

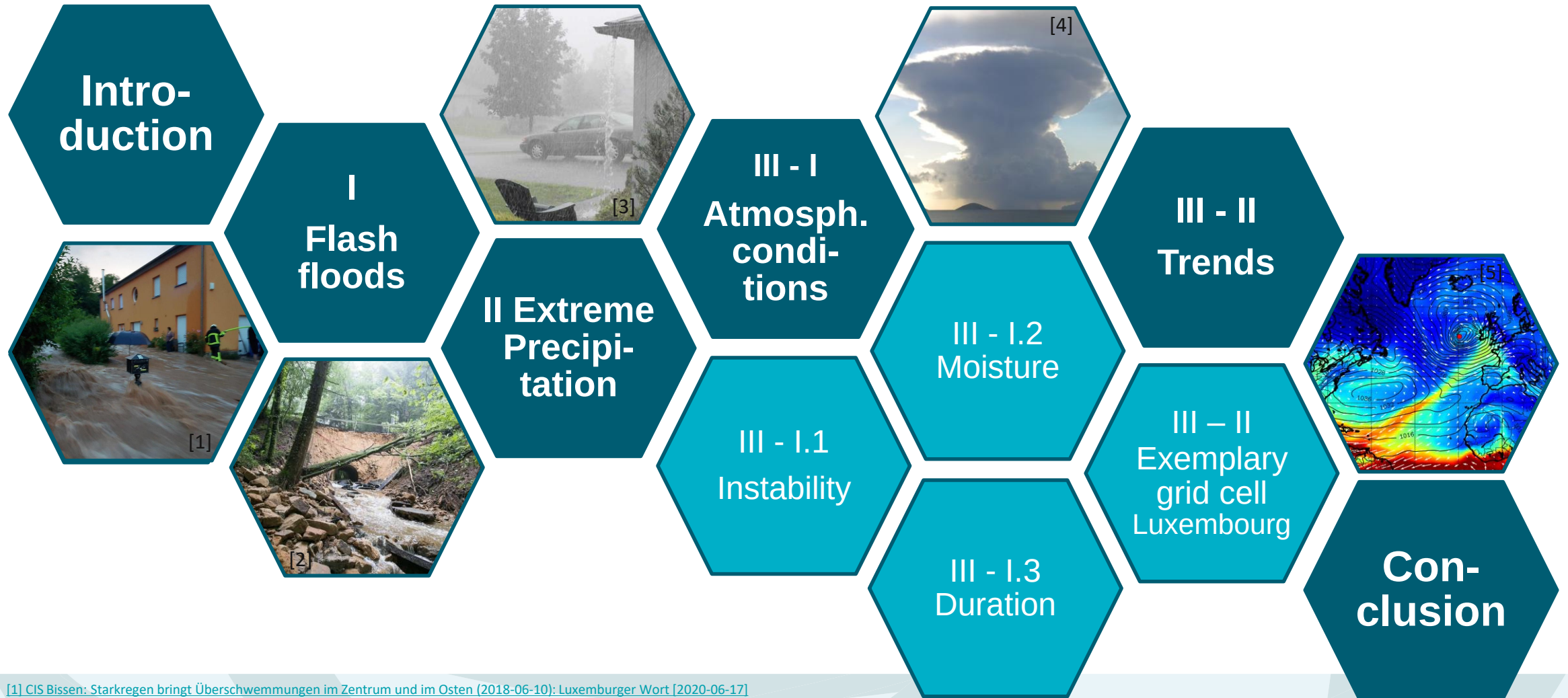
IDENTIFYING AND LINKING FLASH FLOOD PRONE ATMOSPHERIC CONDITIONS TO FLOODING OCCURRENCES IN CENTRAL WESTERN EUROPE

Judith Meyer^{1,2}, Malte Neuper³, Luca Mathias⁴, Audrey Douinot¹, Carol Tamez-Meléndez^{1,5}, Erwin Zehe³, Laurent Pfister^{1,2}

- ¹ Catchment and Ecohydrology Group (CAT), Luxembourg Institute of Science and Technology (LIST), Belvaux, Luxembourg
- ² Faculty of Science, Technology and Medicine (FSTM), University of Luxembourg, Belval, Luxembourg
- ³ Institute of Water Resources and River Basin Management, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
- ⁴ Administration de la Navigation Aérienne, MeteoLux, Findel, Luxembourg
- ⁵ Institute of Hydraulic Engineering and Water Resources Management, TU Vienna, Vienna, Austria

✉ judith.meyer@list.lu

CONTENT OF PRESENTATION



[1] CIS Bissen: Starkregen bringt Überschwemmungen im Zentrum und im Osten (2018-06-10): Luxemburger Wort [2020-06-17]

[2] Blum: Starkregen bringt Überschwemmungen im Zentrum und im Osten (2018-06-10): Luxemburger Wort [2020-06-17]

[3] s58y: Rain – no downspouts (2012-07-28): Flickr [2021-04-19]

[4] Scharlau: pictures (2019-03) https://azalas.de/bilder/2009-03/DSCN7380-1_450.jpg [2021-02-26]

[5] Eiras-Barca et al. (2018): The concurrence of atmospheric rivers and explosive cyclogenesis in the North Atlantic and North Pacific basins, 9, 91-102, Earth Syst. Dynam.

CHANGED FLOODING REGIMES IN CENTRAL WESTERN EUROPE?



Slowly developing floods during winter

- In the past, especially the 1990s
- Large scale inundation plains

[1]



