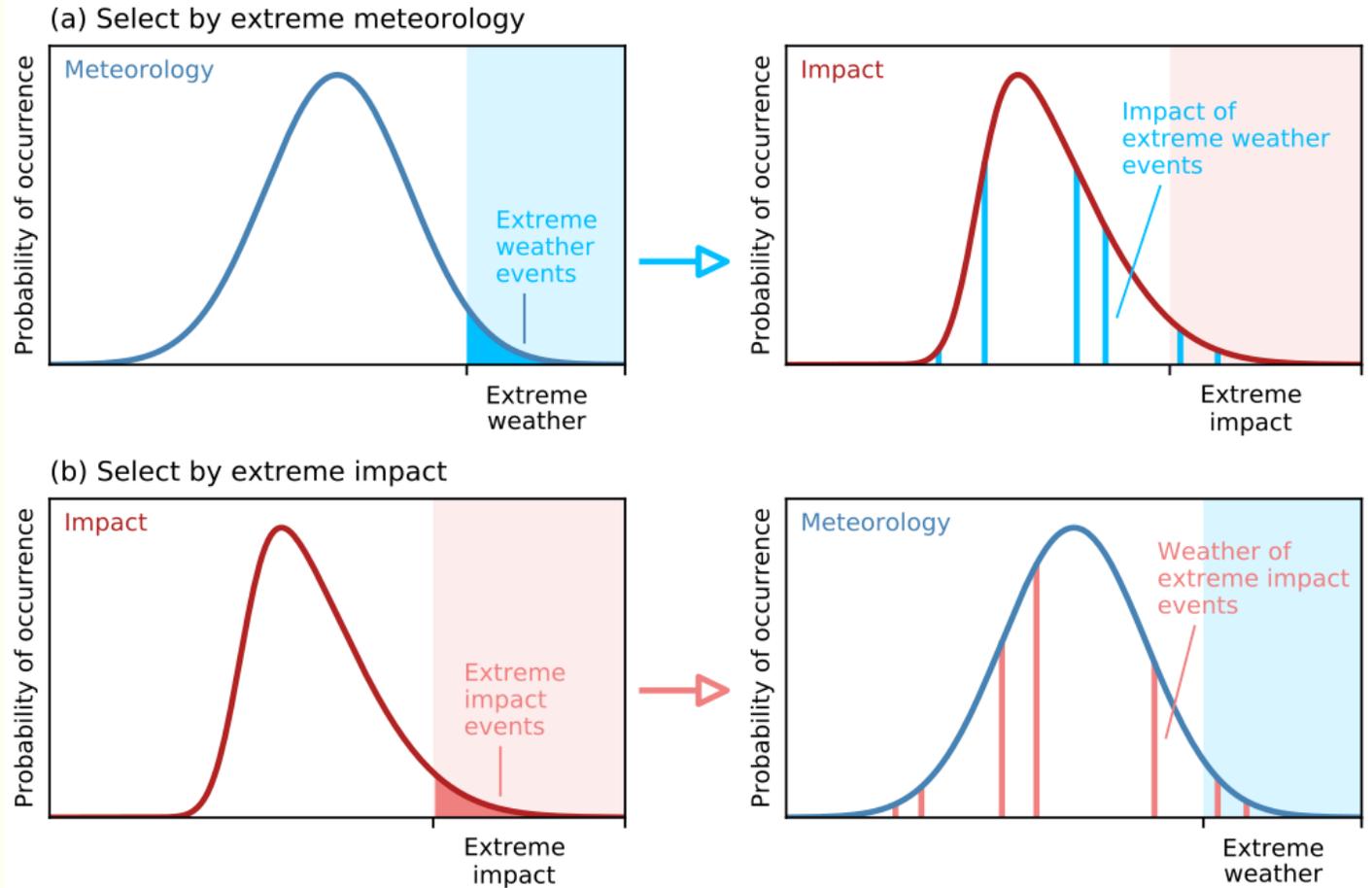


HEATWAVES IN EUROPE 1950-2020: METEOROLOGY, POPULATION AND IMPACTS

A crossed analysis of meteorological, impact, and
population databases

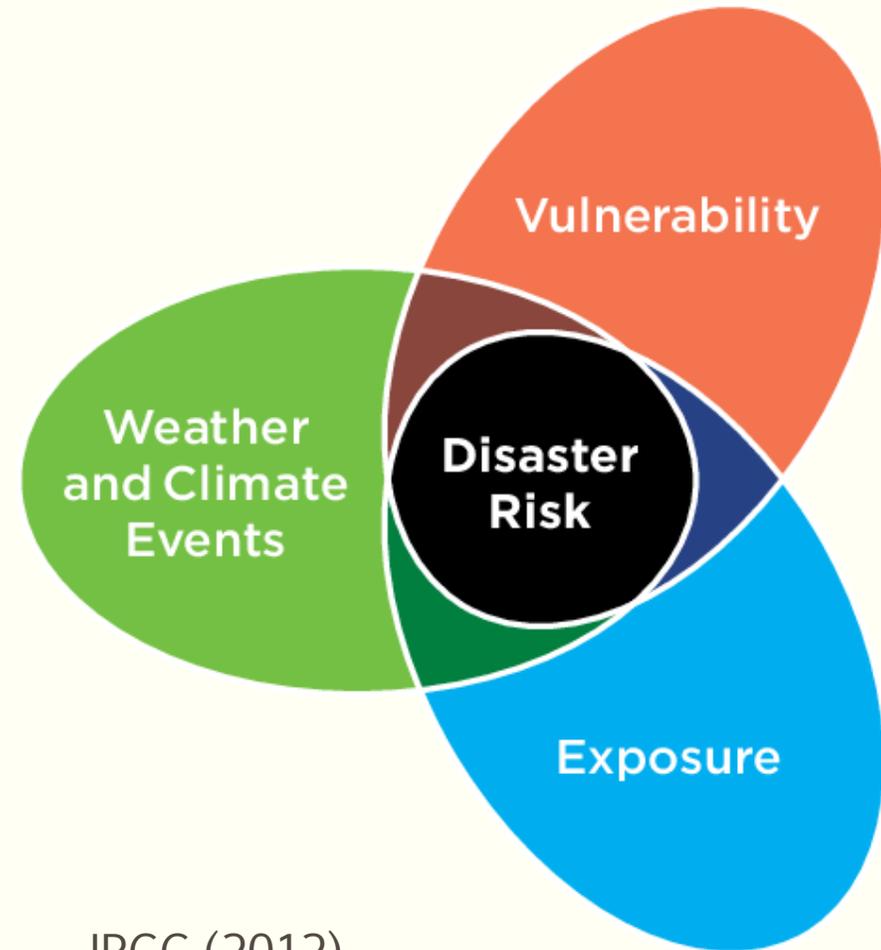
Introduction

- What makes an event extreme ?



