

Supplementary Information for

Human-induced climate change amplification on storm dynamics in Valencia's 2024 catastrophic flash flood

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Supplementary Table 1: CMIP6 models. Further details for each model are available in the references listed in this table.

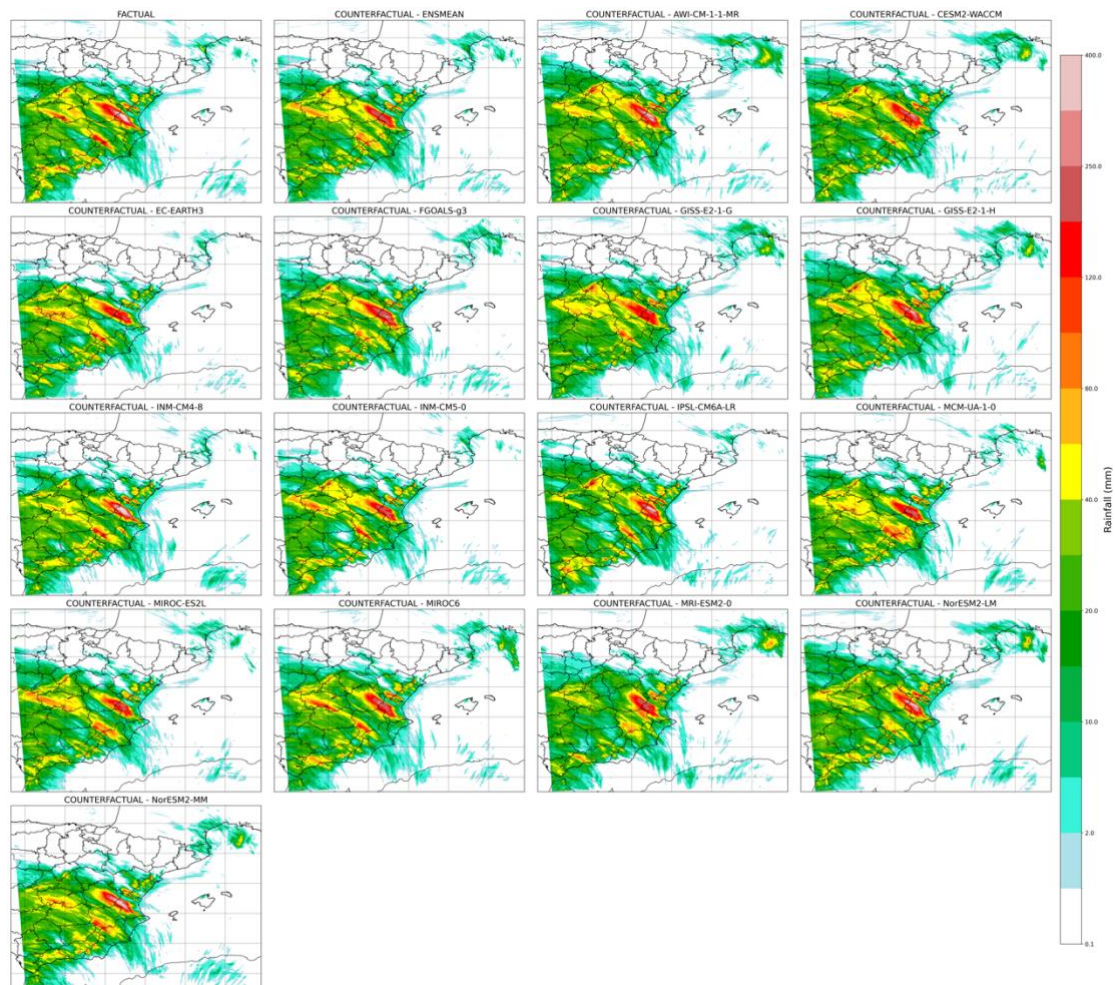
GCM	Institute ID	Resolution (lat. x lon.)	Reference
AWI-CM-1-1-MR	AWI (Germany)	0.937° x 0.937°	Semmler et al. (2018)
CESM2-WACCM	NCAR (USA) EC-Earth-Consortium	1.3° x 0.9°	Danabasoglu (2019)
EC-Earth3	(Europe)	0.7° x 0.7°	EC-Earth (2019)
FGOALS-g3	CAS (China)	2° x 2°	Li et al. (2020)
GISS-E2-1-G	NASA (USA)	2° x 2.5°	Kelley et al. (2020)
GISS-E2-1-H	NASA (USA)	2° x 2.5°	Kelley et al. (2020)
INM-CM4-8	INM (Russia)	1.5° x 2°	Volodin et al. (2018)
INM-CM5-0	INM (Russia)	1.5° x 2°	Volodin et al. (2018)
IPSL-CM6A-LR	IPSL (France)	1.3 x 2.5°	Boucher et al. (2018)
MCM-UA-1-0	UA (USA)	2.25° x 3.75°	Stouffer (2019)
MIROC-ES2L	MIROC (Japan)	2.8° x 2.8°	Tachiiri et al. (2019)
MIROC6	MIROC (Japan)	1.4° x 1.4°	Tatebe et al. (2019) Yukimoto et al.
MRI-ESM2-0	MRI (Japan)	1.121° x 1.125°	(2019)
NorESM2-LM	NCC (Norway)	1.9° x 2.5°	Seland et al. (2020)
NorESM2-MM	NCC (Norway)	0.94° x 1.25°	Seland et al. (2020)