Rapidly developing floods during summer

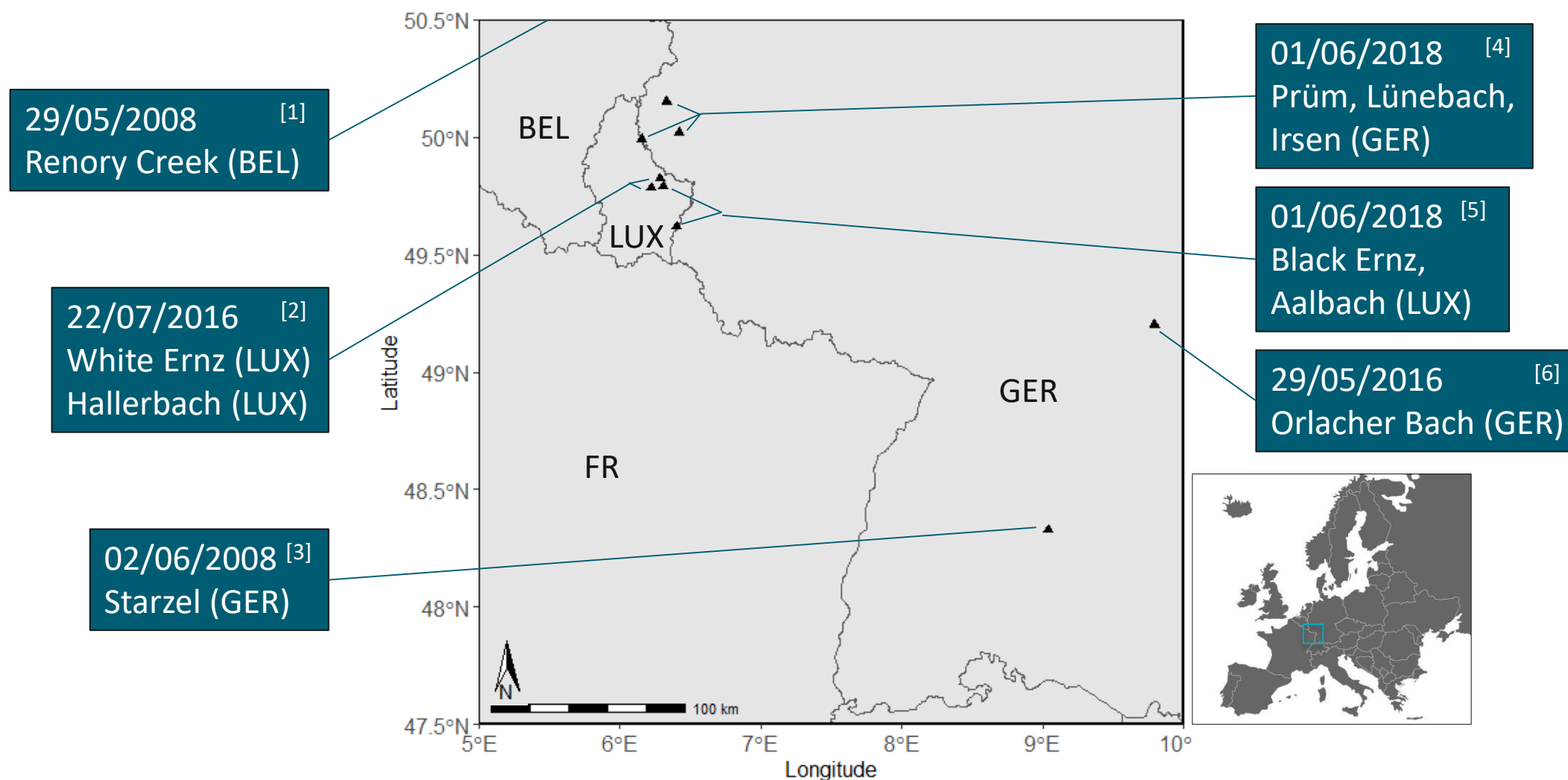
- Accumulation in recent years (2016/18)
- Local flash floods in smaller catchments

[2]

[1] Moselle, Remich, Luxembourg: L'Administration de la gestion de l'eau chargée également de la prévision des crues de la Moselle (2019-05-17): Ministère de l'Environnement, du Climat et du Développement durable [2021-04-19]

[2] Bissen, Luxembourg: Starkregen bringt Überschwemmungen im Zentrum und im Osten (2018-06-10): Luxemburger Wort [2020-06-17]

WELL-DOCUMENTED FLASH FLOODS IN CENTRAL WESTERN EUROPE



[1] Van Campenhout et al. (2015): Belgeo

[2] Pfister et al. (2018): Le gouvernement luxembourgeois.

[3] Ruiz-Villanueva et al. (2012): Hydrol. Earth. Syst. Sci.

[4] Johst et al. (2018): Landesamt für Umwelt, Rheinlandpfalz

[5] Mathias (2019): MeteoLux

[6] Bronstert et al. (2017): Hydrologie und Wasserbewirtschaftung

The recent **increase in flash flood occurrences** and preceding **extreme precipitation events** in central Western Europe is triggered by a **change of atmospheric conditions**.

Testing the hypothesis requires:

- I. Analysis of flash flood occurrences
- II. Analysis of extreme precipitation events
- III. Analysis of atmospheric parameters

DATA & METHODS

Precipitation data

- 82 stations with daily precipitation data
- Sources: ECAD, DWD, LIST, ASTA, AGE, MeteoLux, MeteoFrance

Flash flood data

- 40 events
- Sources: LFU, AGE, France 3 – France info, CCR

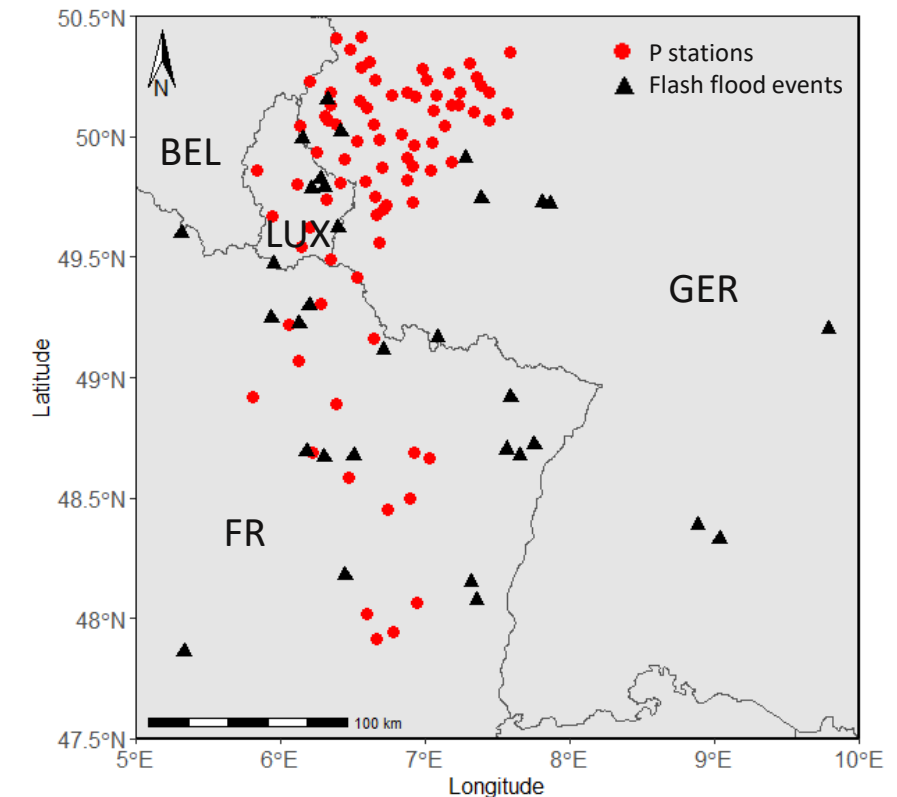
Atmospheric data

- ERA5 reanalysis data, 6-hourly (C3S CDS)
- Ingredients needed for thunderstorms with long, intense rainfall that can potentially trigger flash floods:
 1. Atmospheric Instability:
 - Proxies: Convective Available Potential Energy (CAPE), Convective Inhibition (CIN), K-Index¹
 2. High moisture content:
 - Proxies: Total Column Water (TCW), Specific humidity (700 hPa), Relative humidity (700 hPa)
 3. Long duration of the event
 - Proxies: Wind speed (700 hPa), Deep Layer Shear (DLS), Low Level Shear (LLS)

