

Supplementary Information to “Pan-European hydrodynamic models and their ability to identify compound floods”

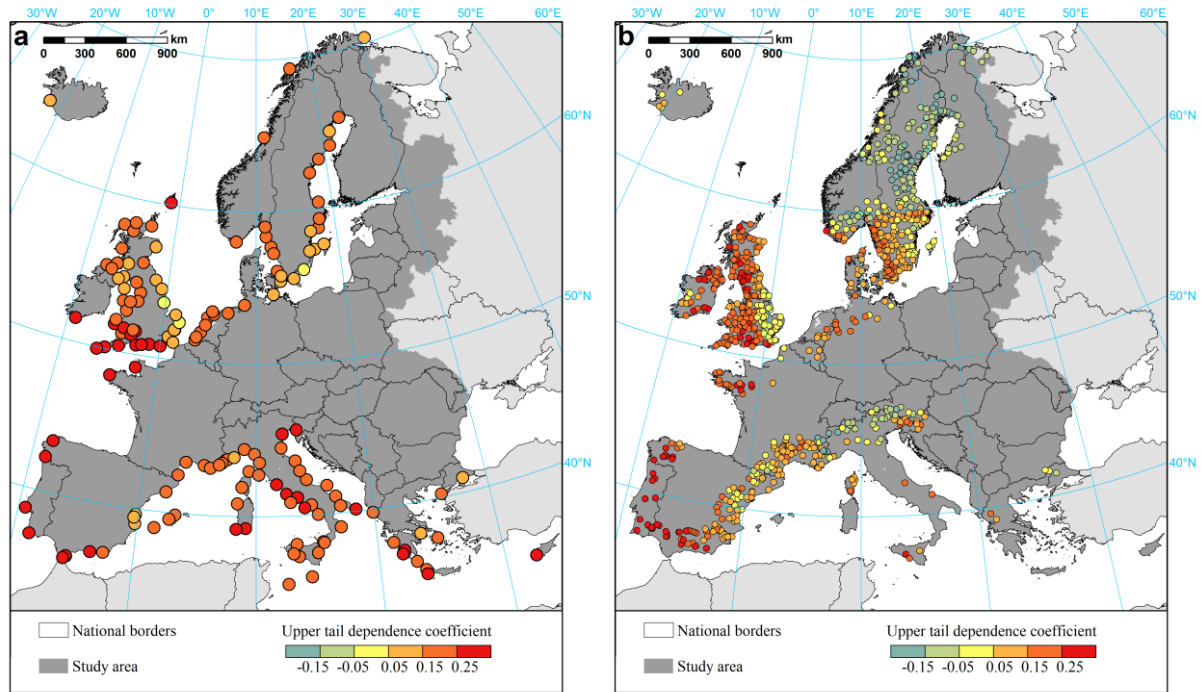


Figure S1. Upper tail dependence coefficient (UTDC) between modelled (**reanalysis**) storm surge events and (a) precipitation; (b) river discharges. The connections between river gauges and tide gauges from observations are preserved here for comparability with Fig. 1 in the main manuscript.

