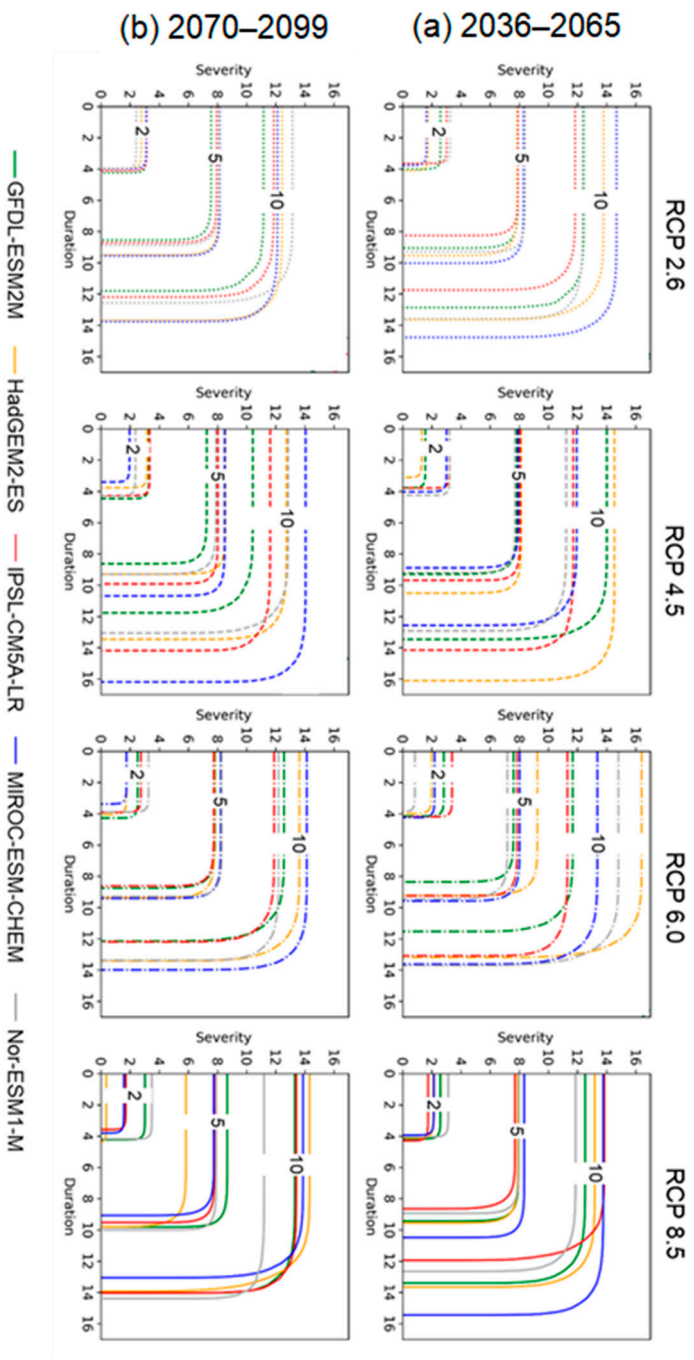
| Variable | Value |
|---|---|
| Number of events | 26 |
| Min. duration | 1 |
| Max. duration | 25 |
| Duration median | 5 |
| Min. severity | 0.014 |
| Max. severity | 26.501 |
| Severity median | 2.850 |

**Supplementary Table S3**: Used copula models and associated parameter space.

| Family | Model | Parameter space |
|---|---|---|
| Frank | $C_\theta(u,v) = -\frac{1}{\theta} log\left\{1 + \frac{\left(e^{-\theta u} - 1\right)\left(e^{-\theta v} - 1\right)}{e^{-\theta} - 1}\right\}$ | $\theta \in (-\infty, \infty)$ |
| Gumbel | $C_\theta(u,v) = e^{-\{(-logu)^\theta + (-logv)^\theta\}^{\frac{1}{\theta}}}$ | $\theta \in [1, \infty)$ |
| Clayton | $C_\theta(u,v) = max\left\{\left(u^{-\theta} + v^{-\theta} - 1\right)^{-\frac{1}{\theta}}, 0\right\}$ | $\theta \in [-1, \infty]\backslash\{0\}$ |
| FGM | $C_\theta(u,v) = uv + \theta uv(1-u)(1-v)$ | $\theta[-1,1]$ |
| AMH | $C_\theta(u,v) = \frac{uv}{1 - \theta(1-u)(1-v)}$ | $\theta \in [-1, 1)$ |




**Supplementary figure S1**: Observed and simulated monthly discharge for calibration and validation period for the River Rhine at Lobith.




**Supplementary figure S2**: Bivariate interdependence duration-severity for return periods 2, 5 and 10 years for the mid (a) - and end (b)-century and five GCMs separated by RCPs.