Introduction

- For an extreme event to be a disaster (high-impact event) :
 - Hazard
 - Exposure
 - Vulnerability
- The case of heatwaves :
 - Most deadly events
 - Large consensus on the increasing intensity and frequency
- Heatwaves classification :
 - 1D index
 - Temperature conditions
 - Demographic parameters



IPCC (2012)

Heatwaves in EM-DAT

1	Country	ISO	Location	EndDate	TotalDeaths	NoInjured	NoAffected	NoHomeless	TotalAffected	Reconstruction_Cos	Insured_Damages	Total_Damages
2	Greece	GRC	Countrywide	1985-8-5	20	0	0	0	0	0	0	0
3	Greece	GRC		1987-7-31	1000	0	0	0	0	0	0	0
4	Greece	GRC		1988-7-3	56	0	0	0	0	0	0	0
5	Yugoslavia	YUG	Belgrade (Serbia)	1988-7-11	38	0	0	0	0	0	0	0
6	France	FRA	Southwestern	1990-7-24	5	0	0	0	0	0	0	0
7	Romania	ROU		1994-5-	0	0	0	0	0	0	0	0
8	Spain	ESP	Andalusia	1995-7-25	30	70	0	0	70	0	0	0
9	Russian Federation (the)	RUS	Moscou	1995-6-14	20	0	0	0	0	0	0	0
10	Romania	ROU		1996-7-4	16	200	0	0	200	0	0	0
11	Italy	ITA	Calabria	1998-7-4	10	0	0	0	0	0	0	0
12	Romania	ROU		1998-8-3	20	0	0	0	0	0	0	0
13	Lithuania	LTU		1999-6-14	32	0	0	0	0	0	0	0
14	Croatia	HRV	Zagreb city (Zagreb provin	2000-6-	40	200	0	0	200	0	0	240000
15	Greece	GRC	Anatoliki Makedonia Kai T	2000-7-	27	176	0	0	176	0	0	3000
16	Romania	ROU	Bucuresti, Dolj provinces	2000-7-	6	100	0	0	100	0	0	0
17	Bulgaria	BGR	Sofia, Sofia-city, Stata Zagc	2000-7-	7	0	0	0	0	0	0	50
18	Serbia Montenegro	SCG	Subotica city (Severno-bac	2000-7-	3	70	0	0	70	0	0	0
19	Russian Federation (the)	RUS	Moskva, Moskovskaya Ob	2001-7-	276	0	0	0	0	0	0	0
20	Austria ; Belgium ; Switzerl	AUT ; BEL ; CHE ; C	Burgenland, Karnten, Nied	2003-8- ; 200	72210	0	0	0	0	0	10000	12120000
21	Albania ; Macedonia (the fo	ALB ; MKD ; ROU	Durres city (Durres district	2004-7- ; 200	45	0	0	0	0	0	0	0
22	Spain ; Canary Is	ESP ; SPI	AndalucÃ-a, Castilla-La Ma	2004-7-30 ; 2	39	113	0	0	113	0	0	0
23	Romania	ROU	Bucuresti province	2005-8-1	13	500	0	0	500	0	0	0
24	Portugal	PRT	Aveiro, Beja, Braga, Bragar	2005-8-	462	0	0	0	0	0	0	0
25	Romania	ROU	Bucarest, Galati, Mehedin	2006-7-	26	200	0	0	200	0	0	0
26	Belgium ; Germany ; Spain	BEL ; DEU ; ESP ; FF	Vlaams Geweest, Region d	2006-7- ; 200	3392	0	0	0	0	0	0	0
27	Albania ; Austria ; Bulgaria	ALB ; AUT ; BGR ; B	Berat, Bulqize, Delvine, De	2007-7-22 ; 2	560	139	352	0	491	0	0	0
28	Russian Federation (the)	RUS	Moska, Moskovskaya Obla	2010-8-	55736	0	0	0	0	0	0	400000
29	Italy	ITA	Milano district (Lombardia	2011-8-24	10	0	0	0	0	0	0	0
30	United Kingdom of Great B	GBR	England, Wales provinces	2013-7-	760	0	0	0	0	0	0	0
31	Belgium ; France	BEL ; FRA	Vlaams Gewest, Region de	2015-7-5 ; 20	3685	0	0	0	0	0	0	0
32	Belgium ; Germany ; Spain	BEL ; DEU ; ESP ; FF	;; ; ; ; ; ; ; ; ; ; ; ;	2018-7- ; 200	9	0	0	0	0	0	0	0
33	Belgium ; Germany ; Spain	BEL ; DEU ; ESP ; FF	;; ; ; Cordoba, Valladolid ; v	2020-7-1 ; 20	709	0	0	0	0	0	0	0
34	Austria ; Belgium ; German	AUT ; BEL ; DEU ; F	;; ; ; Toute la France mÃ©C	2019-7-26 ; 2	1669	0	0	0	0	0	0	0
35	Belgium ; United Kingdom	BEL ; GBR	;	2019-8-29 ; 2	188	0	0	0	0	0	0	0
36	Belgium ; France ; United K	BEL ; FRA ; GBR ; N	;; ; ;	2020-8-8 ; 20	6340	0	0	0	0	0	0	0

Heatwaves in EM-DAT

1	Country	ISO	Location	EndDate	TotalDeaths	NoInjured	NoAffected	NoHomeless	TotalAffected	Reconstruction_Cos	Insured_Damages	Total_Damages
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3	Greece	GRC		1987-7-31	1000	0	0	0	0	0	0	0
4	Greece	GRC		1988-7-3	56	0	0	0	0	0	0	0
5	Yugoslavia	YUG	Belgrade (Serbia)	1988-7-11	38	0	0	0	0	0	0	0
6	France	FRA	Southwestern	1990-7-24	5	0	0	0	0	0	0	0
7	Romania	ROU		1994-5-	0	0	0	0	0	0	0	0
8	Spain	ESP	Andalusia	1995-7-25	30	70	0	0	70	0	0	0
9	Russian Federation (the)	RUS	Moscou	1995-6-14	20	0	0	0	0	0	0	0
10	Romania	ROU		1996-7-4	16	200	0	0	200	0	0	0
11	Italy	ITA	Calabria	1998-7-4	10	0	0	0	0	0	0	0
12	Romania	ROU		1998-8-3	20	0	0	0	0	0	0	0
13	Lithuania	LTU		1999-6-14	32	0	0	0	0	0	0	0
14	Croatia	HRV	Zagreb city (Zagreb provin	2000-6-	40	200	0	0	200	0	0	240000
15	Greece	GRC	Anatoliki Makedonia Kai T	2000-7-	27	176	0	0	176	0	0	3000
16	Romania	ROU	Bucuresti, Dolj provinces	2000-7-	6	100	0	0	100	0	0	0
17	Bulgaria	BGR	Sofia, Sofia-city, Stata Zagc	2000-7-	7	0	0	0	0	0	0	50
18	Serbia Montenegro	SCG	Subotica city (Severno-bac	2000-7-	3	70	0	0	70	0	0	0
19	Russian Federation (the)	RUS	Moskva, Moskovskaya Ob	2001-7-	276	0	0	0	0	0	0	0
20	Austria ; Belgium ; Switzerl	AUT ; BEL ; CHE ; C	Burgenland, Karnten, Nied	2003-8- ; 200	72210	0	0	0	0	0	10000	12120000
21	Albania ; Macedonia (the fo	ALB ; MKD ; ROU	Durres city (Durres district	2004-7- ; 200	45	0	0	0	0	0	0	0
22	Spain ; Canary Is	ESP ; SPI	AndalucÃ-a, Castilla-La Ma	2004-7-30 ; 2	39	113	0	0	113	0	0	0
23	Romania	ROU	Bucuresti province	2005-8-1	13	500	0	0	500	0	0	0
24	Portugal	PRT	Aveiro, Beja, Braga, Bragar	2005-8-	462	0	0	0	0	0	0	0
25	Romania	ROU	Bucarest, Galati, Mehedin	2006-7-	26	200	0	0	200	0	0	0
26	Belgium ; Germany ; Spain	BEL ; DEU ; ESP ; FF	Vlaams Geweest, Region d	2006-7- ; 200	3392	0	0	0	0	0	0	0
27	Albania ; Austria ; Bulgaria	ALB ; AUT ; BGR ; B	Berat, Bulqize, Delvine, De	2007-7-22 ; 2	560	139	352	0	491	0	0	0
28	Russian Federation (the)	RUS	Moska, Moskovskaya Obla	2010-8-	55736	0	0	0	0	0	0	400000
29	Italy	ITA	Milano district (Lombardia	2011-8-24	10	0	0	0	0	0	0	0
30	United Kingdom of Great B	GBR	England, Wales provinces	2013-7-	760	0	0	0	0	0	0	0
31	Belgium ; France	BEL ; FRA	Vlaams Gewest, Region de	2015-7-5 ; 20	3685	0	0	0	0	0	0	0
32	Belgium ; Germany ; Spain	BEL ; DEU ; ESP ; FF	;; ; ; ; ; ; ; ; ; ; ; ;	2018-7- ; 201	9	0	0	0	0	0	0	0
33	Belgium ; Germany ; Spain	BEL ; DEU ; ESP ; FF	;; ; Cordoba, Valladolid ; v	2020-7-1 ; 20	709	0	0	0	0	0	0	0
34	Austria ; Belgium ; German	AUT ; BEL ; DEU ; F	;; ; ; Toute la France mÃ©C	2019-7-26 ; 2	1669	0	0	0	0	0	0	0
35	Belgium ; United Kingdom	BEL ; GBR	;	2019-8-29 ; 2	188	0	0	0	0	0	0	0
36	Belgium ; France ; United K	BEL ; FRA ; GBR ; N	;; ; ;	2020-8-8 ; 20	6340	0	0	0	0	0	0	0