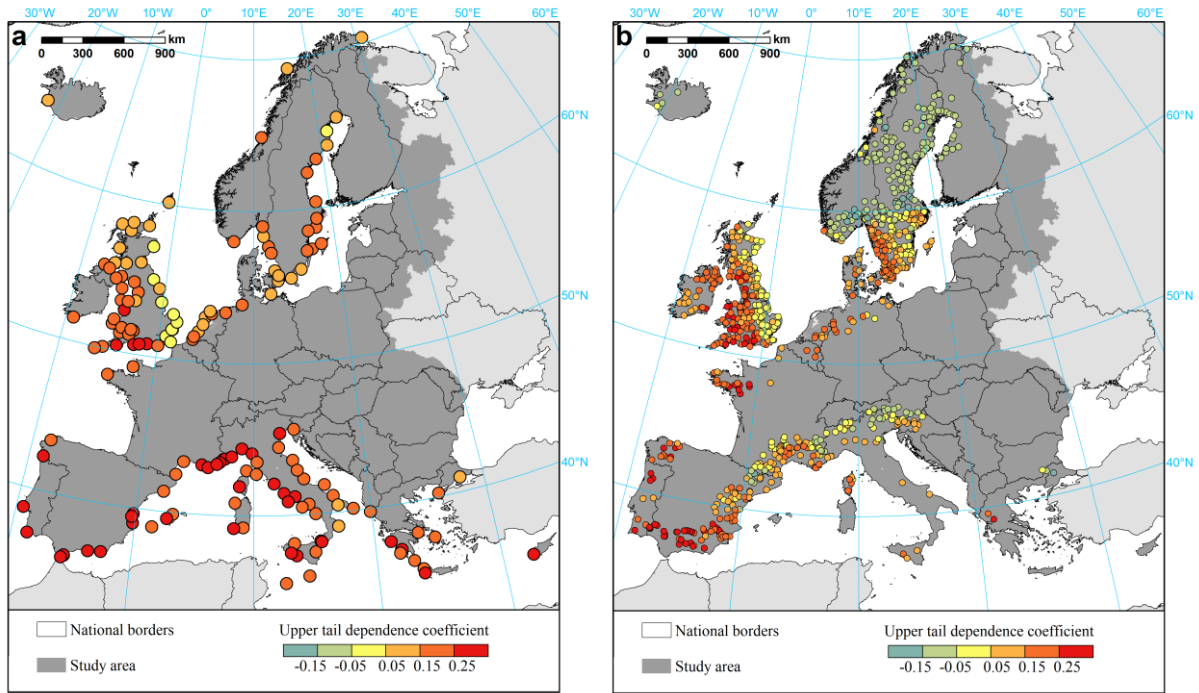


Figure S2. Upper tail dependence coefficient (UTDC) between modelled (**hindcast**) storm surge events and (a) precipitation; (b) river discharges. The connections between river gauges and tide gauges from observations are preserved here for comparability with Fig. 1 in the main manuscript.

Table S1. Compound flood events identified in the reanalysis data. A compound event is defined here as the occurrence of a storm surge event with a peak water level at least equal to a 5-year return period, during which (with an additional ± 1 day window) precipitation or river discharge peaked at a value at least equal to a 5-year return period. "Type" is 'Pr' for a combination of storm surge and precipitation or 'Di' for river discharge. For 'Di' type, the nearest EFAS grid point is used, unless river names are mentioned, which is for compound events involving rivers with catchment area of at least 500 km². Intensity ("Int") is high ('Hi') if both return periods of the marginal events are above 10 years; low ('Lo') otherwise. Reported impacts gathered from Paprotny et al. (2018), Consiglio Nazionale delle Ricerche (2019); Diakakis (2014), Direction Generale de la Prevention des Risques (2019), Direccion General de Proteccion Civil (2015), European Environment Agency (2015), Environment Agency (2017), Meteo France (2019) and Zezere et al. (2014). See main text for details and bibliography. Reported values of losses are in nominal (year-of-event) prices and original currencies.

No	Type	Int	Date	Location	Basin	River	Floods/impacts reports
1	Pr	Lo	22 Jan 1981	Fthiotida, Central Greece region, Greece	Aegean Sea		Flash floods in south Greece
2	Pr	Lo	15 Dec 1981	Samos, North Aegean region, Greece	Aegean Sea		None (low intensity event)
3	Pr	Lo	7 Nov 1982	Cádiz province, Spain	Atlantic Ocean		Extreme flash floods in south & east Spain; 14 fatalities, 112,000 people affected, 40.8 bln peseta losses; floods in France and Italy
4	Pr	Lo	23 Jan 1983	Hornstrandir peninsula, northwest Iceland	Greenland Sea		None (uninhabited area)
5	Pr	Lo	23 Oct 1983	Lofoten, Nordland county, Norway	Norwegian Sea		None (sparsely populated area)