Study period:

1954/1979 – 2018/2020

Study area

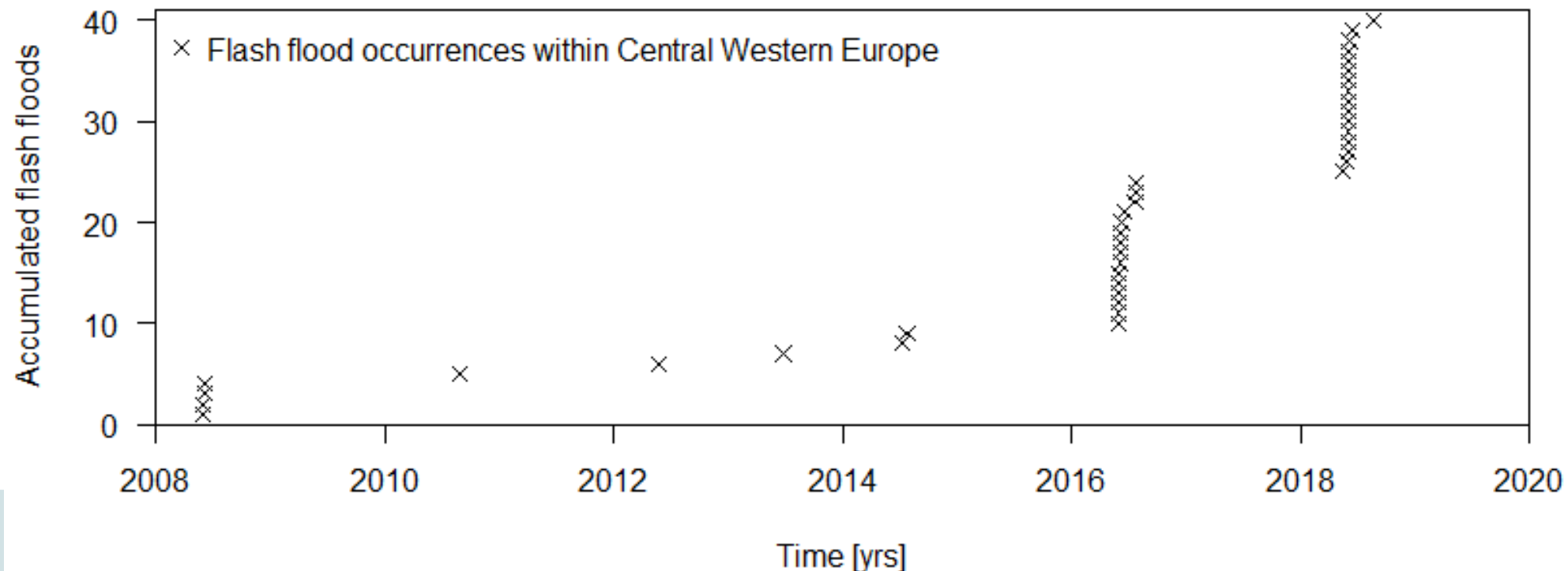


¹"K-Index: This parameter is a measure of potential for a thunderstorm to develop calculated from the temperature and dew point temperature in the lower part of the atmosphere." (C3S CDS)

$$K\ Index = (T[850\ hPa] - T[500\ hPa]) + Td[850\ hPa] - (T[700\ hPa] - Td[700\ hPa])$$

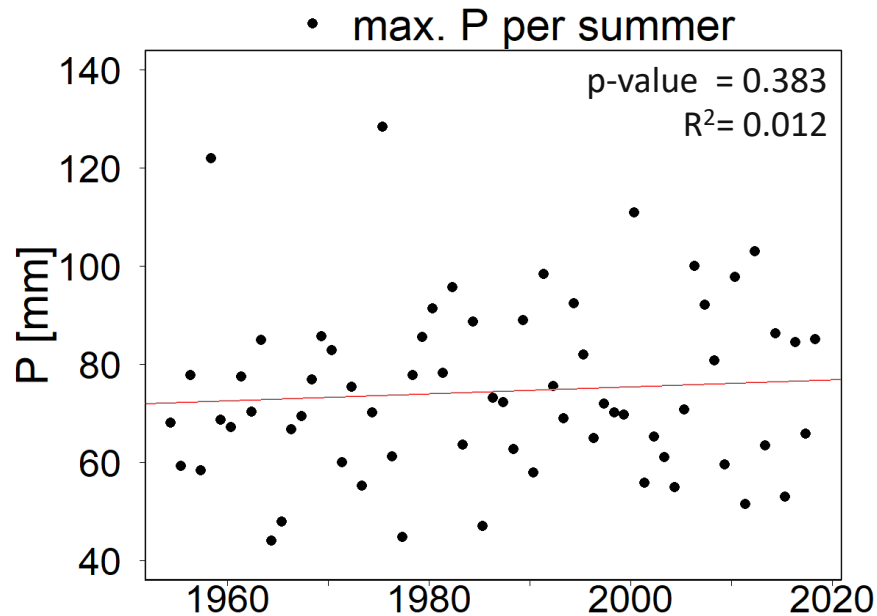
I: INCREASE IN FLASH FLOODS?