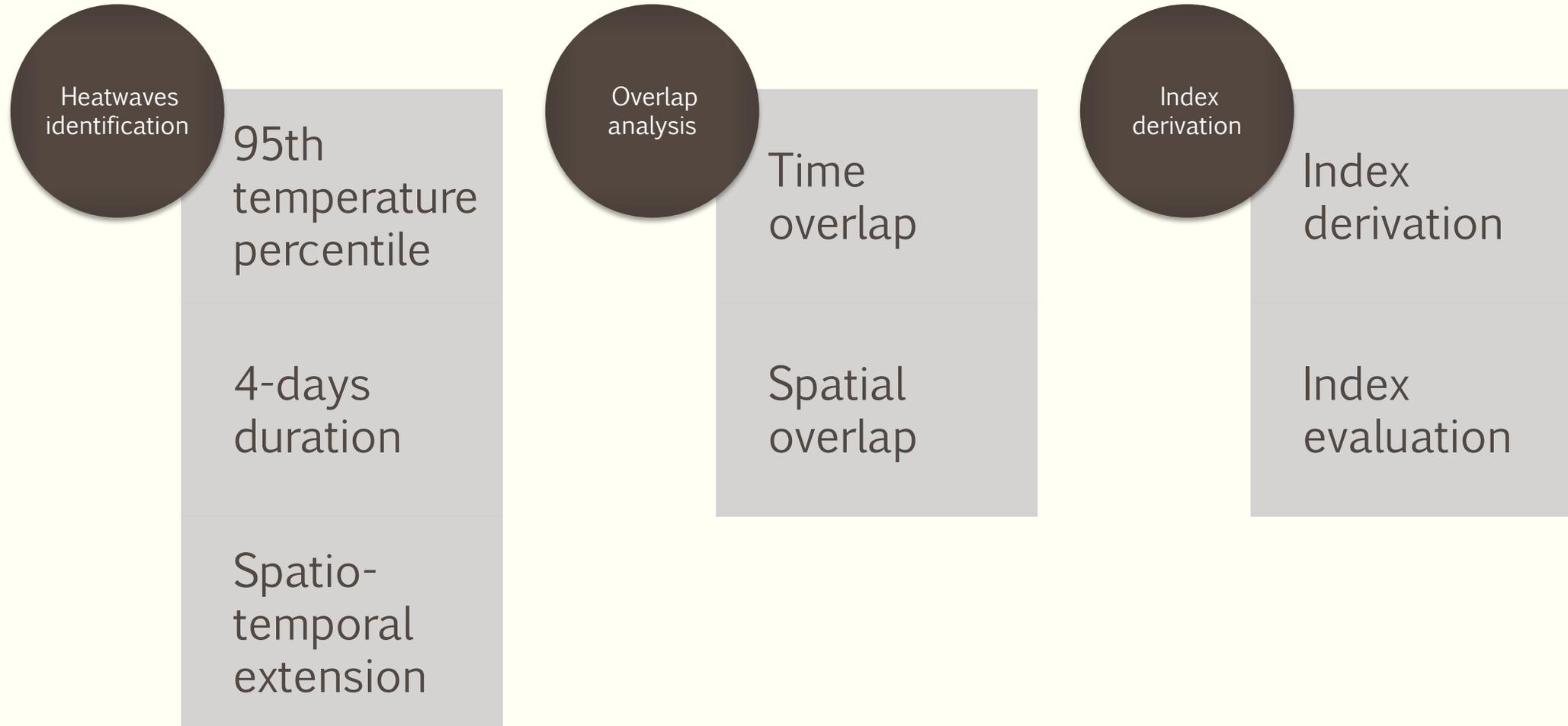
GHS-POP

- GHS-POP :
 - 1975 - 2020, every 5 years
 - 1km resolution
- Regridded to 0.1° resolution grid for E-OBS
- Regridded to 0.25° resolution grid for ERA5