6	Pr	Lo	4 Oct 1984	A Coruña, Lugo, Asturias provinces, Spain	Bay of Biscay		Fluvial flood reported in Cantabria province, houses damaged
7	Pr	Lo	31 Jan-1 Feb 1986	Venezia, Udine provinces, Italy	Adriatic Sea		Major compound flood from storm surge ('acqua alta') and rainfall; 5 fatalities, 30 bln lira losses
8	Pr	Lo	14 Jan 1987	Bouches-du-Rhône, Var departments, France	Western Mediterranean Sea		Fluvial flood reported
9	Pr	Hi	15 Oct 1987	Pontevedra, A Coruña provinces, Spain; Vendée, Loire-Atlantique, Morbihan departments, France	Atlantic Ocean, Bay of Biscay		Recorded by gauges; fluvial floods reported in Spain, with some houses/roads damaged and evacuations
10	Pr	Lo	24 Nov 1987	Venezia, Udine, Gorizia, Trieste provinces, Italy	Adriatic Sea		Coastal flood and damages in Venice reported
11	Pr	Lo	31 Jan-1 Feb 1988	Constanta county, Romania	Black Sea		None (low intensity event)
12	Pr	Hi	15 Jan 1989	Møre og Romsdal county, Norway	Norwegian Sea		None
13	Pr	Hi	26 Dec 1989	Cádiz, Huelva provinces, Spain; Algarve, Alentejo Litoral regions, Portugal	Atlantic Ocean		Flash floods in Portugal (187 people affected)
14	Di	Lo	7 Feb 1990	Hampshire, West Sussex, United Kingdom	English Channel		Fluvial floods and property damage reported
15	Di	Hi	27 Feb 1990	Nordjylland, Østjylland provinces, Denmark	Skagerrak, Kattegat		Coastal flood and economic losses reported; recorded by gauges in Sweden
16	Pr	Lo	5 Dec 1992	Gorizia, Trieste provinces, Italy; Slovenia	Adriatic Sea		Fluvial floods in Slovenia, 1 fatality
17	Di	Hi	8 Dec 1992	Ravenna province, Italy	Adriatic Sea		Fluvial floods, dike breaches and building/infrastructure damage reported
18	Pr	Lo	8 Dec 1994	Manche department, France	English Channel		Major river floods in northern France between Sep 1994 and Jan 1995
19	Pr	Lo	25 Oct 1995	Eyjafjörður, northern Iceland	Greenland Sea		None (sparsely populated area)
20	Di	Lo	30 Dec 1995	Cork county, Ireland	Celtic Sea		None
21	Di	Hi	7-9 Feb 1996	Sicily, Calabria, Puglia regions, Italy; Epirus, Western Greece, Peloponnese regions, Greece	Tyrrhenian, Ionian, Adriatic, Eastern Mediterranean seas	Simeto, Salso, Platani, Neto, Gela, Dirillo, Magazzolo, Verdura, Arachthos, Alfios, Evrotas	None
22	Di	Lo	22 Dec 1996	Cádiz province, Spain	Atlantic Ocean	Barbate	Major flash floods in south Spain; 13