35 **Supplementary Table 2.** Percentage increase in precipitation gridpoint weighted average and area for the factual simulation compared to
36 counterfactual GCMs. "MAX" indicates that the respective models fail to resolve the specified precipitation threshold under counterfactual
37 conditions.

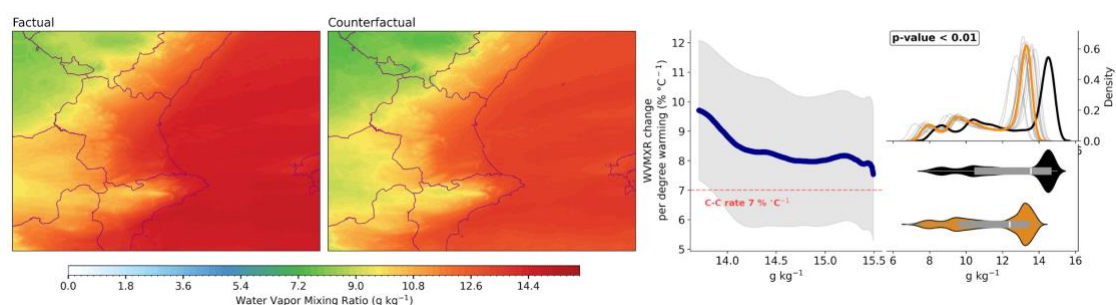
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GCM	Average				Area				Gridpoint weighted average			
	> 100 mm	> 180 mm	> 200 mm	> 300 mm	> 100 mm	> 180 mm	> 200 mm	> 300 mm	> 100 mm	> 180 mm	> 200 mm	> 300 mm
AWI-CM-1-1-MR	5	8	8	5	26	25	27	111	33	35	37	121
CESM2-WACCM	20	21	20	13	18	71	101	1220	42	107	141	1390
EC-Earth3	28	40	33	MAX	48	322	1306	MAX	90	491	1773	MAX
FGOALS-g3	9	24	25	11	19	11	29	3758	29	38	60	4182
GISS-E2-1-G	33	32	29	MAX	24	526	864	MAX	65	724	1143	MAX
GISS-E2-1-H	13	16	13	11	21	46	75	412	37	69	98	469
INM-CM4-8	-8	-5	-4	-2	35	9	4	-13	25	3	0	-15
INM-CM5-0	19	35	31	MAX	39	73	254	MAX	66	134	364	MAX
IPSL-CM6A-LR	11	9	8	3	30	60	69	193	45	75	83	202
MCM-UA-1-0	25	34	30	MAX	25	131	353	MAX	57	210	490	MAX
MIROC-ES2L	21	36	31	MAX	82	150	456	MAX	120	239	628	MAX
MIROC6	18	23	23	MAX	2	37	59	MAX	21	68	95	MAX
MRI-ESM2-0	14	33	31	MAX	47	71	179	MAX	68	127	266	MAX
NorESM2-LM	5	5	4	5	38	44	48	85	45	50	54	94
NorESM2-MM	-2	5	4	8	27	5	8	29	25	10	13	39
ENSMEAN	14	30	30	MAX	47	50	105	MAX	68	96	166	MAX