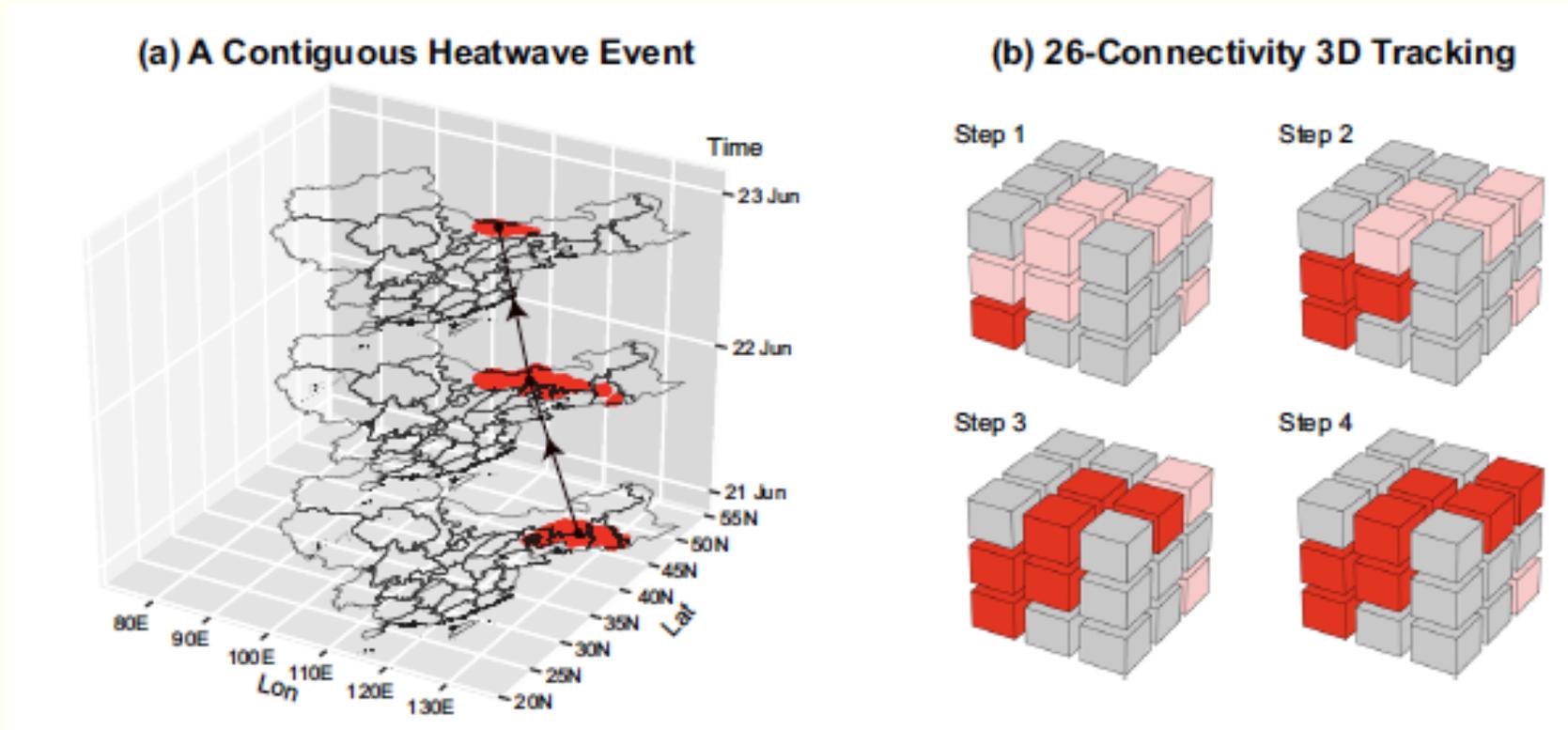
E-OBS & ERA5 temperature dataset

- 1950 – 2021
- Resolution and spatial coverage :
 - E-OBS : 0.1° ; 25°N - 71.5°N x 25°W - 45°E
 - ERA5 : 0.25° ;
- Variable : Daily mean temperature

Methodology



Connected components algorithm



Luo *et al* (2022)

Results of the scanning process and overlap analysis

- 88 heatwaves in EM-DAT (Europe, JJA, 1950-2021)
- 374 heatwaves detected in ERA5
- 387 heatwaves detected in E-OBS
- 18 EM-DAT heatwaves not detected (10 after merge)
- 16 EM-DAT heatwaves not detected (9 after merge)
- After merging, 359 heatwaves, including 23 extreme heatwaves
- After merging, 376 heatwaves, including 24 extreme heatwaves

Heatwaves not detected

Affected countries	Total Deaths	Year
Greece	20	1985
Greece	56	1988
Romania	16	1996
Croatia	40	2000
Albania, Macedonia, Romania	45	2004
Romania	26	2006
Italy	10	2011
Belgium, Great Britain	188	2019