							fatalities, 4000 people affected, 137 bln peseta losses; 2000 people affected in Portugal
23	Pr	Lo	17 Dec 1997	Huelva province, Spain; Alentejo Litoral, Península de Setúbal regions, Portugal	Atlantic Ocean		Fluvial floods reported in south Spain, houses damaged; compound flood in France
24	Pr	Lo	5 Feb 1998	Tekirdağ Province, Turkey	Sea of Marmara		None (low intensity event)
25	Pr	Lo	16 Jan 1999	Eyjafjörður, northern Iceland	Greenland Sea		None (sparsely populated area)
26	Pr, Di	Lo	25 Dec 1999	East Sussex, United Kingdom; Calvados, Seine-Maritime, Somme departments, France	English Channel		Compound flood from storms ('Lothar', 'Martin') and rainfall; 1,200 people affected in UK; major coastal floods in west France (17 fatalities, mostly by windstorm)
27	Di	Lo	30 Oct 2000	East Sussex, United Kingdom	English Channel		Wettest October on record, major river floods; 10 fatalities, 40,000 people affected, 1 bln pound losses; recorded by gauges in Norway
28	Pr, Di	Hi	6 Nov 2000	Landes, Gironde, Charente-Maritime, Vendée departments, France	Bay of Biscay		Floods in Corsica and south France (2 fatalities)
29	Di	Lo	7 Dec 2000	Pontevedra province, Spain; Minho-Lima region, Portugal	Atlantic Ocean		Flash floods further upstream the Duero river; 620 people affected in Spain
30	Pr, Di	Lo	22 Dec 2000	Huelva province, Spain; Algarve region, Portugal	Atlantic Ocean		Floods and landslides in Portugal (1 fatality, 150 people affected); fluvial floods reported in Huelva province, houses damaged
31	Di	Lo	29 Dec 2000	Corse-du-Sud department, France	Western Mediterranean Sea		None (low intensity event)
32	Di	Hi	30 Dec 2000 – 1 Jan 2001	Siracusa, Catania provinces, Italy; Epirus, Western Greece, Peloponnese regions, Greece	Eastern Mediterranean, Ionian seas	Simeto, Arachthos, Alfios, Evrotas, Pinios	River floods in south Italy - 1700 people affected; flash floods in south Greece – 11 fatalities, 450 people affected
33	Pr	Lo	11 Nov 2001	Mallorca, Balearic Islands, Spain	Balearic Sea		Flash floods in east Spain; 1500 people affected
34	Di	Lo	27 Dec 2002	Baixo Vouga, Grande Porto regions, Portugal	Atlantic Ocean		Flash floods in north Portugal; 99 people affected
35	Di	Lo	28 Oct 2004	Waterford county, Ireland	Celtic Sea		Compound flood from storm

							(‘Jeanett’) and rainfall in south Ireland; 200 people affected, 50 mln euro losses
36	Di	Hi	9-10 Jan 2005	Hiiu, Lääne, Harju counties, Estonia	Gulf of Riga, Gulf of Finland		Major coastal flood in Estonia; 93 km ² inundated, 1 fatality, 3150 people affected, 750 mln kroon losses (Estonia); coastal flood in Finland; recorded by gauges in Sweden
37	Di	Lo	3 Dec 2006	Galway, Mayo, Sligo counties, Ireland; Argyll and Bute, North Ayrshire, Highland council areas, United Kingdom	Firth of Clyde, Sea of the Hebrides		Coastal floods reported in UK, 1 fatality, infrastructure damages; recorded by gauges
38	Di	Lo	14 Dec 2008	Mallorca, Balearic Islands, Spain	Balearic Sea		Storm and rainfall reported, houses damaged
39	Di	Lo	23 Jan 2009	Gironde department, France	Bay of Biscay		Pluvial and fluvial floods reported
40	Di	Hi	24-26 Jan 2009	Sicily, Calabria, Campania, Sardinia regions, Italy; Central Macedonia, North Aegean, Thessaly, Epirus, Western Greece, Peloponnese regions, Greece	Mediterranean (Western & Eastern basins), Ionian, Tyrrhenian, Aegean seas	Simeto, Salso, Platani, Neto, Gela, Dirillo, Magazzolo, Verdura, Modione, Nocella, Arachthos, Alfios, Evrotas, Pinios, Pamisos	Inundation (5 km ²) and losses in rural areas reported in Greece
41	Pr, Di	Hi	1-2 Feb 2009	Cádiz, Huelva, Málaga provinces, Spain; Grande Lisboa region, Portugal	Alboran Sea, Atlantic Ocean	Guadalmedina	Windstorm and rainfall damage reported in south Spain
42	Di	Hi	6-7 Mar 2009	Sicily, Calabria regions, Italy; Ileia, Western Greece region, Greece	Eastern Mediterranean, Tyrrhenian, Ionian seas	Simeto, Neto, Magazzolo, Platani, Verdura, Modione, Nocella, Alfios	None
43	Di	Lo	14 Dec 2009	Valencia province, Spain	Balearic Sea		None
44	Di	Lo	24 Dec 2009	Cádiz province, Spain	Atlantic Ocean		River floods in south Spain and Portugal; 620 and 195 people affected, respectively
45	Di	Lo	2 Jan 2010	Arta, Epirus region, Greece	Ionian Sea	Arachthos	None
46	Di	Hi	7 Jan 2010	Granada, Málaga province, Spain	Alboran Sea	Guadalmedina, Verde	Flash floods reported
47	Pr, Di	Lo	15 Jan 2010	Caltanissetta, Agrigento provinces, Italy	Eastern Mediterranean Sea	Platani, Salso	None (low intensity event)
48	Di	Lo	18 Jan 2010	Burgas province, Bulgaria	Black Sea		None
49	Di	Lo	22 Dec 2010	Cádiz province, Spain	Atlantic Ocean	Barbate	Fluvial flood in south Spain, 690 people affected