- Major clustering of events in May/June 2016 and May/June 2018
- Only one event was found within the study area before 2008:
 - in central Eastern Luxembourg, in 1958
- Few event days accommodate floods in different catchments

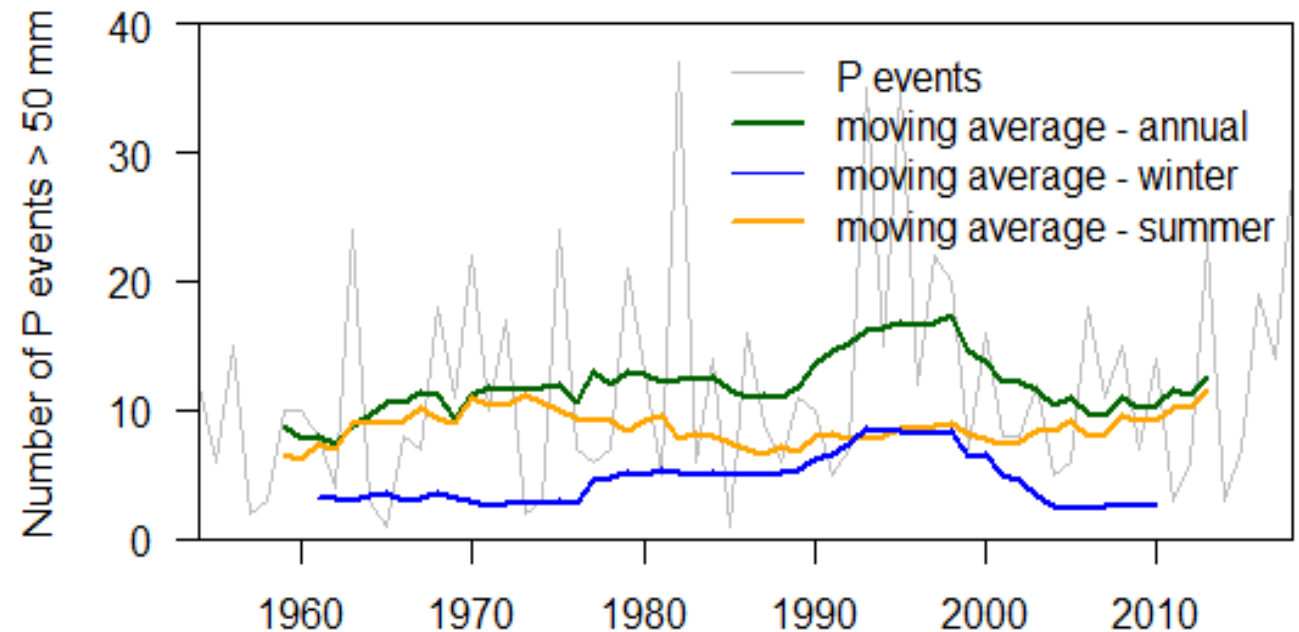


II: INCREASE IN PRECIPITATION?¹

- No significant trend in daily precipitation totals of the largest events per year *[left fig.]*
- Variation in the total number of precipitation events > 50 mm per year *[right fig.]*
- Rather constant number of precipitation events during the summer *[right fig.]*



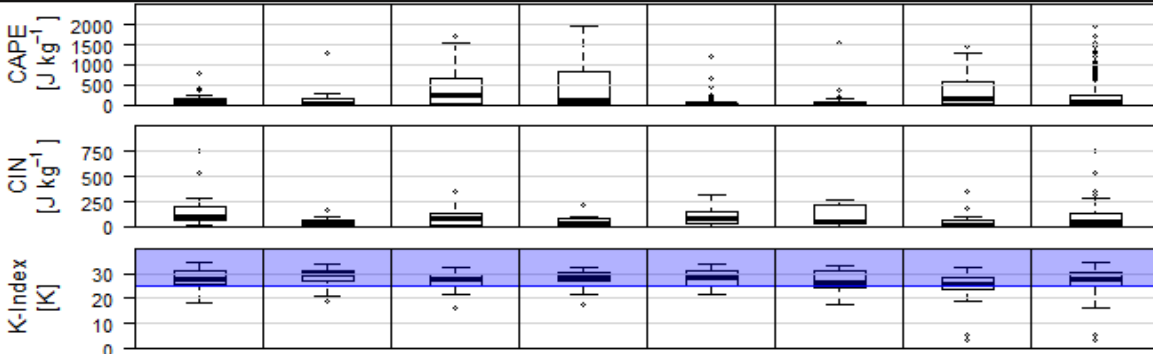
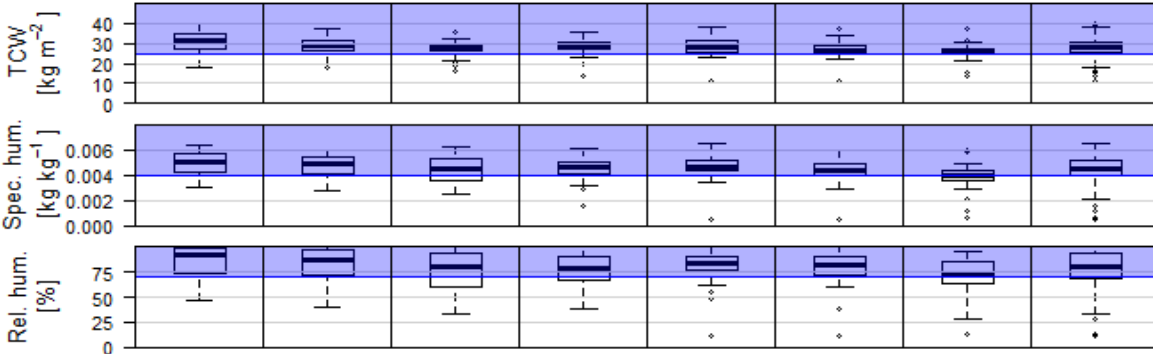
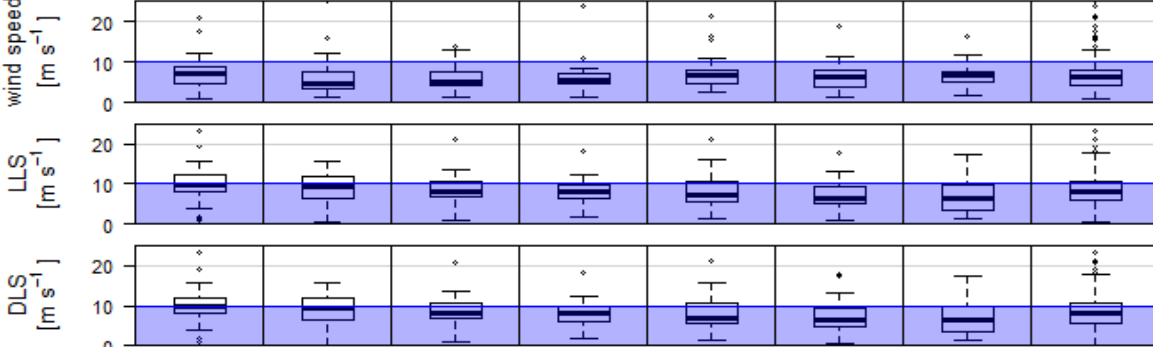
Max. precipitation event per summer.