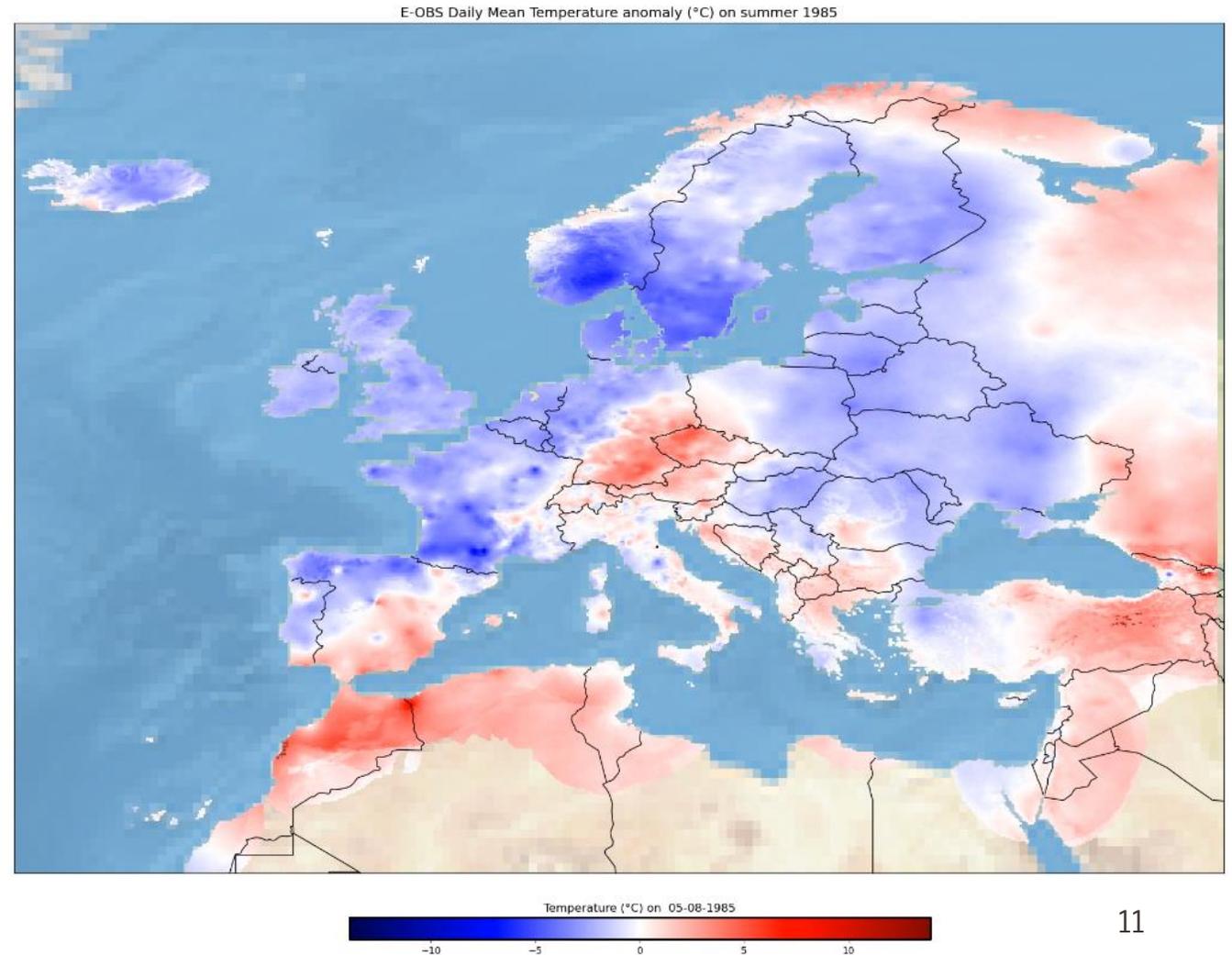


Illustration of the worst and best cases : E-OBS

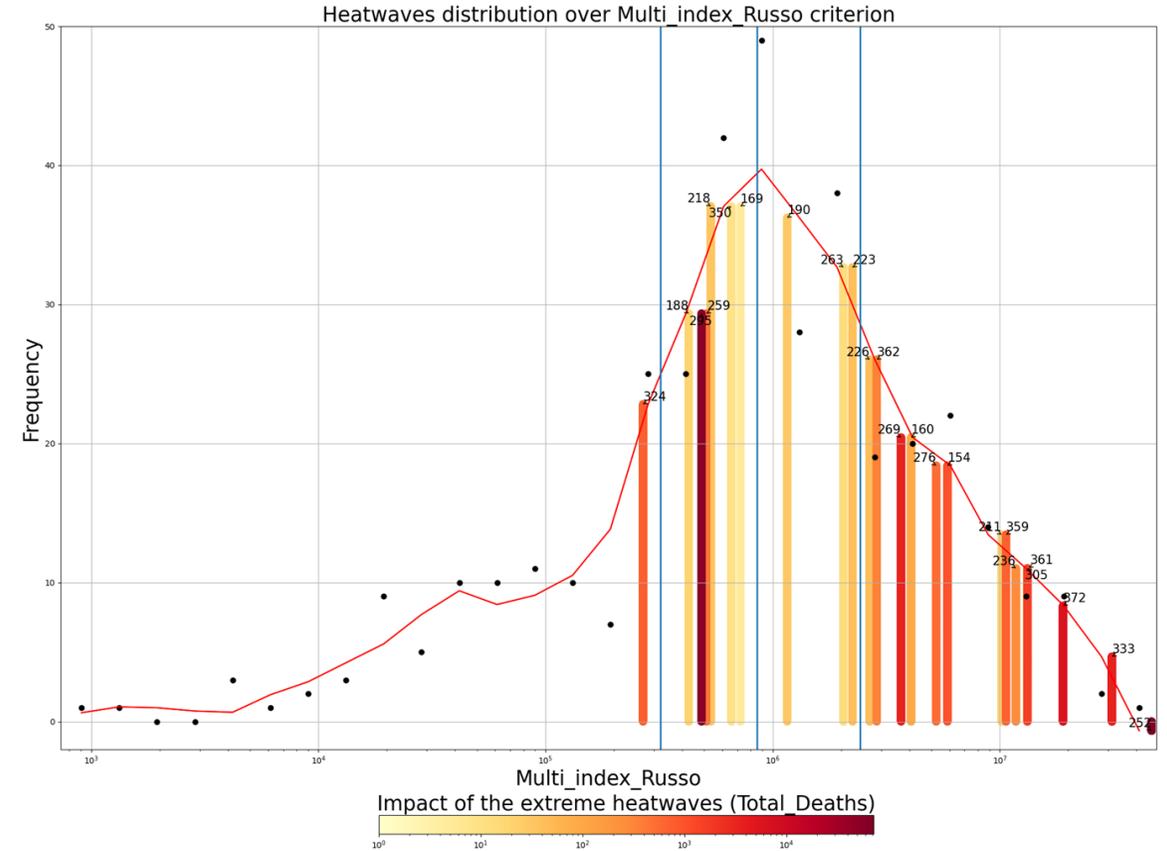
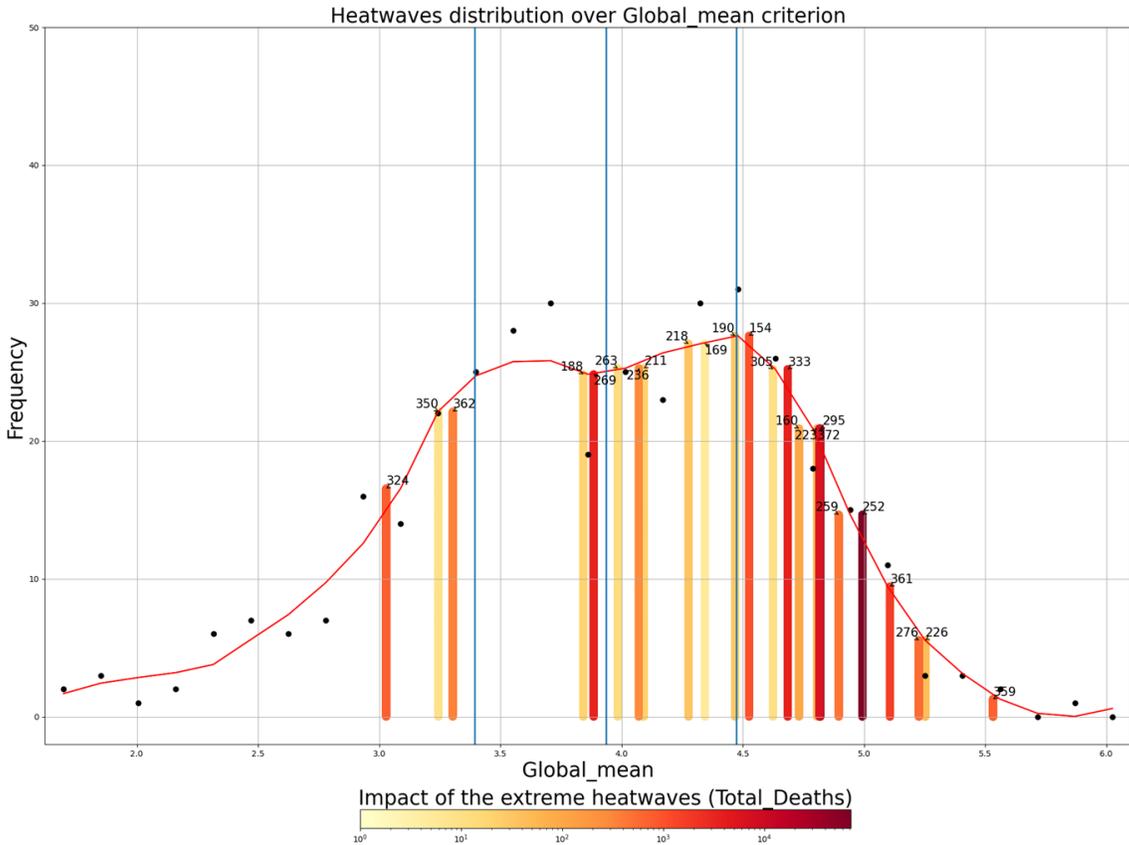
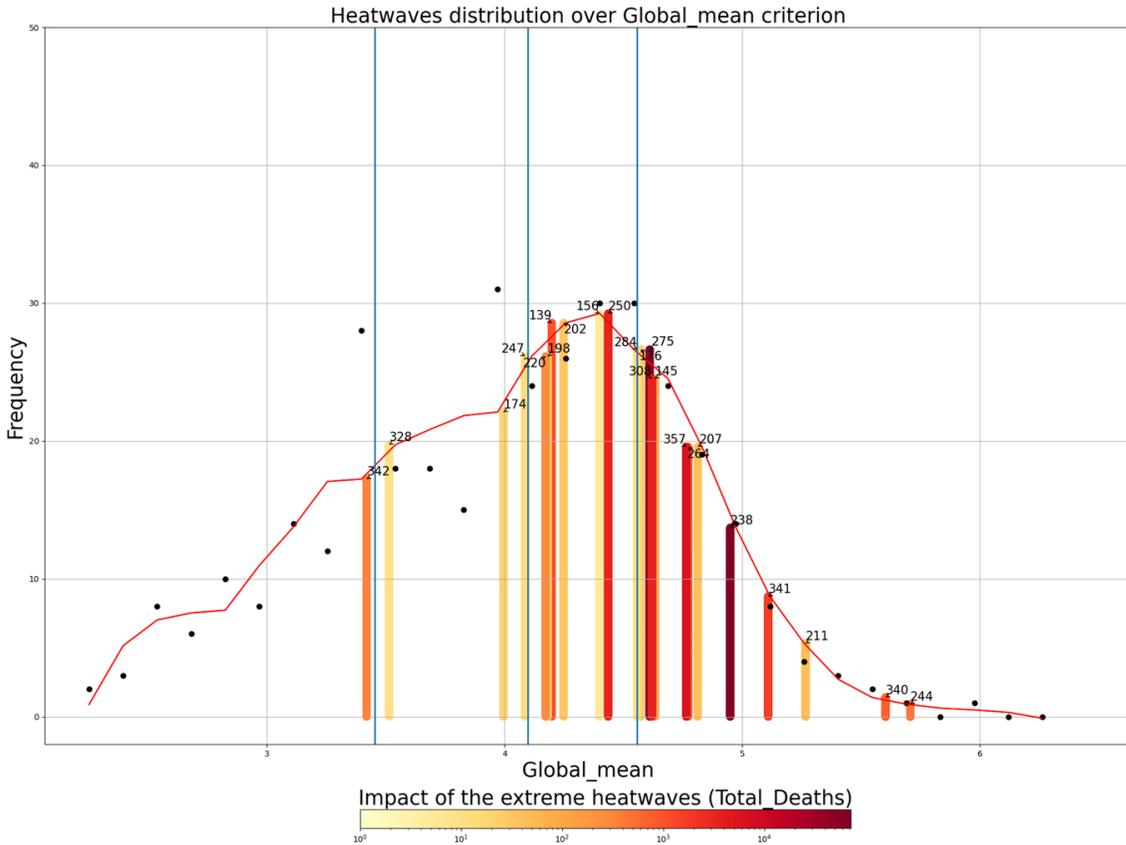
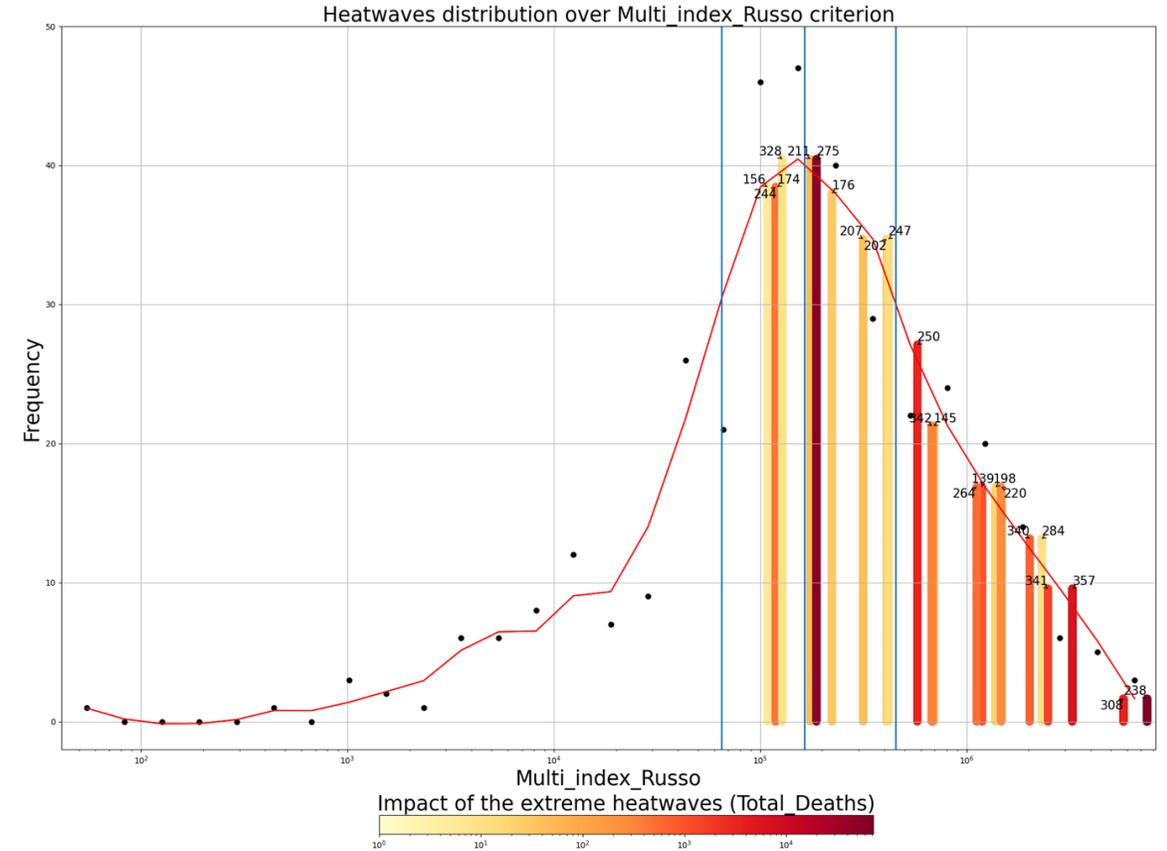