50	Di	Hi	13 Dec 2011	Argyll and Bute, Highland council areas, United Kingdom	Sea of the Hebrides		Localised inundation reported, storm ('Friedhelm') damage
51	Di	Lo	26 Dec 2011	Leningrad Oblast, Russia	Gulf of Finland		Storm ('Patrick') damages reported, Saint Petersburg Dam closure
52	Di	Lo	4 Jan 2012	Åland, Varsinais-Suomi regions, Finland	Gulf of Bothnia		Storm damages reported
53	Di	Lo	6 Jan 2012	Central Macedonia, Eastern Macedonia and Thrace, Thessaly regions, Greece; Sydjylland, Fyn provinces, Denmark	Aegean Sea, the Danish Straits		Storm ('Ulli') damages reported
54	Di	Lo	12-14 Jan 2012	Hiiu, Saare county, Estonia; Kurzeme region, Latvia; Bornholm province, Denmark;	Baltic Sea		Storm and floods reported in Latvia; recorded by gauges in Sweden
55	Di	Lo	7 Feb 2012	Ileia, Western Greece region, Greece	Ionian Sea	Alfios, Pinios	Flash floods in west Greece; 1 fatality, 200 people affected
56	Pr	Hi	10 Sep 2012	Eyjafljörður, northern Iceland	Greenland Sea		None (sparsely populated area)
57	Pr	Lo	19 Jan 2013	Asturias, Cantabria provinces, Spain	Bay of Biscay		None (low intensity event)
58	Di	Lo	26 Jan 2013	Western Greece, Peloponnese regions, Greece	Eastern Mediterranean, Ionian seas	Alfios, Evrotas, Pinios, Pamisos	None
59	Pr, Di	Hi	14-15 Mar 2013	Shkodër, Lezhë, Vlorë counties, Albania; Salerno, Palermo provinces, Italy; Montenegro; Arta, Epirus region, Greece	Tyrrhenian, Ionian, Adriatic seas	Nocella, Arachthos	Fluvial flood reported in Albania, 2800 people affected
60	Pr, Di	Hi	24-27 Dec 2013	Charente-Maritime, Vendée, Loire-Atlantique, Morbihan, Finistère departments, France; Isle of Man; southern, western and northern coasts of the United Kingdom	English Channel, Sea of the Hebrides, Atlantic Ocean, Bay of Biscay; North, Celtic, Irish seas		Heavy rainfall and floods from storm ('Dirk') in France; major river floods in UK between Dec 2013 and Feb 2014 – 450 km ² inundated, 25,000 people affected, 580 mln pound losses

