Climate change impact on thunderstorms: Analysis of thunderstorm indices using high-resolution COSMO-CLM simulations

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1. Introduction

It is generally assumed that temperature increase, due to global climate change, will increase thunderstorm and heavy precipitation intensity. In the present study it is investigated whether the frequency of thunderstorm occurrences will in- or decrease and how the spatial distribution will change for the A1B scenario. The region of interest is the Saar-Lor-Lux region (Saarland, Lorraine, Luxembourg) with a focus on Rhineland-Palatinate.

2. Study area

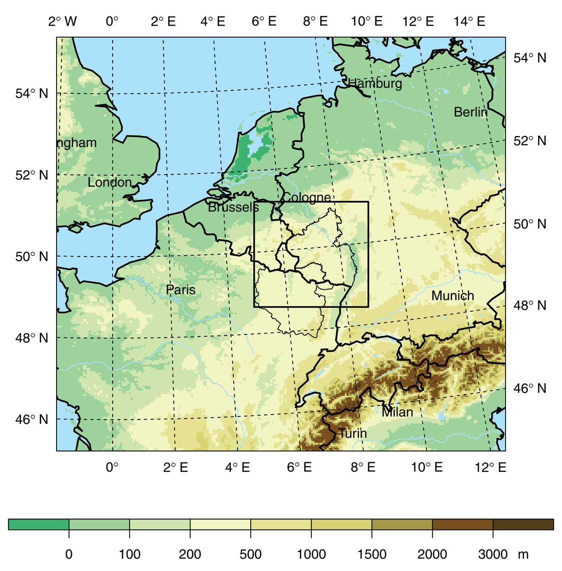

Figure 1a: The domain of the COSMO-CLM model with height of orography (resolution of 4.5 km, borders of Saar-Lor-Lux and Rhineland-Palatinate marked, black box is area of interest)

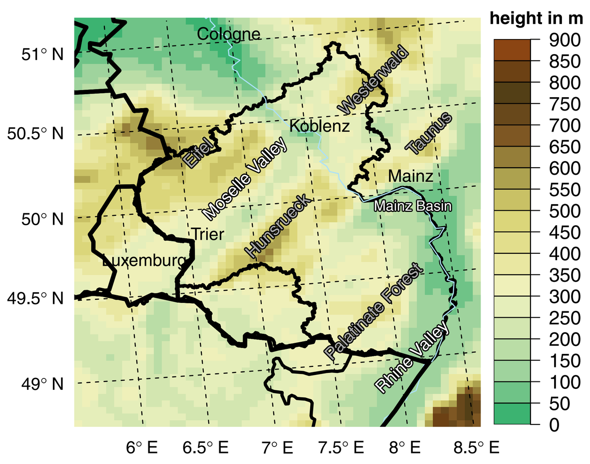

Figure 1b: The subdomain of interest of the COSMO-CLM model with height (resolution of 0.04°, with the borders of Saar-Lor-Lux and Rhineland-Palatinate marked)

3. Model and data

COSMO-CLM

- COSMO-CLM (v4.8_clm11, [1]) forced by 18km consortial runs [2]
- 30-year time slices: 1971-2000 (C20) and 2071-2100 (A1B)
- only sommer months (JJA) are used
- Indices CAPE, SLI, TSP
- Runge-Kutta scheme, Tiedtke scheme, graupel scheme, dt=45s, 42 levels, 65x65 grid points and 254x254 whole domain, 4.5km resolution