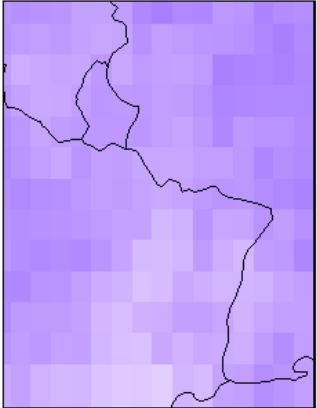
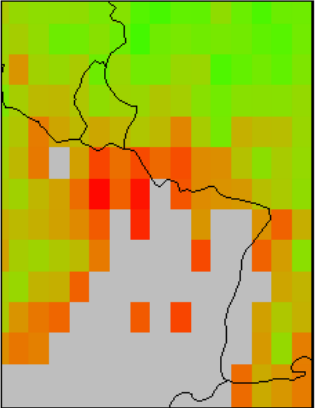
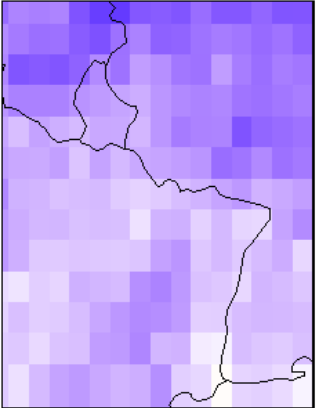
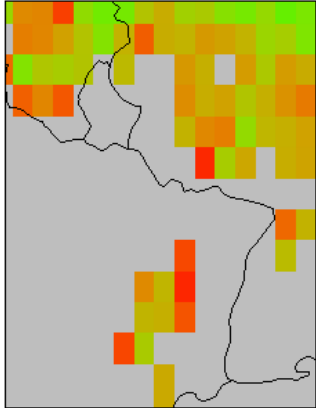
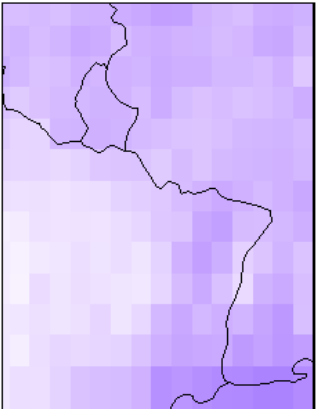
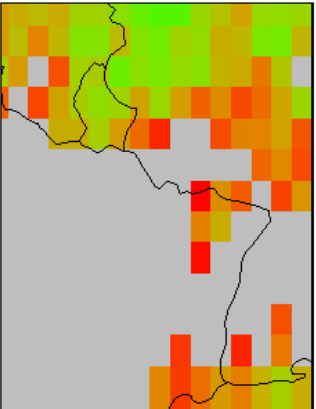
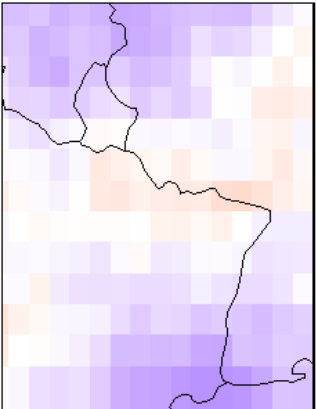
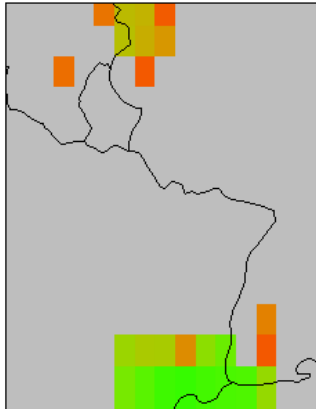
11-year moving average of the number of P events per year.

¹ Meyer, J., Douinot, A., Zehe, E., Tamez-Meléndez, C., Francis, O., and Pfister, L.: Impact of Atmospheric Circulation on Flooding Occurrence and Type in Luxembourg (Central Western Europe), EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-13953, <https://doi.org/10.5194/egusphere-egu2020-13953>, 2020

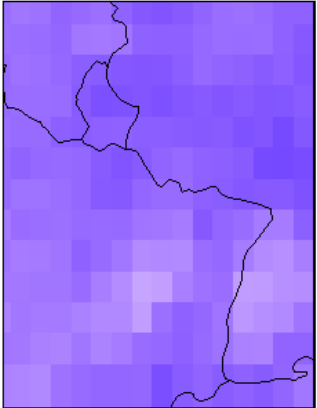
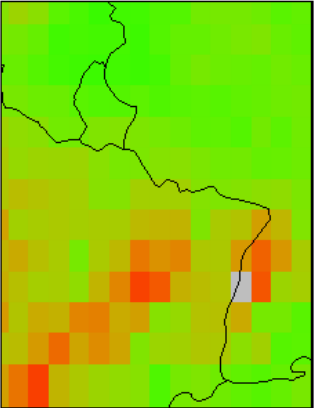
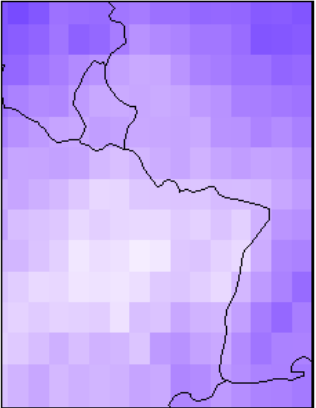
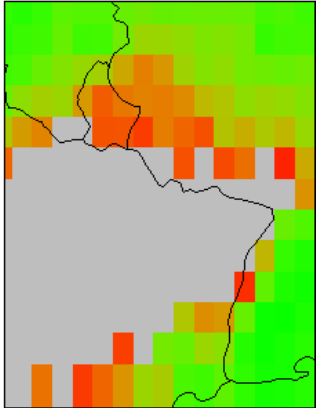
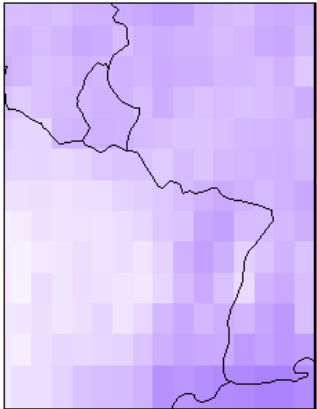
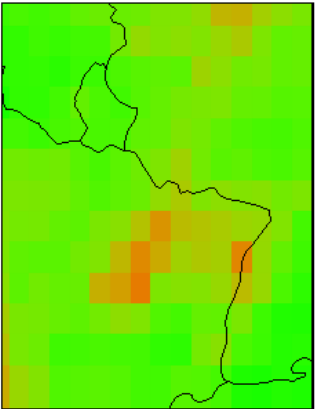
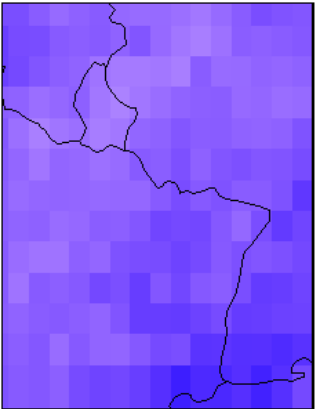
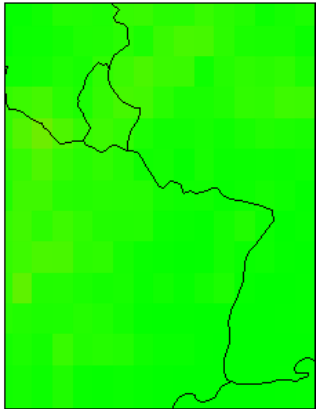
III: CHANGE IN ATM. CONDITIONS DURING FLASH FLOODS?