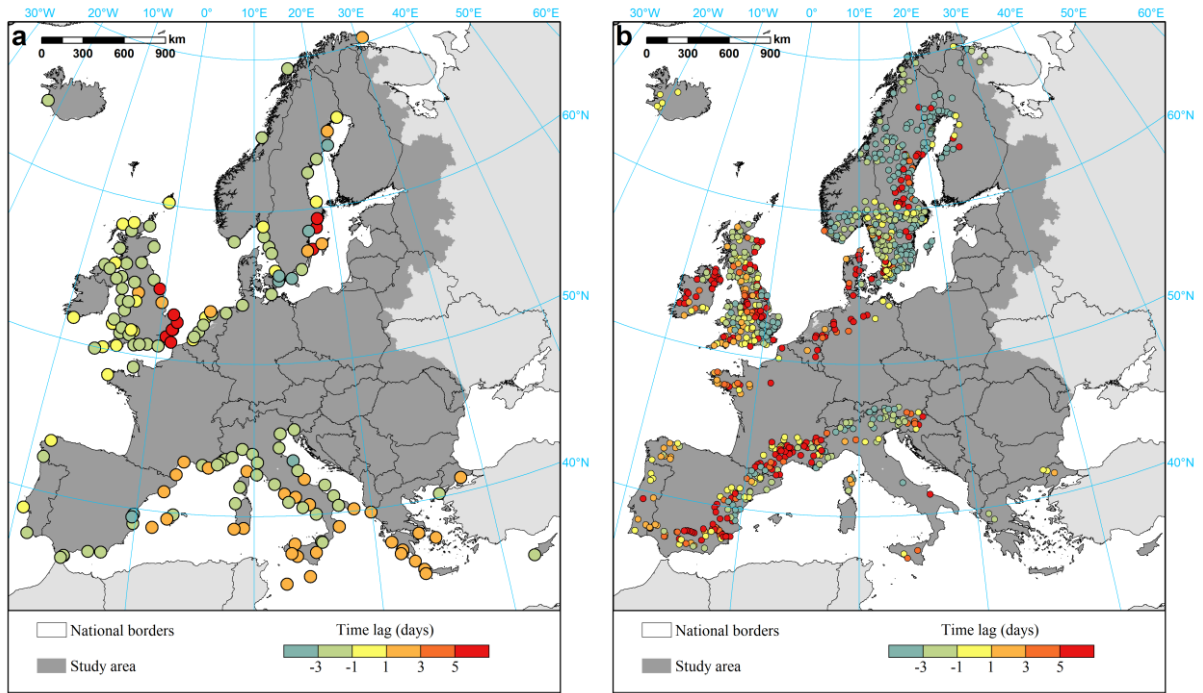


Figure S3. Time lag in occurrence of storm surge events and (a) precipitation; (b) river discharges, that results in the highest value of the upper tail dependence coefficient (UTDC), according to **reanalysis** data. The connections between river gauges and tide gauges from observations are preserved here for comparability with Fig. 4 in the main manuscript.