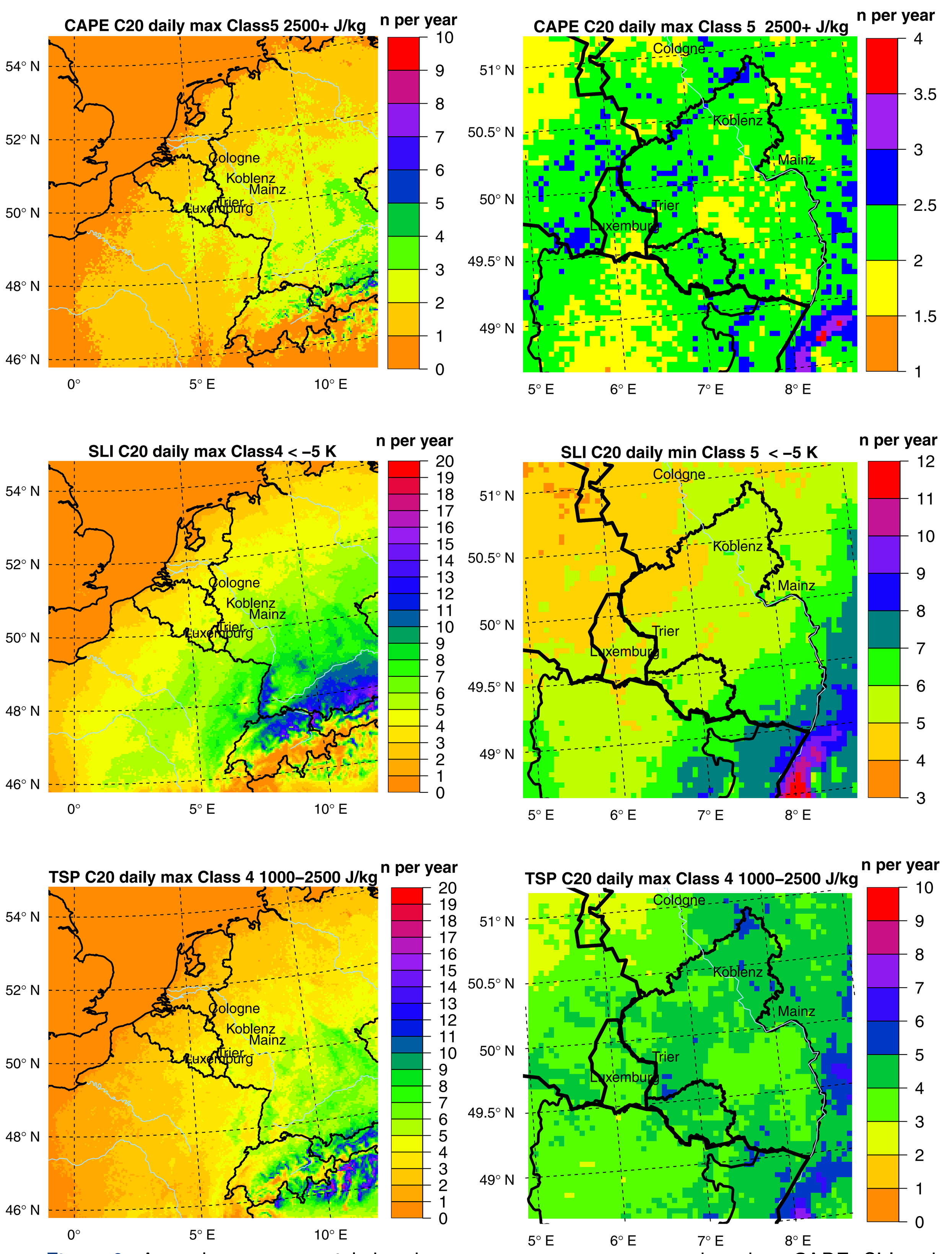

Figure 2: Annual mean potential thunderstorm occurrences per year based on CAPE, SLI and TSP (1971 – 2000, C20). Note different scales

4. Methods

- Used indices to determine potential occurrences of thunderstorms
  - Convective Available Potential Energy **CAPE** [3]

$$CAPE = \int_{z_0}^{z} \frac{g}{T_{vU}} (T_v - T_{vU}) dz$$

  - Surface Lifted Index **SLI** [4] $T_{e500hPa} - T_p$
  - Thunderstorm Severity Potential **TSP** [5]

$$DLS \times w_{max}$$

  DLS = Deep-Layer-Shear, wind difference between 6km height and 10m

$$w_{max} = \sqrt{2 \times CAPE}$$

- Classifying indices for counting purposes

Table 1. : Classes for CAPE , TSP and SLI

class	CAPE / TSP in J/kg	SLI in K	effect
1	0 - 100	> 0	non
2	100 - 300	0 to -3	shower
3	300 - 1000	-3 to -5	light Thunderstorm
4	1000 - 2500	-3 to -5	medium TS
5	2500+	< -5	severe TS

- Counting the occurrences based on daily maximum data
- Calculating differences: A1B - C20
- Performing a t-test and a power analysis to quantify the significance and uncertainty of the signal [6]