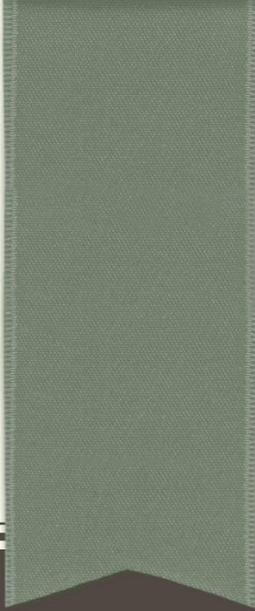
Illustration of the worst and best cases : ERA5



Global_mean



Multi_index_Russo



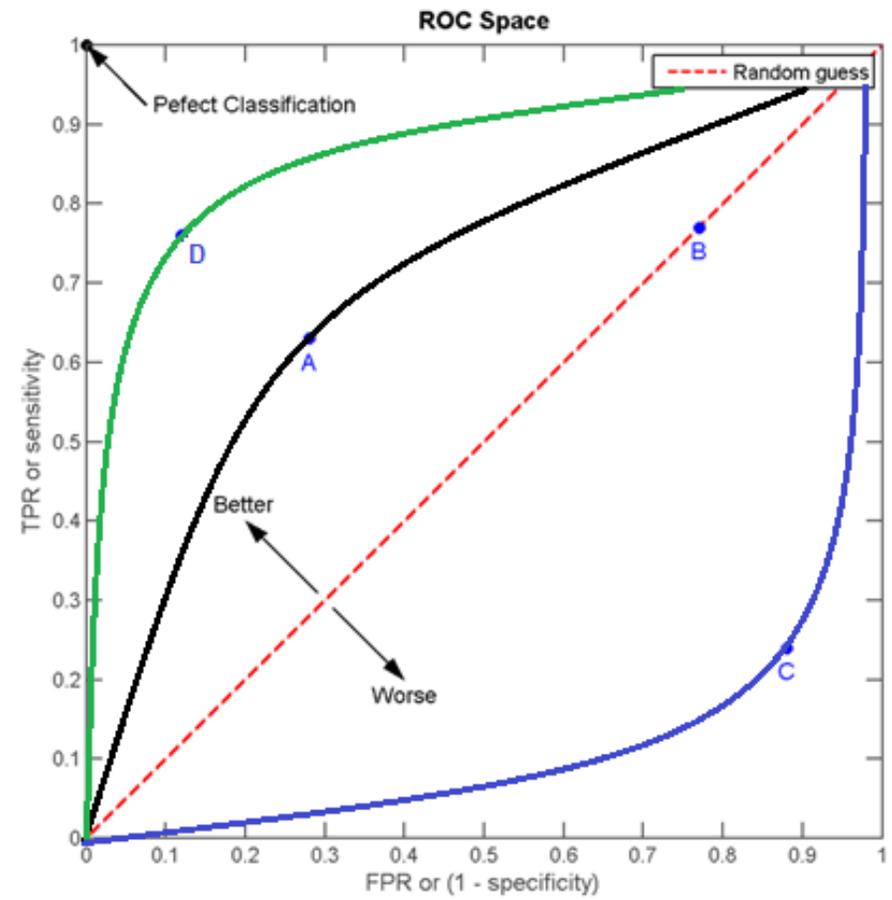
APPENDICES

Derived indices

- **Global_mean** : The daily mean temperature anomaly averaged over every grid point that is part of the given heatwave (time and spatial average)
- **Spatial_extent** : Sum of the area of every affected grid cell (every grid cell is considered only once, time is not accounted for)
- **Duration** : number of days of the given heatwave
- **Max** : Maximum of the daily mean temperature anomaly over the whole heatwave (time and space)
- **Max_spatial** : Max multiplied by Spatial_extent
- **Temp_sum** : Sum of the daily mean temperature anomaly on every grid point that is part of the given heatwave (time and spatial integration)
- **Pseudo_Russo** : Spatial integration of an index adapted from the HWMId defined in Russo *et al* (2015)
- **Pop_unique** : Total affected population
- **Multi_index_Russo** : Pseudo_Russo weighted with population density
- **Multi_index_temp_NL** : Temp_sum weighted with population density and we use a 1000 ppl/km² threshold