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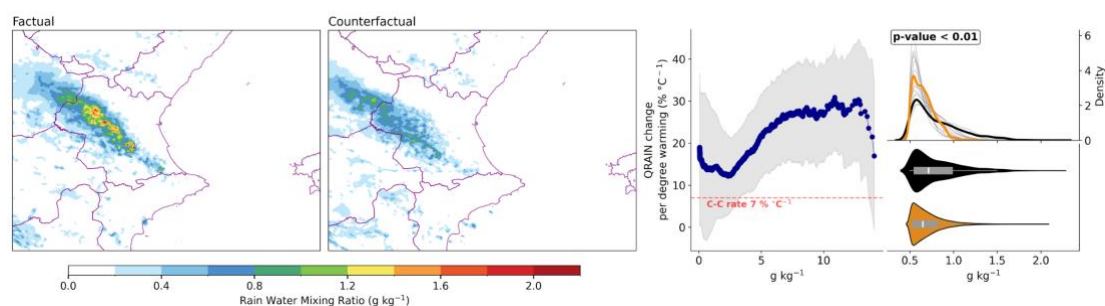


Supplementary Figure 1: Total rainfall accumulation for October 29th for the factual simulation (first plot from the top left), the counterfactual ensemble mean simulation (second plot) and the counterfactual simulations for each climate model forcing (from the third to the last plot).

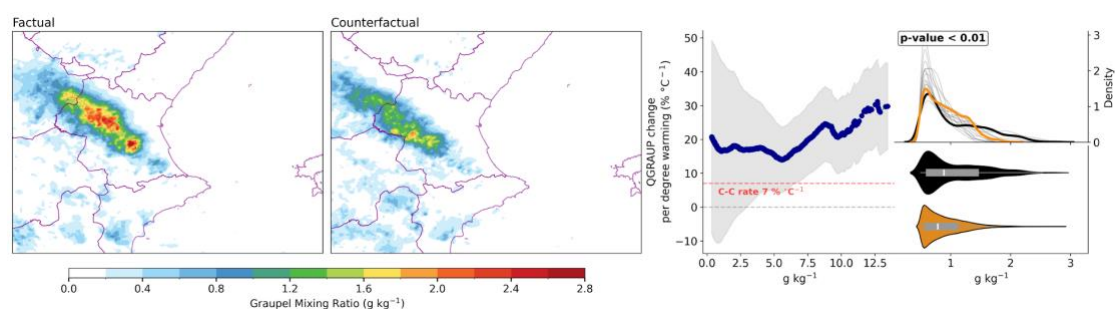


Supplementary Figure 2: Comparison between the factual and counterfactual simulations during the storm period: temporal mean and maximum value within the vertical of the water vapor mixing ratio. Adjacent plots show their percentage change

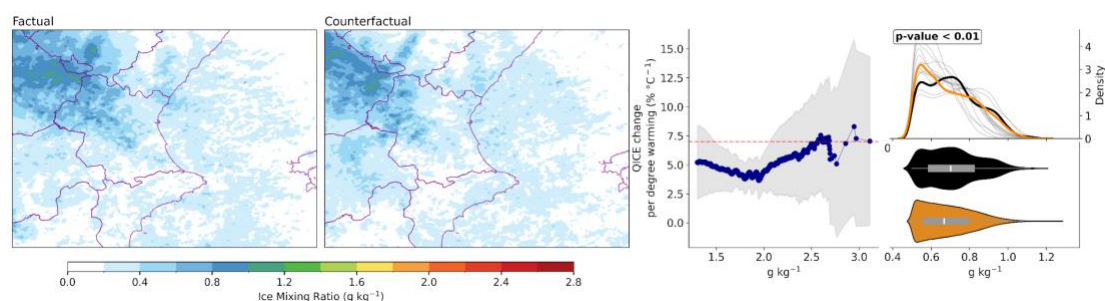
per degree warming (the difference between the two climates states is $+1.08^{\circ}\text{C}$), the Probability Density Function for each simulation (black: factual simulation; orange: counterfactual ensemble mean simulation; grey: each counterfactual simulation non-climate CMIP6 model forcing), and the violin plot. The legend in PDF shows statistical significance according to the Mann-Whitney U test.