	Parameters	Time of day on the event day and the following morning (UTC) 00:00 06:00 12:00 18:00 00:00 06:00 12:00 sum	Conclusion
Instability	Convective available potential energy (CAPE)		- Large daily and spatial variation of CAPE & CIN - CAPE above 150-200 J kg⁻¹ should be sufficient to trigger extreme precipitation events K-Index → good measure for the identification of the atm. thunderstorm potential.
	Convective inhibition (CIN)		
	K-index > 25 K		
Moisture	Total column water (TCW) > 25 kg m ⁻²		- Proxies for the atmospheric moisture content always at high levels - During all events above their respective thresholds
	Specific humidity > 0.004 kg kg ⁻¹		
	Relative humidity > 70%		
Duration	Wind speed < 10 m s ⁻¹		Characteristically low (<10 m s⁻¹) proxies representing the motion speed of thunderstorm cells and their organizational modes
	Low level shear < 10 m s ⁻¹		
	Deep layer shear < 10 m s ⁻¹		

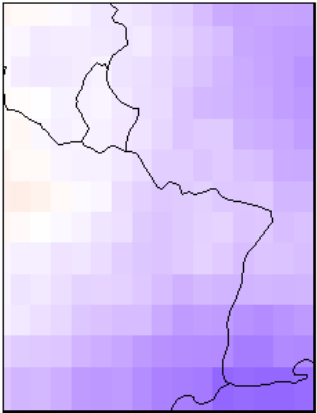
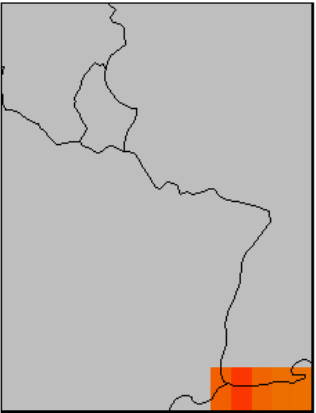
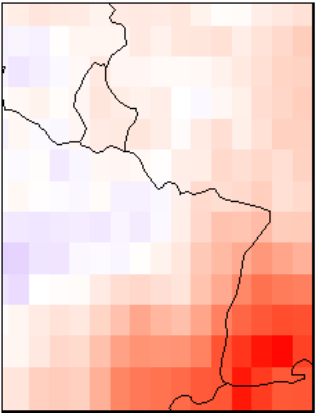
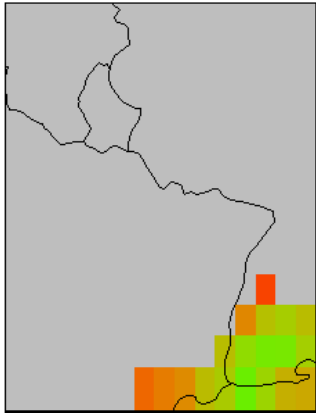
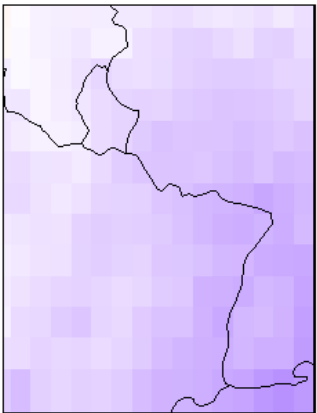
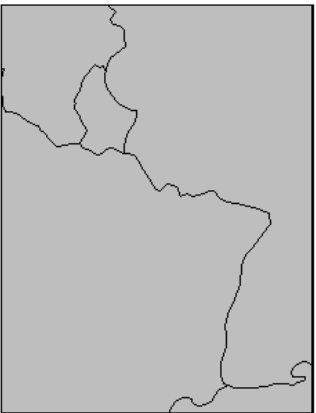
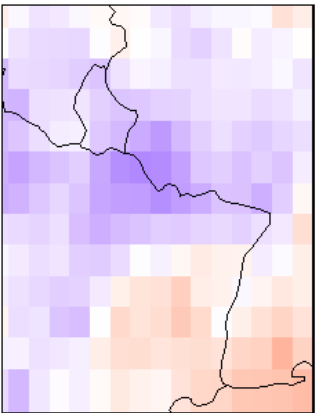
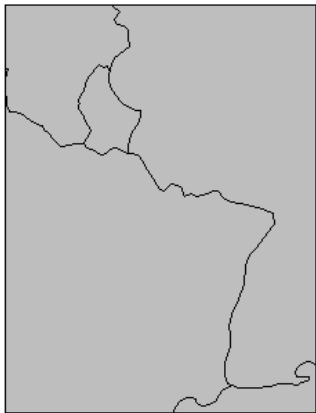
III.1 TRENDS IN ATMOSPHERIC INSTABILITY PARAMETERS

1979-2020	No. of 6-h occurrences per summer		Normalized mean per summer		Interpretation
	Trend lin. model	P-value	Trend lin. model	P-value	
K-Index > 25 K yr^{-1}					- Days with K-Index > 25 K increase in the entire study area, partly significant. - The mean of all days with K-indices above 25 K increases throughout the study area. - Overall increase in the occurrence of days with CAPE above 150 J kg^{-2}. - Less significant increase of CAPE compared to the K-Index. - The values above 150 J kg^{-2} show unclear, mostly non-significant trends. ► Partly significant increase of atmospheric instability
CAPE ≥ 150 $\text{J kg}^{-2} \text{ yr}^{-1}$					