5.Results

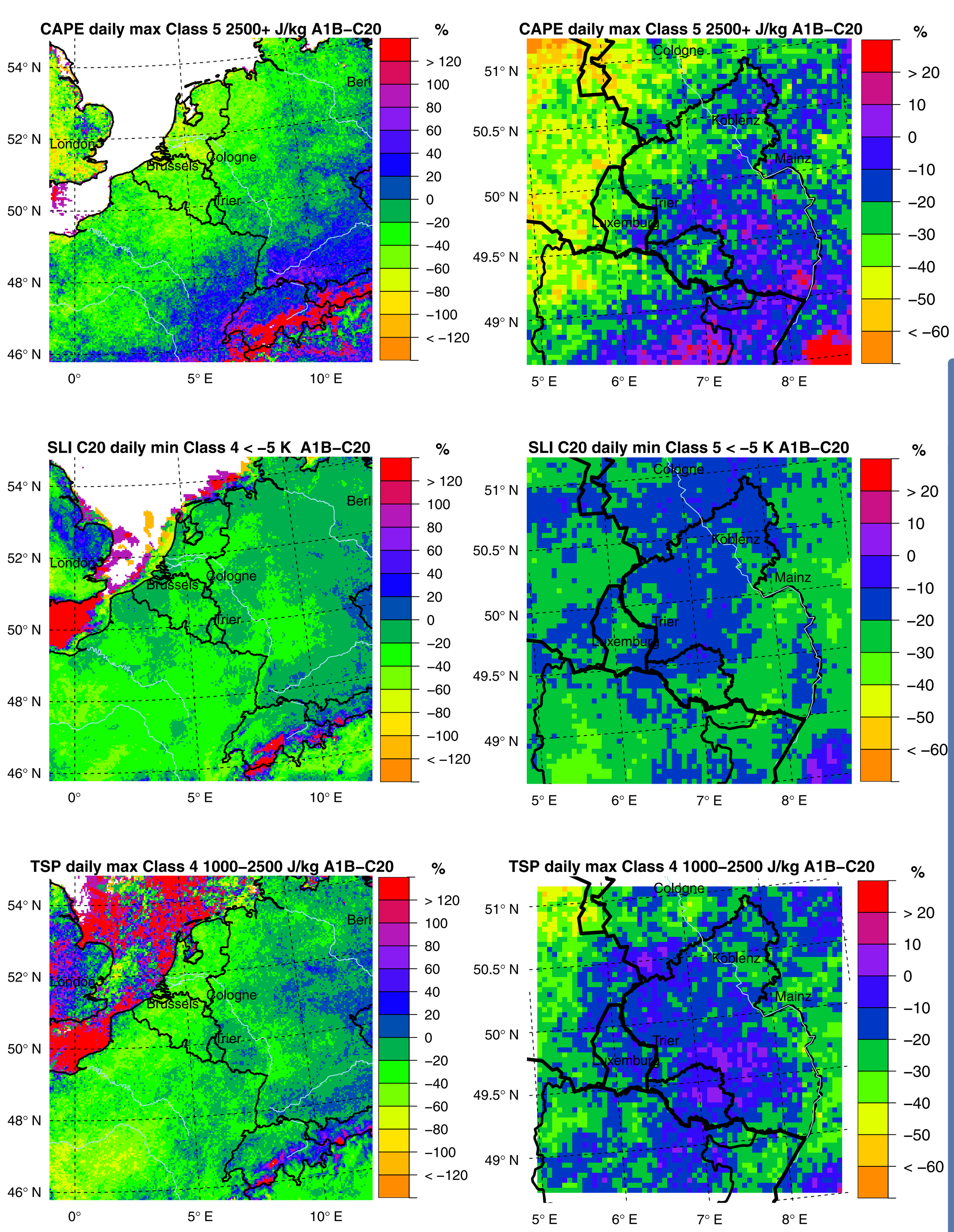

Figure 3: Relative differences of potential thunderstorm occurrences (CAPE, SLI and TSP) between 1971–2000(C20) and 2071–2100(A1B).

Table 2 : Area mean climate change signals (D) of potential thunderstorm occurrences of the significant grid boxes for CAPE classes . The corresponding results of the two-sided t-test (α = 5%) with its power ($\tilde{x}$) and standard deviation (σ) of the power is shown. The ratio of significant grid boxes to the total number of grid boxes is shown in the % column. n shows the area mean of occurrences per year for C20/A1B.

	RLP 30 years					mid-EU 30 years				
Class	n	%	D	$\tilde{x}$	σ	n	%	D	$\tilde{x}$	σ
1	48/66	100	17.34	1.00	0.00	59/70	99	13.61	1.00	0.02
2	16/10	99	-5.78	1.00	0.08	12/8	82	-5.06	1.00	0.13
3	19/9	100	-9.95	1.00	0.00	14/8	99	-7.99	1.00	0.04
4	7/6	10	-2.38	0.62	0.09	5/5	23	-1.89	0.68	0.14
5	1/1	9	-1.06	0.60	0.09	1/1	8	-0.16	0.63	0.13

- Figure 2 shows the number of potential thunderstorm occurrences of the severe classes per year.
  - Nearly no occurrences over the North Sea and high occurrences over mountainous regions.
  - All three indices show a local maximum in the Rhine valley near the Black Forest.
- Figure 3 shows the relative differences of the most severe thunderstorm occurrences (A1B – C20)
  - High CAPE values show an overall decrease, with significant decrease over the Netherlands.
  - A significant increase can be found over the Alps.
  - Slight non significant increase in the regions of between the Hunsrück and Palatinate Forest for the severe classes.
  - All Classes of CAPE show a decrease (Table 2), except the non thunderstorm class (class 1).
  - SLI and TSP show same results as CAPE.
  - All three non-severe classes (class 1 – 3) have high power values.
  - Higher uncertainty for climate change signal for severe thunderstorms (power = 0.60 – 0.68).

6. Conclusion

The investigation shows a significant increase in the non-thunderstorm class and an overall significant decrease in the light to medium thunderstorm classes.

The severe thunderstorm classes also show a decrease in occurrences, but the changes are not overall significant with high uncertainties.

Regions like Netherlands, Belgium and Northern France show significant decrease. The Alps even show a significant increase.

It can be concluded, that an overall decrease of thunderstorm occurrences most likely happens. The assumption of a raise in thunderstorm occurrences intensity, due temperature increase in the future, cannot be confirmed. At least with our simulations.

Acknowledgements

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CLM community

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