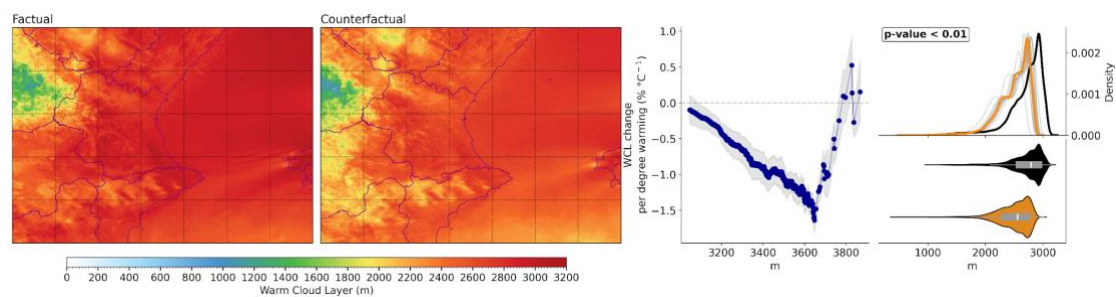
Supplementary Figure 3: As in Extended Data Figure 2, but for rainwater mixing ratio.



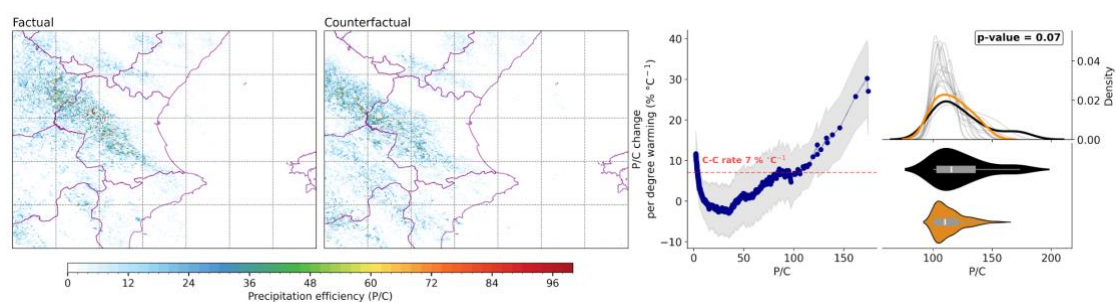
Supplementary Figure 4: As in Extended Data Figure 2, but for graupel mixing ratio.