Index evaluation method

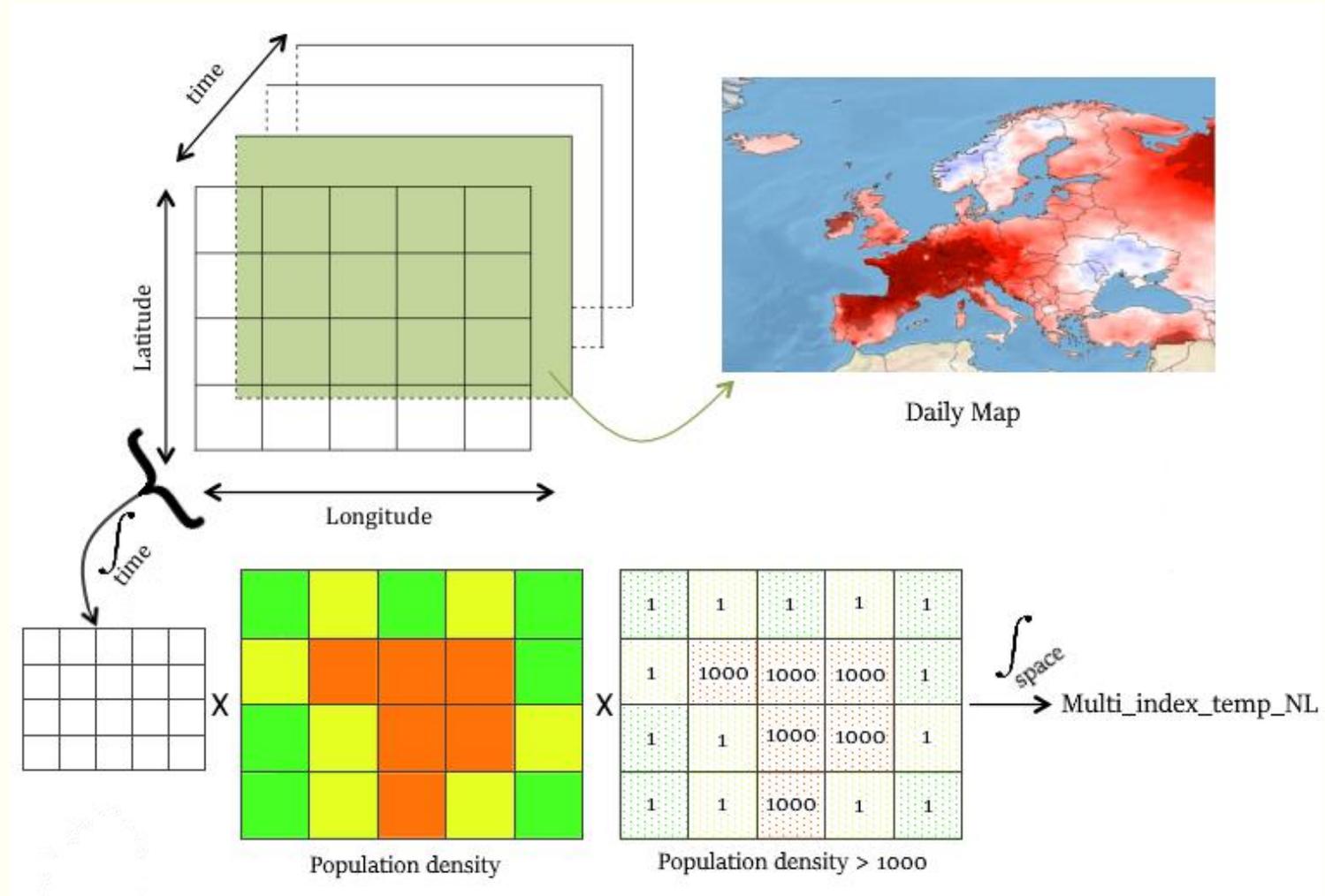
- Correlation coefficient between index and impact for extreme heatwaves
- Area Under the Receiver Operating Characteristic Curve (AUROCC)



Undetected heatwaves :

ERA5	88 heatwaves in EM-DAT (Europe, JJA, 1950-2021)	E-OBS
1985-0257-GRC		1985-0257-GRC
1998-0204-ITA		1998-0204-ITA
1996-0362-ROU		1996-0362-ROU
2003-0391-CHE, 2003-0391-HRV, 2003-0391-CZE, 2003-0391-GBR, 2003-0391-LUX, 2003-0391-SVK		2003-0391-CHE, 2003-0391-HRV, 2003-0391-CZE, 2003-0391-GBR, 2003-0391-LUX, 2003-0391-SVK
2004-0333-ALB, 2004-0333-ROU, 2004-0333-MKD		2004-0333-ALB, 2004-0333-ROU, 2004-0333-MKD
2004- 361-ESP		2004- 361-ESP
2006-0348-ROU		2006-0348-ROU
2007-0235-ITA		2007-0235-ITA
2013-0549-GBR		
2019-0296-BEL, 2019-0296-GBR		2019-0296-GBR

Impact predictor



Indices scores

Index	Correlation coefficient	p-value	AUROC	Global score
Global_mean	0.029182	0.894847	0.72177	0.021062
Spatial_extent	0.526818	0.009801	0.785267	0.413693
Duration	0.527938	0.009618	0.771348	0.407224
Max	0.201875	0.355627	0.674851	0.136236
Max_spatial	0.499399	0.01526	0.784329	0.391693
Temp_sum	0.56172	0.005283	0.786831	0.441979
Pseudo_Russo	0.581288	0.003626	0.794495	0.46183
Pop_unique	0.601997	0.002372	0.837348	0.504081
Global_mean_pop	0.467748	0.024404	0.793869	0.371331
Duration_pop	0.490455	0.017500	0.847513	0.415667
Max_pop	0.56373	0.005088	0.835784	0.471156
Max_spatial_pop	0.556027	0.005869	0.819987	0.455935
Spatial_extent_pop	0.573395	0.004232	0.822959	0.471881
Temp_sum_pop	0.591867	0.002929	0.823272	0.487267
Pseudo_Russo_pop	0.602201	0.002361	0.827338	0.498224
Temp_sum_pop_NL	0.646314	0.000862	0.837504	0.54129
Pseudo_Russo_pop_NL	0.636301	0.001099	0.841883	0.535691
Multi_index_temp	0.628619	0.001315	0.846419	0.532075
Multi_index_Russo	0.605356	0.002208	0.850172	0.514657
Multi_index_temp_NL	0.641905	0.000960	0.853144	0.547637
Multi_index_Russo_NL	0.615370	0.001775	0.856741	0.527213

