Supplementary Information

Evolution of flood protection levels and flood vulnerability in Europe since 1950 estimated with vine-copula models

Contents

S1: Data distributions

In the zipped folder, three sets of figures are provided:

MODEL_N_RawData.png -> shows distribution of raw data

MODEL_N_RankData.png -> shows distribution of ranked data

MODEL_N_FullRankData.png -> shows distribution of data generated by sampling the vine model

"MODEL" identifies the vine-copula model, "N" is the number of nodes in the model.

S2: Rank correlation matrices

Table S1. Flood protection (event level)

	HANZE_ events_20yr	Risk_eco	RPv1	**ImpactCont**	Duration	GDP_pc	GDP_Agr
HANZE_events_20yr	1.000	-0.039	-0.001	**0.064**	0.016	0.133	-0.204
Risk_eco	-0.039	1.000	-0.284	**0.343**	0.251	0.071	-0.071
RPv1	-0.001	-0.284	1.000	**0.176**	-0.049	0.109	-0.090
ImpactCont	**0.064**	**0.343**	**0.176**	**1.000**	**0.559**	**-0.042**	**-0.003**
Duration	0.016	0.251	-0.049	**0.559**	1.000	-0.060	0.112
GDP_pc	0.133	0.071	0.109	**-0.042**	-0.060	1.000	-0.770
GDP_Agr	-0.204	-0.071	-0.090	**-0.003**	0.112	-0.770	1.000

Table S2. Flood protection (region level)

	HANZE_ events_30yr	RPv1	**ImpactCont**	Duration	GDP_pc
HANZE_events_30yr	1.000	-0.044	**0.202**	-0.021	0.106
RPv1	-0.044	1.000	**0.288**	0.196	0.092
ImpactCont	**0.202**	**0.288**	**1.000**	**0.152**	**-0.075**
Duration	-0.021	0.196	**0.152**	1.000	-0.109
GDP_pc	0.106	0.092	**-0.075**	-0.109	1.000

Table S3. Chance of fatalities

	Rel_loss_ fat_continuous	RPv1	GDP_Ser	LU_OtherArt	PopUrban
Rel_loss_fat_continuous	**1.000**	**0.240**	**-0.004**	**0.146**	**0.164**
RPv1	**0.240**	1.000	0.070	0.075	-0.015
GDP_Ser	**-0.004**	0.070	1.000	0.394	0.369
LU_OtherArt	**0.146**	0.075	0.394	1.000	0.599
PopUrban	**0.164**	-0.015	0.369	0.599	1.000

Table S10. Mortality (magnitude)

	HANZE_ events_10yr	Pot_rel_ loss_fat	**Rel_loss_ fat_above_0**	WaterDepth	GDP_Agr
HANZE_events_20yr	1.000	-0.086	**-0.103**	-0.025	-0.132
Pot_rel_loss_fat	-0.086	1.000	**-0.762**	0.449	-0.132
Rel_loss_fat_above_0	**-0.103**	**-0.762**	**1.000**	**-0.306**	**0.322**
WaterDepth	-0.025	0.449	**-0.306**	1.000	-0.132
GDP_Agr	-0.132	-0.132	**0.322**	-0.132	1.000

Table S11. Relative population affected

	Risk_eco	Pot_rel_ loss_pop	**Rel_loss_ pop**	GDP_pc	GDP_Ind	FA_Res
Risk_eco	1.000	0.641	**-0.321**	0.147	0.143	-0.016
Pot_rel_loss_pop	0.641	1.000	**-0.447**	0.115	0.213	-0.169
Rel_loss_pop	**-0.321**	**-0.447**	**1.000**	**-0.331**	**0.063**	**-0.102**
GDP_pc	0.147	0.115	**-0.331**	1.000	-0.167	0.202
GDP_Ind	0.143	0.213	**0.063**	-0.167	1.000	-0.418
FA_Res	-0.016	-0.169	**-0.102**	0.202	-0.418	1.000