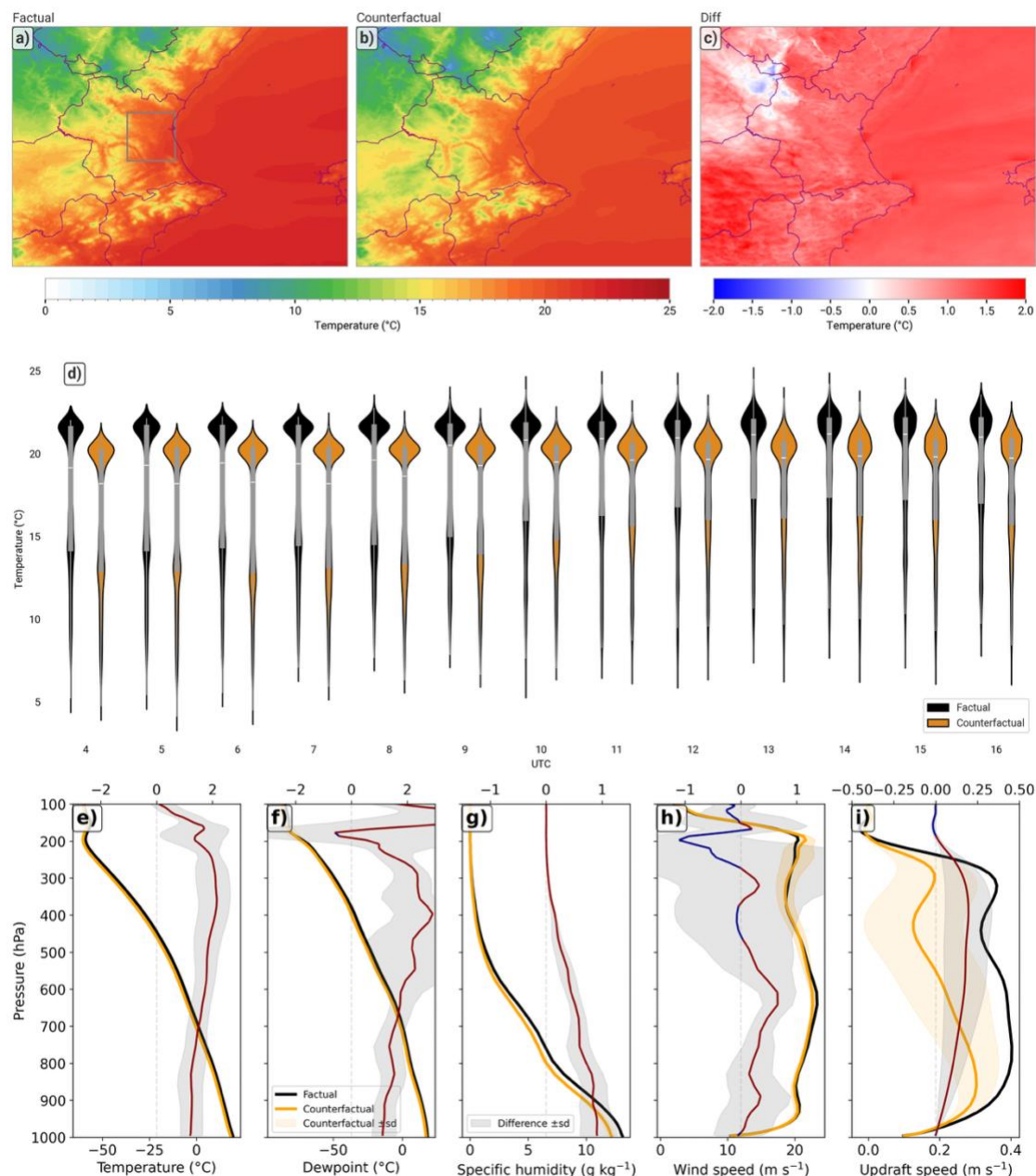
Supplementary Figure 5: As in Extended Data Figure 2, but for ice mixing ratio.



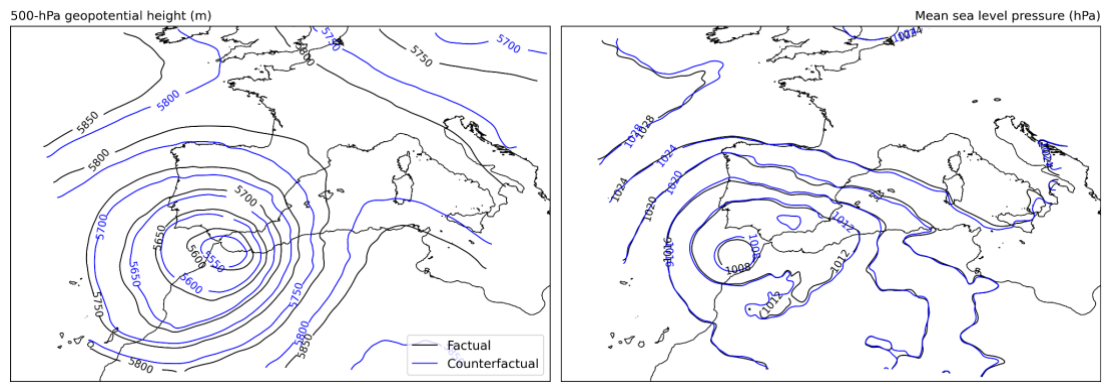
Supplementary Figure 6: As in Extended Data Figure 2, but for warm cloud layer.