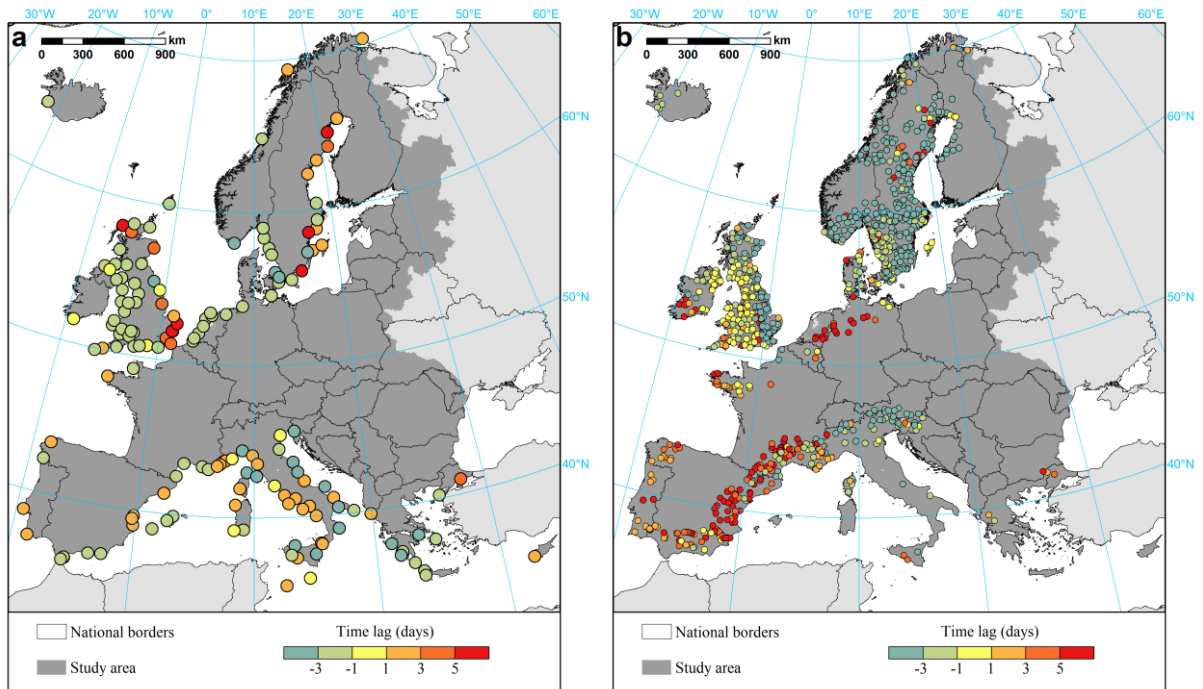


Figure S4. Time lag in occurrence of storm surge events and (a) precipitation; (b) river discharges, that results in the highest value of the upper tail dependence coefficient (UTDC), according to **hindcast** data. The connections between river gauges and tide gauges from observations are preserved here for comparability with Fig. 4 in the main manuscript.

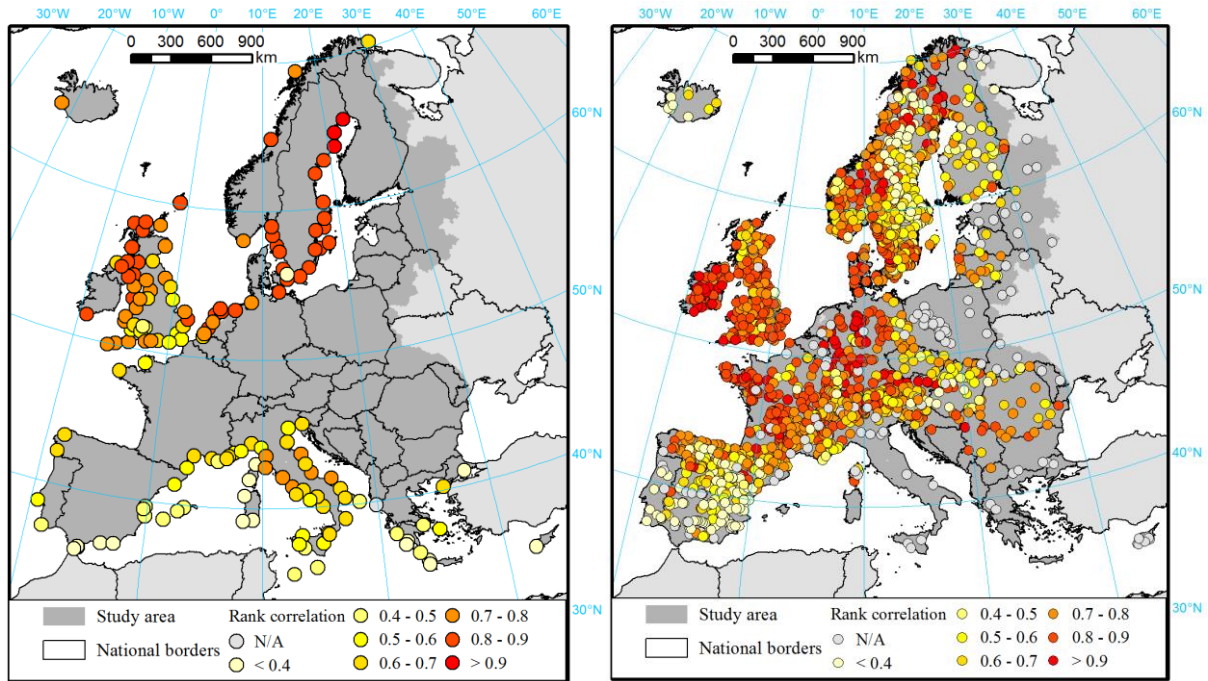


Figure S5. Rank correlation between modelled (reanalysis) and observed (a) daily storm surge, (b) precipitation. N/A = not available due to insufficient length of data or too much distance between river and tide gauge.