Table S12. Relative economic loss

	HANZE_ events_30yr	Pot_rel_ loss_eco	**Rel_loss_ eco**	GDP_pc	FA_Agr	EgalDem
HANZE_events_30yr	1.000	-0.123	**-0.056**	0.129	-0.092	0.108
Pot_rel_loss_eco	-0.123	1.000	**-0.465**	0.136	-0.071	0.055
Rel_loss_eco	**-0.056**	**-0.465**	**1.000**	**-0.475**	**0.281**	**-0.399**
GDP_pc	0.129	0.136	**-0.475**	1.000	-0.544	0.758
FA_Agr	-0.092	-0.071	**0.281**	-0.544	1.000	-0.452
EgalDem	0.108	0.055	**-0.399**	0.758	-0.452	1.000

S3: Full structure of vine-copula models

Table S7. Flood protection (event level)

Tree	Branch	Copula	Parameter 1	Parameter 2
0	5,7	Gumbel 90°	2.24485	
	2,4	BB8 270°	1.55201	0.949709
	4,1	BB8 180°	1.67129	0.955624
	1,3	Gaussian	0.561737	
	3,7	Clayton	0.152358	
	6,7	Frank	-1.24209	
1	5,3 | 7	Joe 180°	1.04765	
	2,1 | 4	Gaussian	0.385369	
	4,3 | 1	Clayton	0.080582	
	1,7 | 3	Student	-0.0747664	19.7542
	3,6 | 7	Joe 180°	1.11425	
2	5,1 | 3,7	Clayton 270°	0.189664	
	2,3 | 1,4	BB8 270°	1.73992	0.657487
	4,7 | 3,1	BB8 90°	1.31502	0.755842
	1,6 | 7,3	Student	0.0369852	8.86155
3	5,4 | 1,3,7	BB8	1.11762	0.98713
	2,7 | 3,1,4	BB8 90°	1.37615	0.782236
	4,6 | 7,3,1	BB8 270°	1.15499	0.992079
4	5,2 | 4,1,3,7	BB8 180°	1.39391	0.839923
	2,6 | 7,3,1,4	Student	-0.048857	16.0085
5	5,6 | 2,4,1,3,7	Clayton	0.0143306	

Table S8. Flood protection (region level)

Tree	Branch	Copula	Parameter 1	Parameter 2
0	3,1	Clayton 270°	0.204408	
	4,1	Frank	1.84418	
	1,2	BB8	1.50822	0.829244
	2,5	BB8 180°	1.31905	0.97324
1	3,4 | 1	BB8 180°	1.64871	0.716955
	4,2 | 1	BB8 270°	2.38998	0.355233
	1,5 | 2	Gaussian	0.133193	
2	3,2 | 4,1	BB8	1.36468	0.731462
	4,5 | 2,1	Student	-0.0429604	21.9154
3	3,5 | 2,4,1	Frank	-0.66266	

Table S9. Chance of fatalities

Tree	Branch	Copula	Parameter 1	Parameter 2
0	2,1	Gaussian	0.254169	
	1,3	Frank	1.00847	
	3,5	BB1 180°	0.614795	1.30042
	4,5	BB8 180°	2.78564	0.72175
1	2,3 | 1	Clayton 270°	0.0950623	
	1,5 | 3	Frank	0.410131	
	3,4 | 5	Frank	1.21049	
2	2,5 | 3,1	Clayton 180°	0.17212	
	1,4 | 5,3	Gaussian	-0.0954445	
3	2,4 | 5,3,1	BB8	1.14509	0.97292

Table S10. Mortality (magnitude)

Tree	Branch	Copula	Parameter 1	Parameter 2
0	4,3	Frank	-1.12097	
	3,1	Frank	2.05801	
	1,2	BB6 270°	1.94877	1.57304
	2,5	Gumbel 180°	1.51476	
1	4,1 | 3	Joe 90°	1.12262	
	3,2 | 1	Gumbel 180°	1.13371	
	1,5 | 2	Clayton 180°	0.146821	
2	4,2 | 1,3	Frank	-1.56905	
	3,5 | 2,1	Clayton 270°	0.0966599	
3	4,5 | 2,1,3	Gumbel 180°	1.01984	