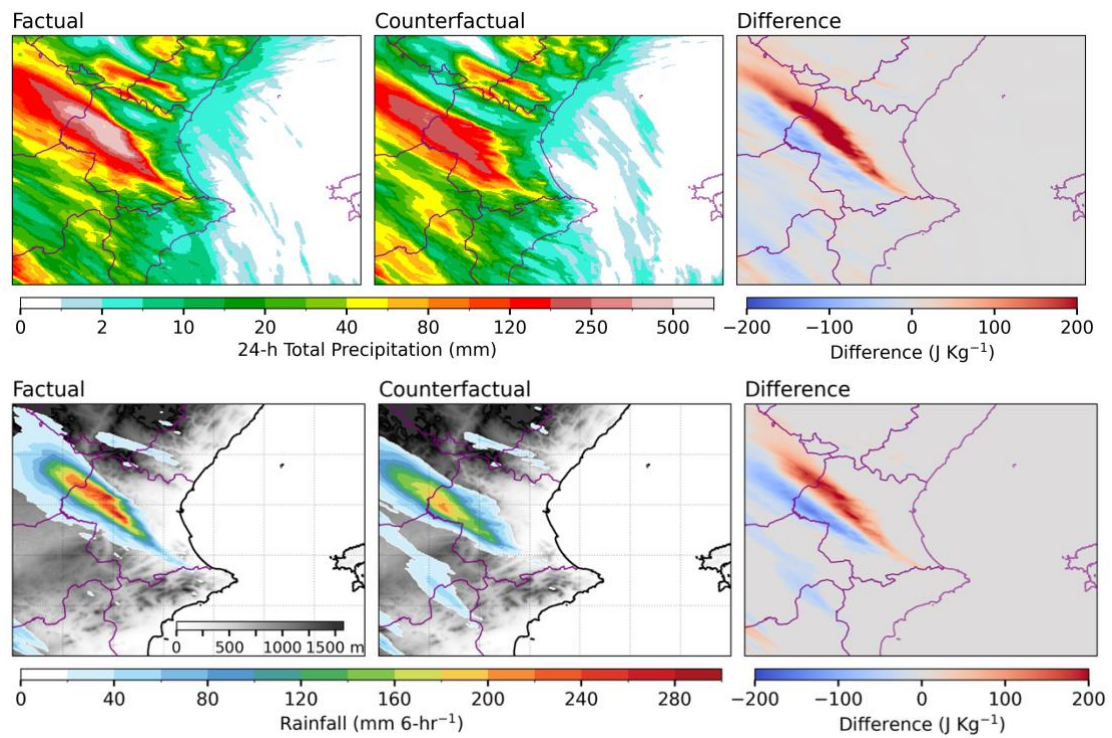
Supplementary Figure 7: As in Extended Data Figure 2, but for precipitation efficiency (P/C).