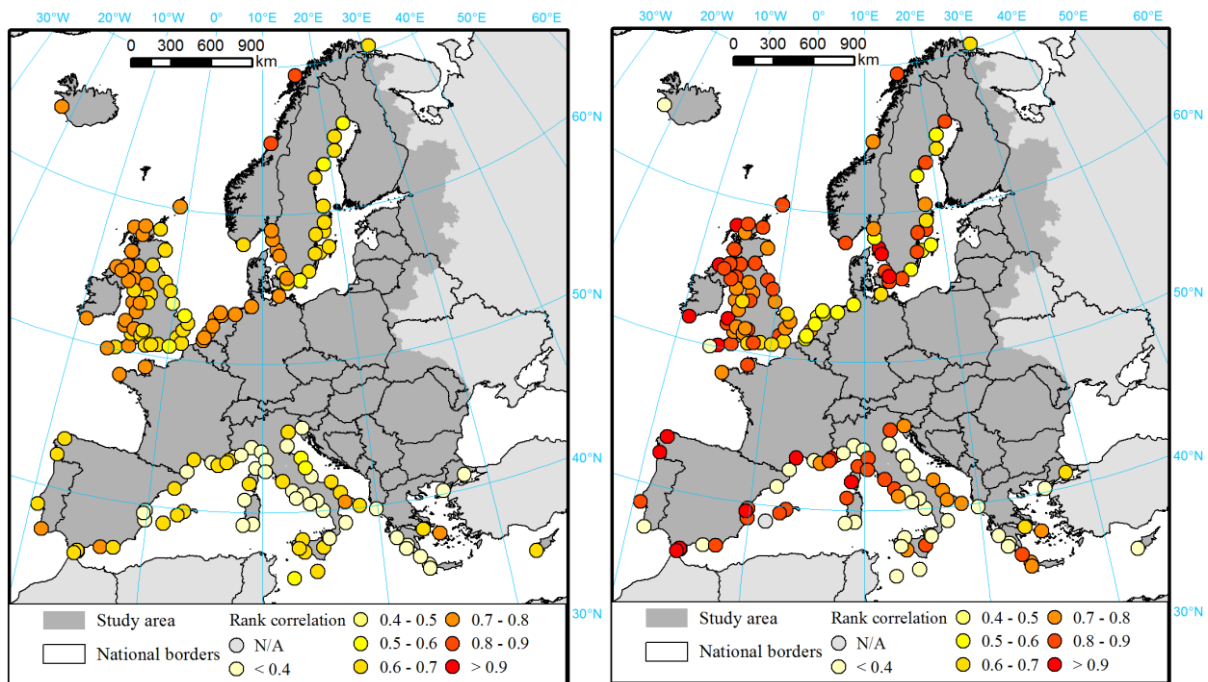


Figure S6. Rank correlation between (a) modelled (ERA-Interim) and observed (E-OBS) precipitation, (b) observed precipitation in E-OBS and EFAS-Meteo datasets. N/A = not available due to insufficient length of data or too much distance between river and tide gauge.

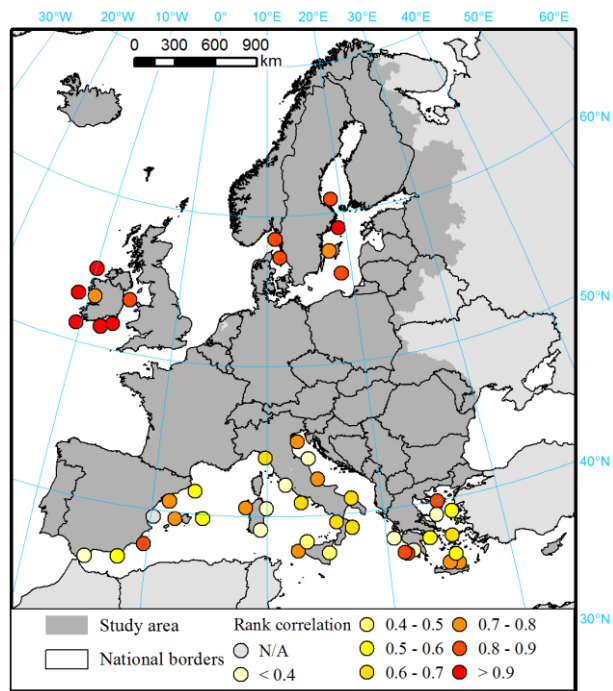


Figure S7. Rank correlation between modelled and observed daily significant wave height. N/A = not available due to insufficient length of data or too much distance between river and tide gauge.