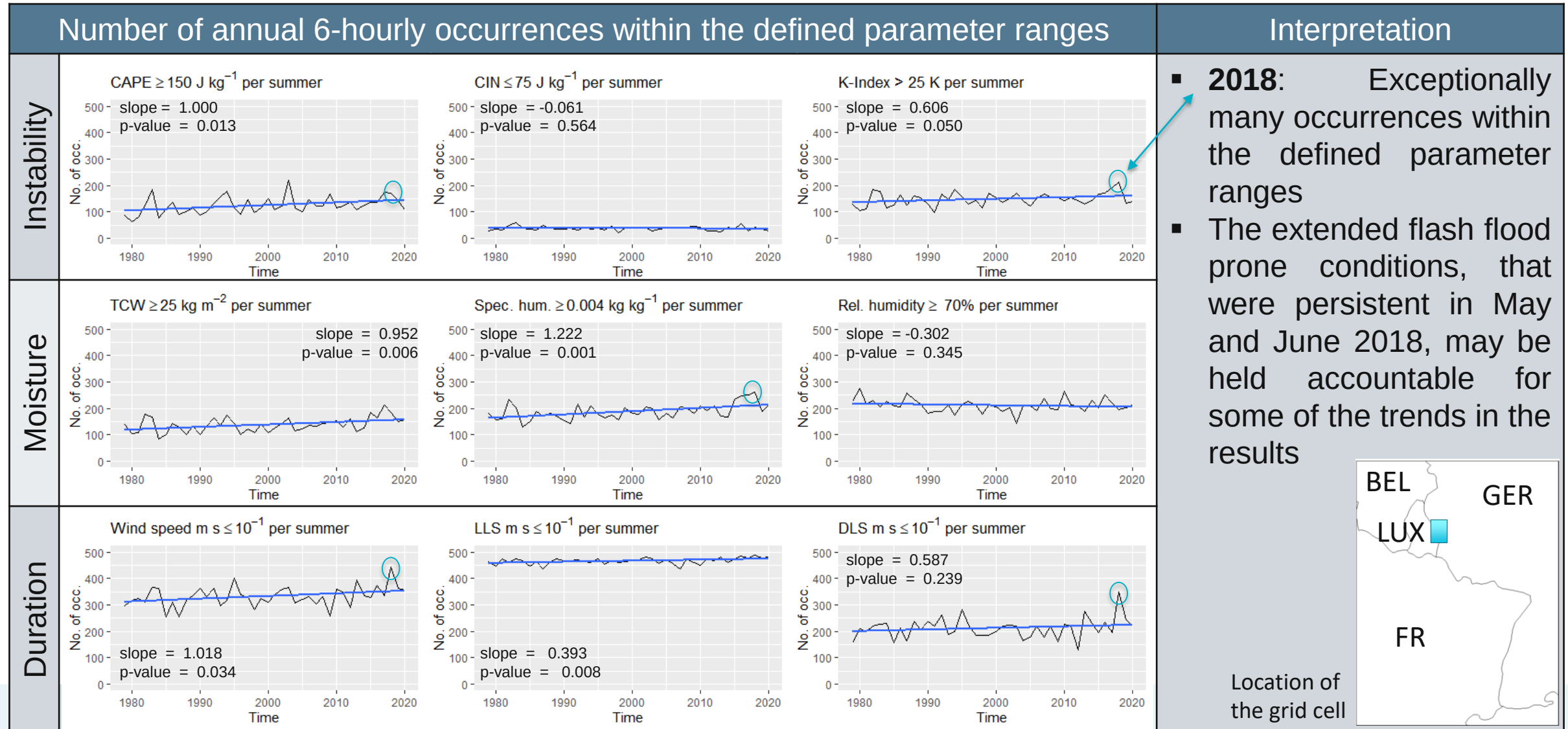
III.2 TRENDS IN ATMOSPHERIC MOISTURE PARAMETERS

1979-2020	No. of 6-h occurrences per summer		Normalized mean per summer		Interpretation
	Trend lin. model	P-value	Trend lin. model	P-value	
Total column water (TCW) ≥ 25 kg m ⁻² yr ⁻¹					▪ Increase in the number of days per summer with TCW ≥ 25 kg m⁻² and specific humidity ≥ 0.004 kg kg⁻¹. ▪ Also above these thresholds, trends suggest increasing moisture contents of the atmosphere. ▪ The trend of the TCW is not significant over North-Eastern France, but over the rest of the study area. ▪ For specific humidity the increase is significant to P = 0.05 in the entire area. ► Overall significant increase of atmospheric moisture.
Specific humidity (q) ≥ 0.004 kg kg ⁻¹ yr ⁻¹					

III.3 TRENDS IN DURATION PARAMETERS

1979-2020	No. of 6-h occurrences per summer		Normalized mean per summer		Interpretation
	Trend lin. model	P-value	Trend lin. model	P-value	
Wind speed $\leq 10 \text{ m s}^{-1} \text{ yr}^{-1}$					▪ Slight increase in the number of days per summer with windspeeds and DLS $\leq 10 \text{ m s}^{-1}$. ▪ However, these trends are not significant. ▪ No clear trends for the mean values within the range of $0\text{-}10 \text{ m s}^{-1}$. ► Tendency towards a (non-significant) increase in the occurrence of non-moving atmospheric parameters.
Deep layer shear (DLS) $\leq 10 \text{ m s}^{-1} \text{ yr}^{-1}$					

III: ATMOSPHERIC PARAMETERS OF A GRID CELL IN EASTERN LUXEMBOURG, WHERE FLASH FLOODS OCCURRED IN 2016 & 2018



III: ATMOSPHERIC PARAMETERS OF A GRID CELL IN EASTERN LUXEMBOURG, WHERE FLASH FLOODS OCCURRED IN 2016 & 2018

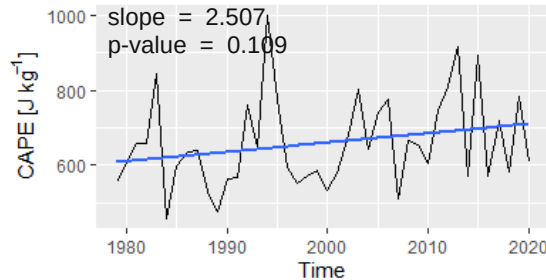
Note
differing
y-axes

Annual means of 6-hourly occurrences within the defined parameter ranges

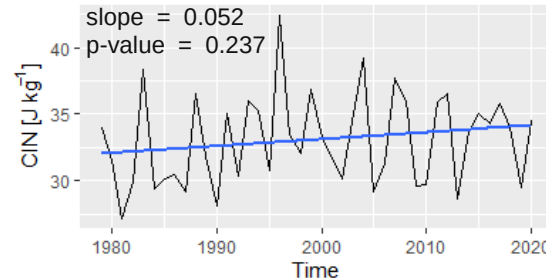
Interpretation

Instability

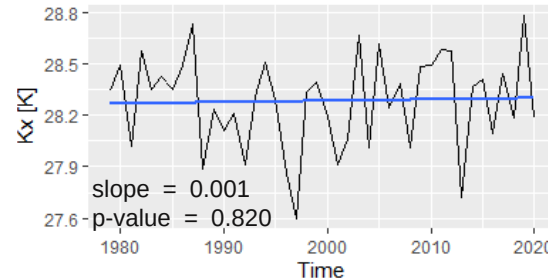
Mean CAPE $\geq 150 \text{ J kg}^{-1}$ per summer