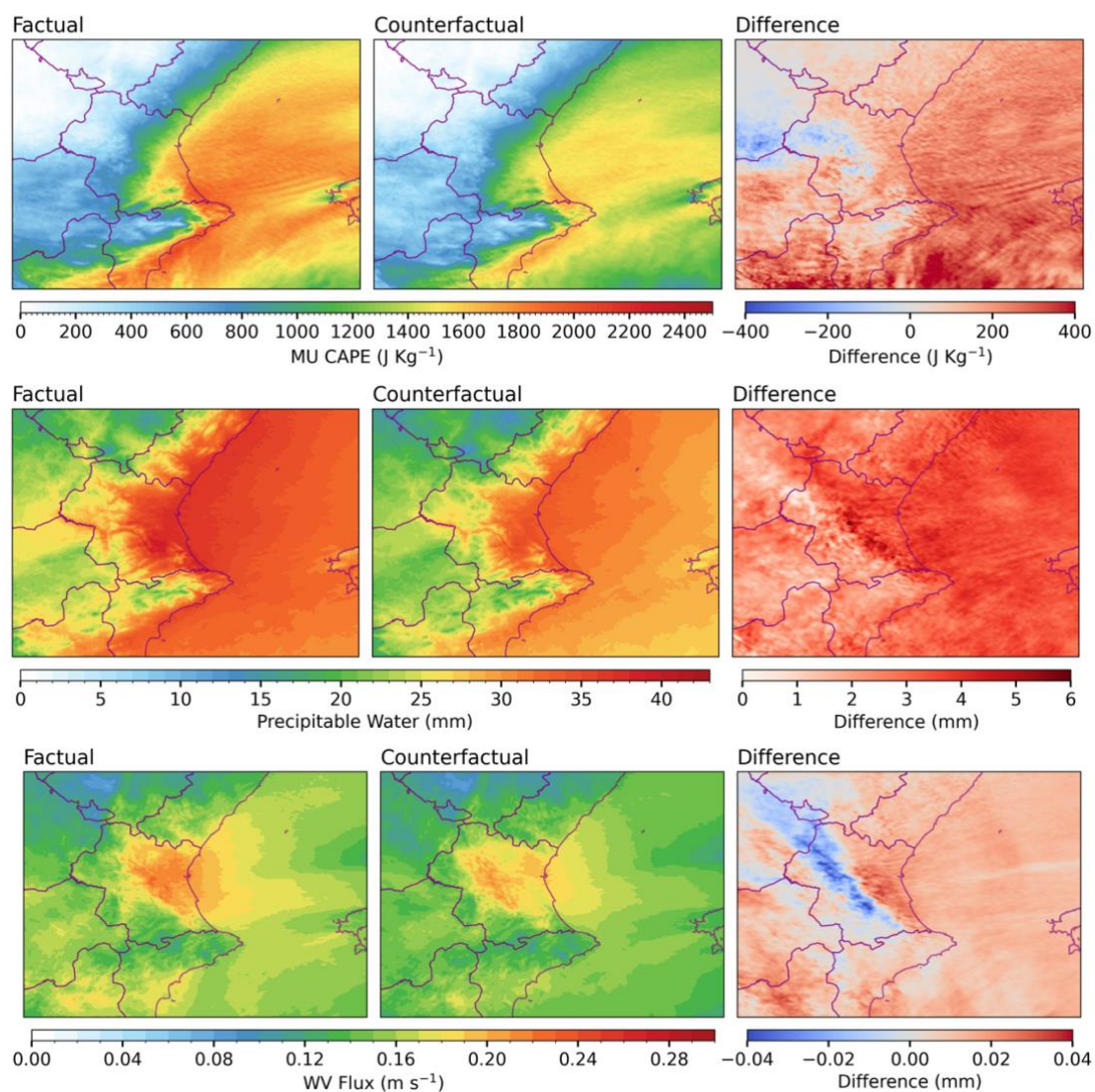
Supplementary Figure 8: 2-m temperature spatial distribution during the storm period in (a) factual, (b) counterfactual runs, and (c) the difference between (a) and (b). (d) 2-m temporal evolution in factual and counterfactual simulations. Vertical profiles of (e) temperature, (f) dewpoint, (g) specific humidity, (h) wind speed, and (i) updraft speed for factual (black line) and counterfactual (orange line) and their difference. Orange dashed represents $\pm$ standard deviation of the 15 counterfactual simulations and grey dashed represents $\pm$ standard deviation of the 15 differences between factual and counterfactual. The scale for the difference is reported on the top of the figure.