Connected components algorithms

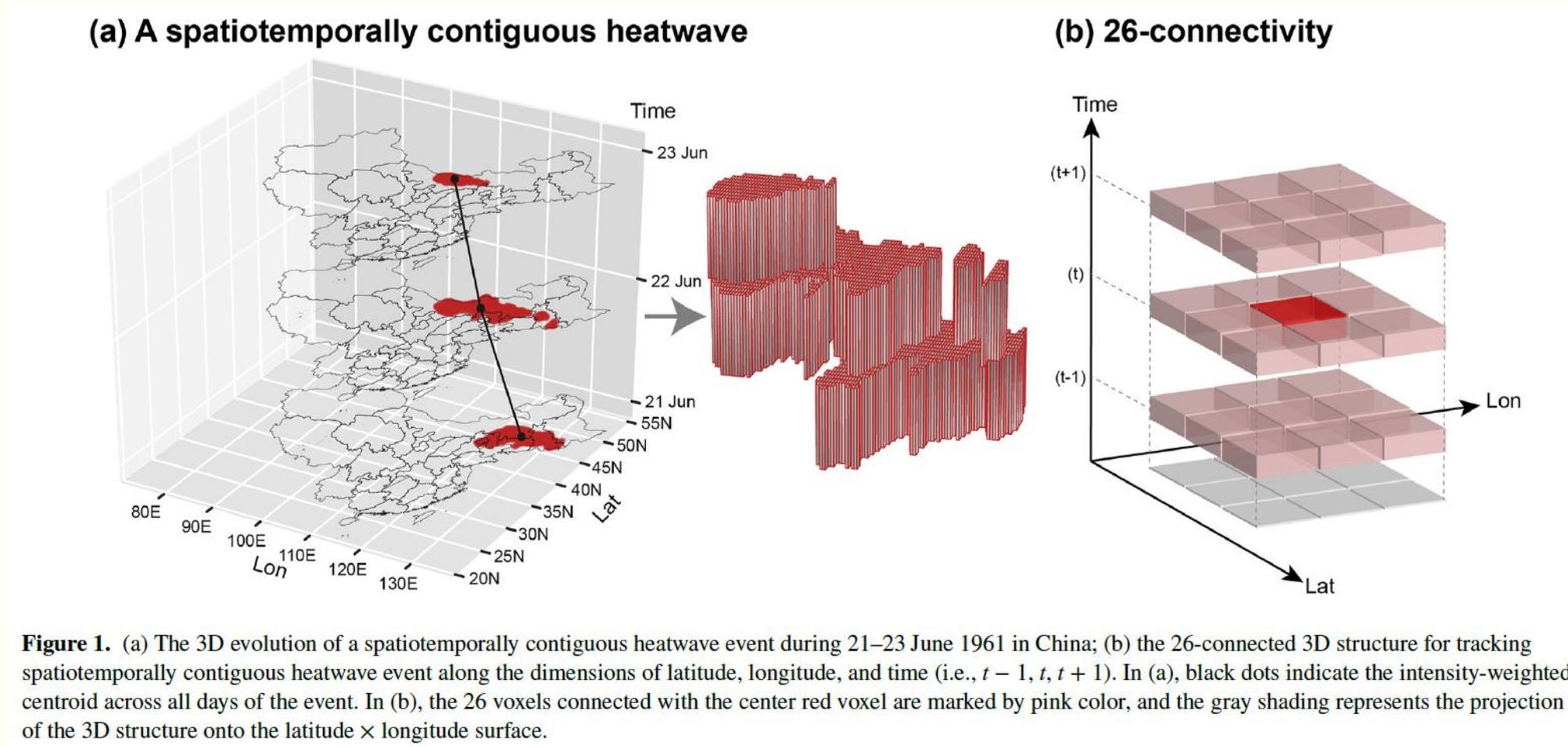
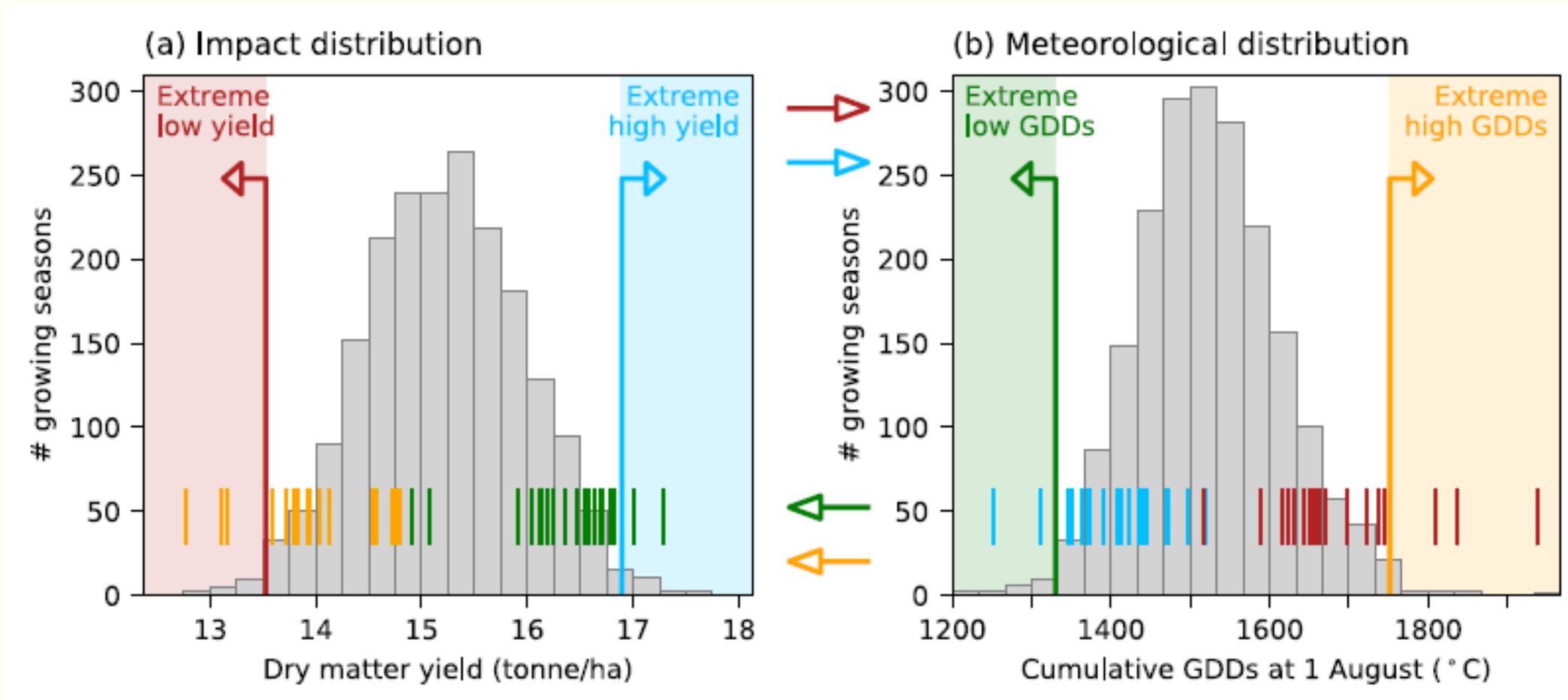


Illustration : crop yield in Netherlands Van der Wiel *et al* (2020)



Van der Wiel *et al* (2020)

Russo *et al* (2015) : HWMI_d

$$M_d(T_d) = \begin{cases} \frac{T_d - T_{30y25p}}{T_{30y75p} - T_{30y25p}} & \text{if } T_d > T_{30y25p} \\ 0 & \text{if } T_d \leq T_{30y25p} \end{cases}$$

$$A_d = \bigcup_{y=1950}^{2020} \bigcup_{i=d-7}^{d+7} T_{y,i}$$

$$M_d = \begin{cases} \frac{T_d - T_{25}}{T_{75} - T_{25}} & \text{if } T_d \geq T_{95} \\ 0 & \text{if } T_d < T_{95} \end{cases}$$