Mean CIN $\leq 75 \text{ J kg}^{-1}$ per summer

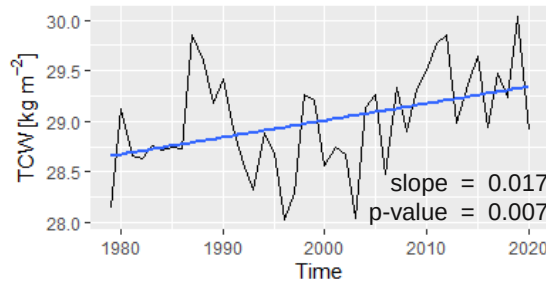


Mean K-Index $> 25 \text{ K}$ per summer

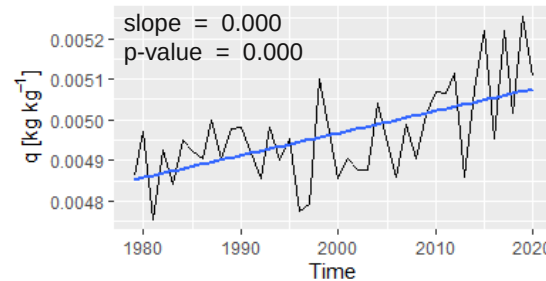


Moisture

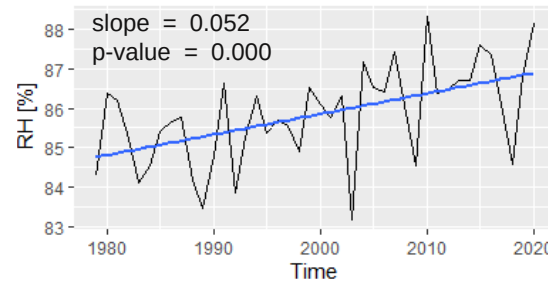
Mean TCW $\geq 25 \text{ kg m}^{-2}$ per summer



Mean $q \geq 0.004 \text{ kg kg}^{-1}$ per summer

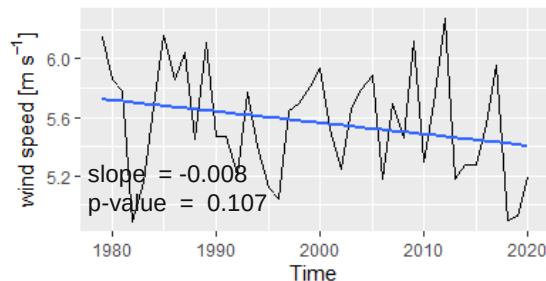


Mean RH $\geq 70\%$ per summer

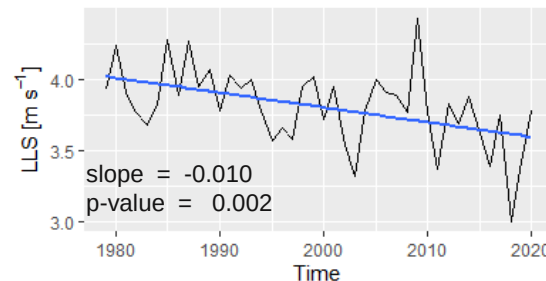


Duration

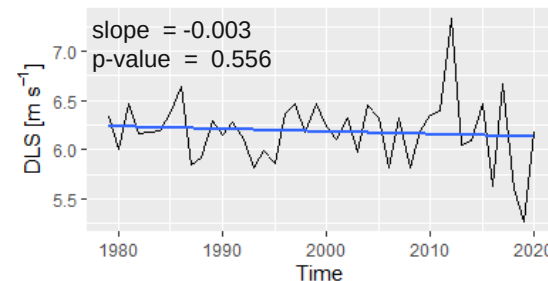
Mean wind speed m s^{-1} per summer



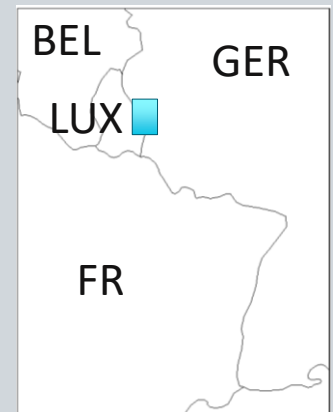
Mean LLS m s^{-1} per summer



Mean DLS m s^{-1} per summer



- Less significant trends in instability parameters
- Significant trend for moisture parameters
- Decreasing, partly significant trend of parameters representing the motion speed of thunderstorm cells and their organizational modes



Location of
the grid cell

The recent **increase in flash flood occurrences** and preceding **extreme precipitation events** in central Western Europe is triggered by a **change of atmospheric conditions**.

- I. Increase in **flash flood** occurrences ✓ → hypothesis accepted
- II. Increase of **extreme precipitation** events ✗ → equivocal
→ further investigation with higher resolved data required
- III. Change of **atmospheric parameters** ✓ → hypothesis accepted

- Refining the precipitation event database with higher resolved radar data
- Adjusting the parameter ranges of the atmospheric parameters according to the new event catalogue
- Analysing combined occurrences of parameters
- Including pre-event moisture to discern extreme precipitation events that may trigger flash floods
- Investigating the air mass direction and therefore moisture origin in the days before the event
- Adding EURO-CORDEX data to get a glimpse on possible future conditions

- 1) Increase in unstable atmospheric conditions
- 2) Increase in atmospheric moisture content
- 3) Duration parameters stay unchanged

→ The analysed atmospheric parameters favouring extreme precipitation events and potentially flash floods are occurring more often and with higher intensity.

ACKNOWLEDGEMENTS & REFERENCES

Thanks for making data available to:

- ECAD: European Climate Assessment & Dataset, De Bilt, The Netherlands
- DWD: German Weather Service, Mainz, Germany
- LIST: Luxembourg Institute of Science and Technology, Esch-sur-Alzette, Luxembourg
- ASTA: Administration des Services Techniques de l'Agriculture, Luxembourg, Luxembourg
- AGE: Administration de la Gestion de l'Eau, Esch-sur-Alzette, Luxembourg
- MeteoLux: Luxembourgish Weather Service, Findel, Luxembourg
- MétéoFrance: French Weather Service, Paris, France
- LFU: Landesamt für Umwelt Rheinland-Pfalz, Mainz, Germany
- France 3 – France info
- CCR: Caisse Centrale de Réassurance, Paris, France
- C3S - CDS: Copernicus Climate Change Service - Climate Data Store