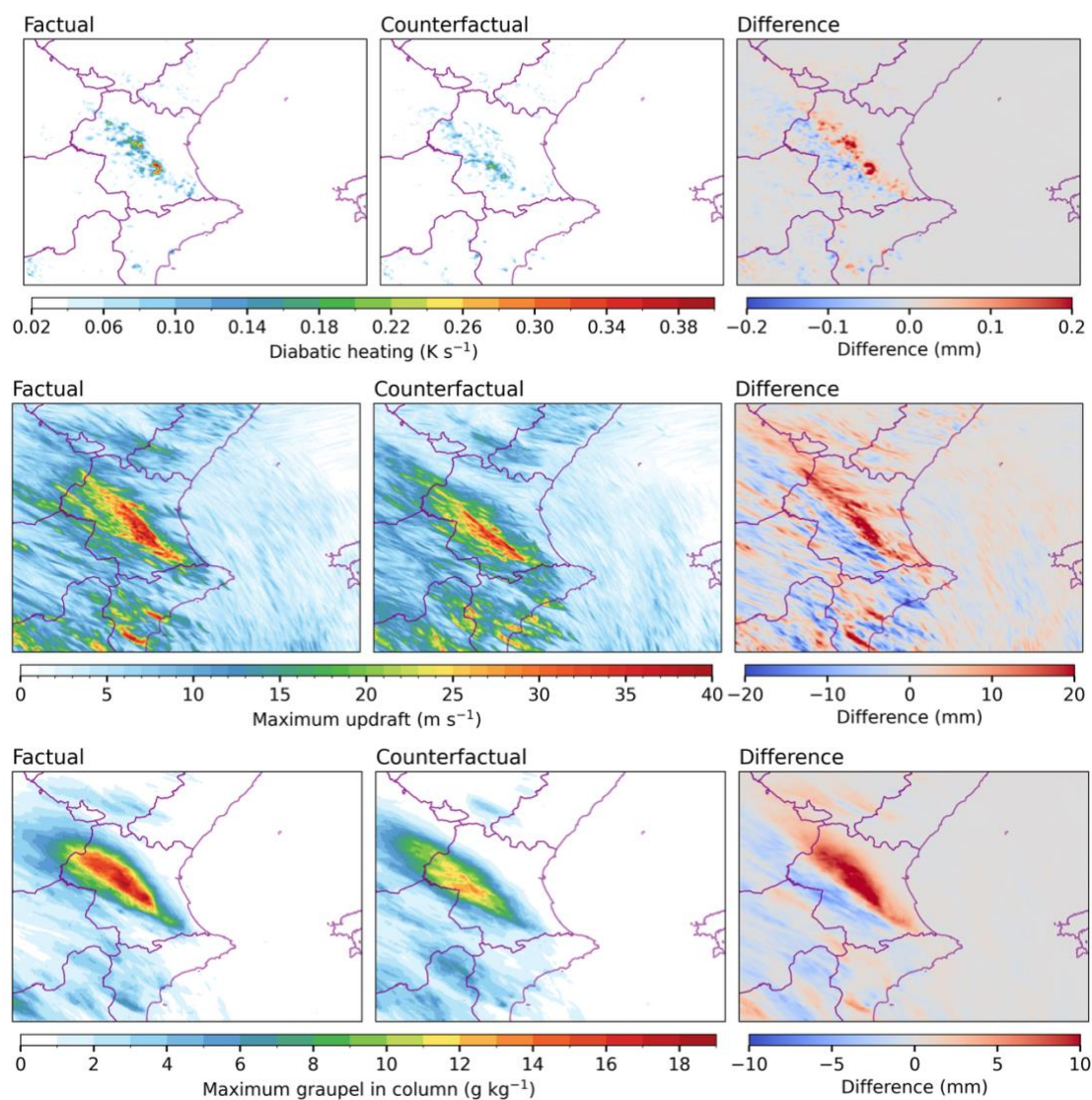
Supplementary Figure 9: Comparison between factual and counterfactual simulation of (a) 500-hPa geopotential height (m) and mean sea level pressure (hPa) at October 29th, 2024 12 UTC.



Supplementary Figure 10: Factual (left), counterfactual (center) and difference of Factual and Counterfactual (right) for 24-h total precipitation (above) and 6-h rainfall (bottom).



Supplementary Figure 11: As Supplementary Figure 1, but for MU CAPE (above), Precipitable Water (center) and Water Vapor Flux (bottom).



Supplementary Figure 12: As Supplementary Figure 1, but for Diabetic Heating (above), Maximum updraft (center) and Maximum graupel in column (bottom).