Table S11. Relative population affected

Tree	Branch	Copula	Parameter 1	Parameter 2
0	3,1	BB8 270°	2.61322	0.678134
	4,2	Student	0.676083	5.05827
	1,2	Clayton 90°	0.957793	
	2,5	Frank	1.40467	
	5,6	Frank	-3.28459	
1	3,2 | 1	BB8 90°	1.32002	0.822004
	4,1 | 2	Clayton 270°	0.125669	
	1,5 | 2	Clayton 180°	0.265759	
	2,6 | 5	Gaussian	-0.0754454	
2	3,5 | 2,1	Frank	-0.988464	
	4,5 | 1,2	Gumbel 270°	1.02124	
	1,6 | 5,2	BB8 270°	1.56613	0.693423
3	3,6 | 5,2,1	BB8 180°	1.36584	0.951555
	4,6 | 5,1,2	BB7	1.0699	0.144826
4	3,4 | 6,5,2,1	Student	0.0175928	5.64628

Table S12. Relative economic loss

Tree	Branch	Copula	Parameter 1	Parameter 2
0	4,2	BB8 270°	1.87868	0.660247
	2,1	BB7 270°	1.09926	0.884515
	5,3	BB8 270°	2.84211	0.821577
	1,3	Gaussian	-0.458682	
	3,6	BB8 180°	5.57815	0.813259
1	4,1 | 2	Gaussian	-0.177562	
	2,3 | 1	Clayton 90°	0.0968519	
	5,1 | 3	Clayton	0.124278	
	1,6 | 3	Gaussian	-0.11947	
2	4,3 | 1,2	BB8 180°	1.44172	0.848975
	2,6 | 3,1	Gaussian	-0.116134	
	5,6 | 1,3	Frank	-0.333672	
3	4,6 | 3,1,2	Joe 180°	1.05433	
	2,5 | 6,3,1	Gaussian	0.0115394	
4	4,5 | 6,3,1,2	Joe 90°	1.1656	

S4: Comparison between flood protection datasets

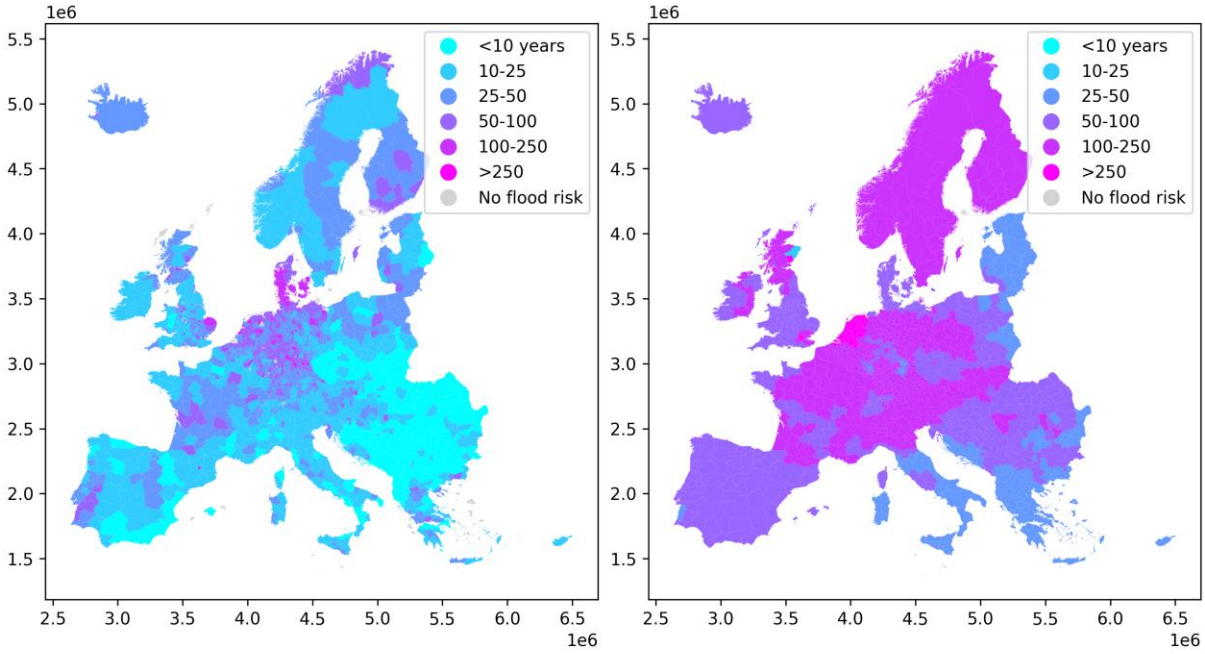

Figure S1. Comparison between flood protection levels for riverine floods from this study for year 2020 (left panel) with PESETA IV dataset (right panel), as return period in subnational regions of the study area

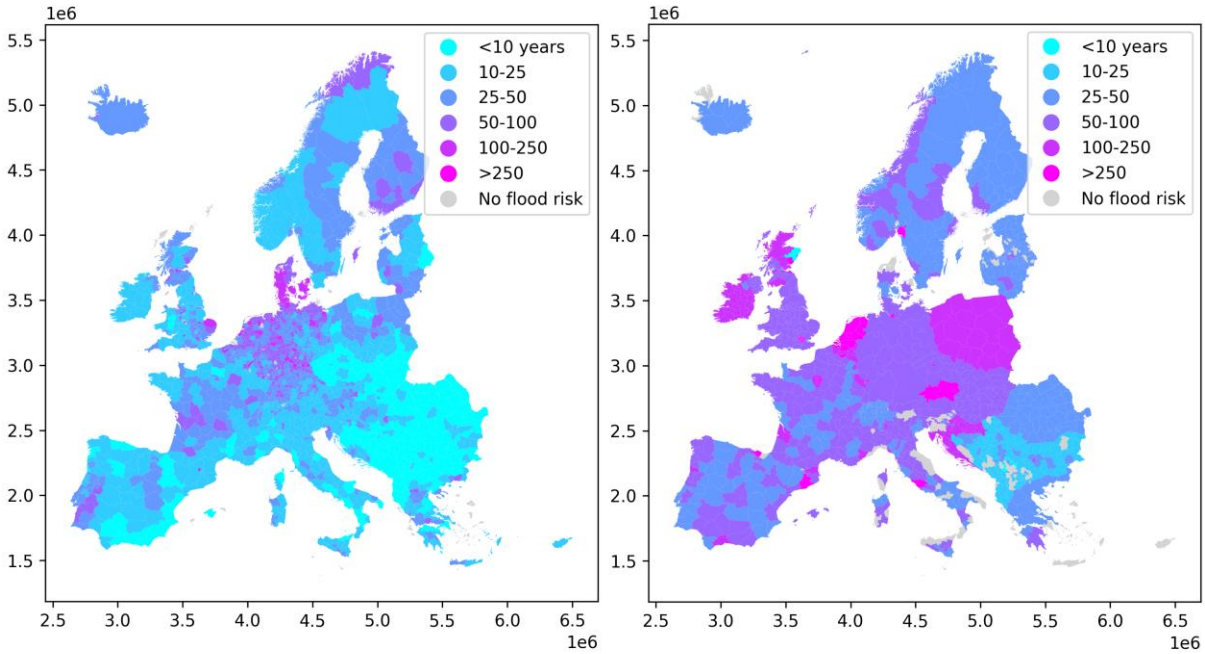

Figure S2. Comparison between flood protection levels for riverine floods from this study for year 2020 (left panel) with FLOPROS dataset (right panel), as return period in subnational regions of the study area

S5: Absolute modelled and reported losses, 1950-2020, without 10 largest events.

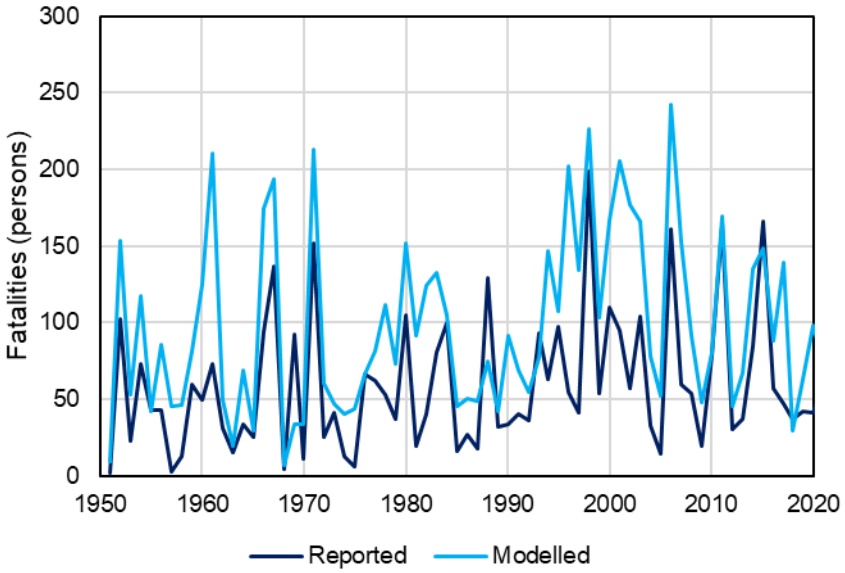

Figure S3. Annual reported fatalities in Europe and model estimate, without 10 largest events.

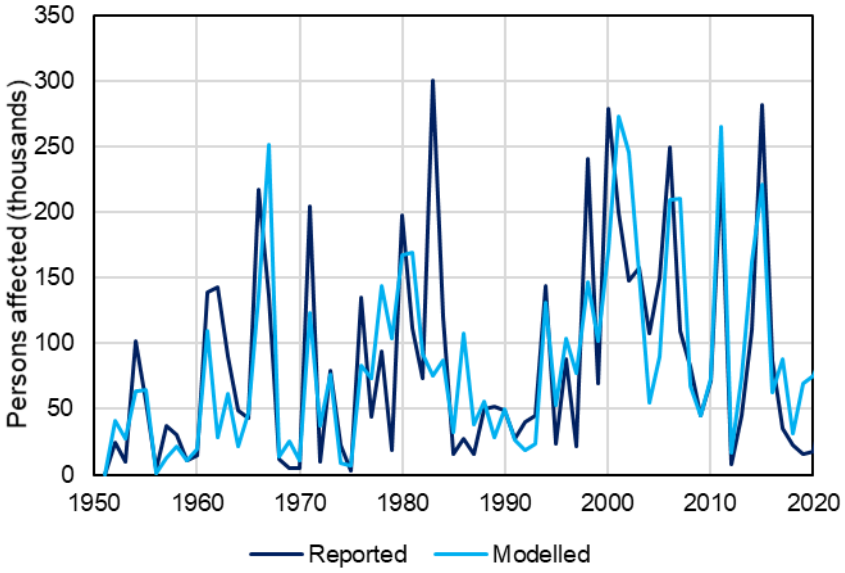

Figure S4. Annual reported population affected in Europe and model estimate, without 10 largest events.

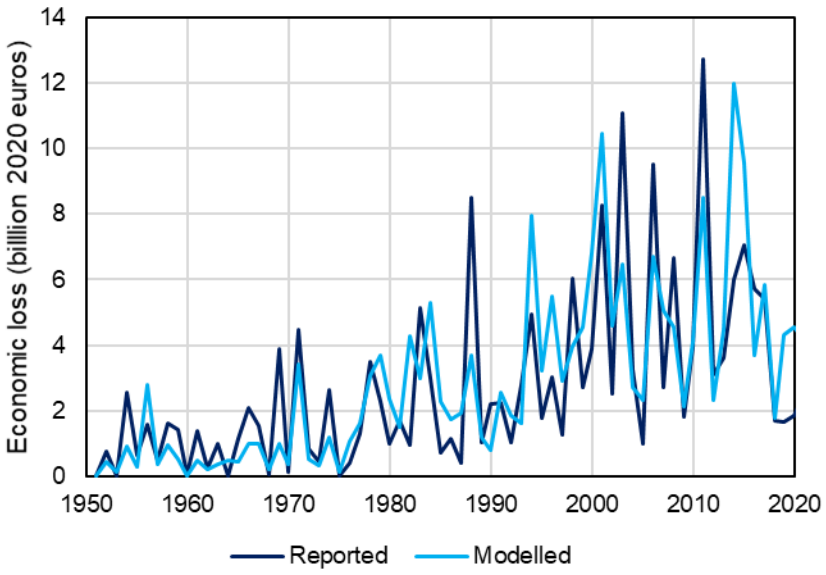

Figure S5. Annual reported economic loss in Europe and model estimate, without 10 largest events.