

Evolution of synoptic weather patterns leading to extreme precipitation events in Europe, with a focus on Belgium: Linking synoptic-scale events to their local impacts

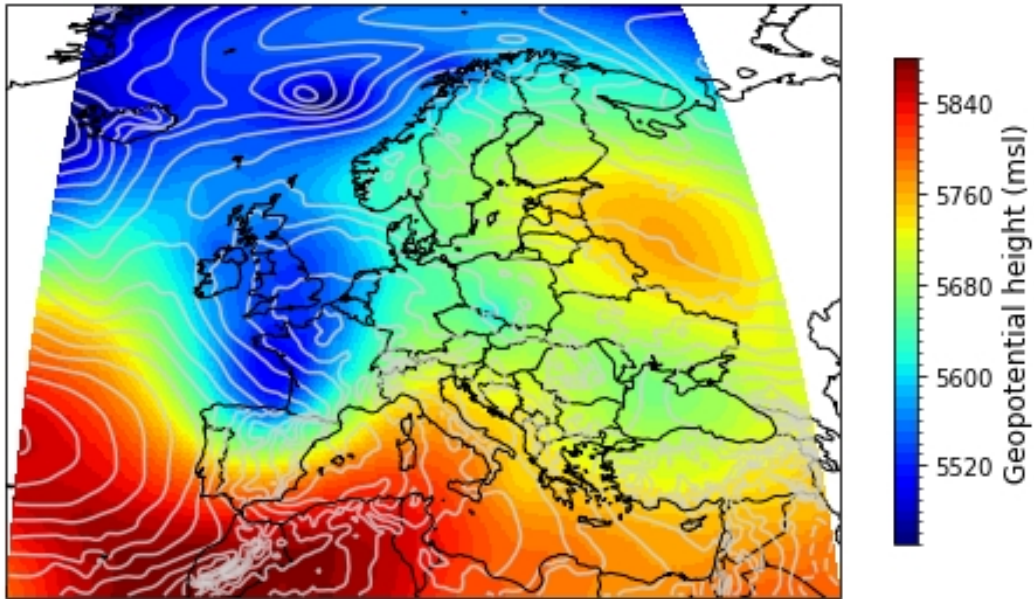
International Meuse Symposium 2025
Liège, 11-09-2025
Josip BRAJKOVIC



July 2021 Rainfall event

2021-07-12 14h

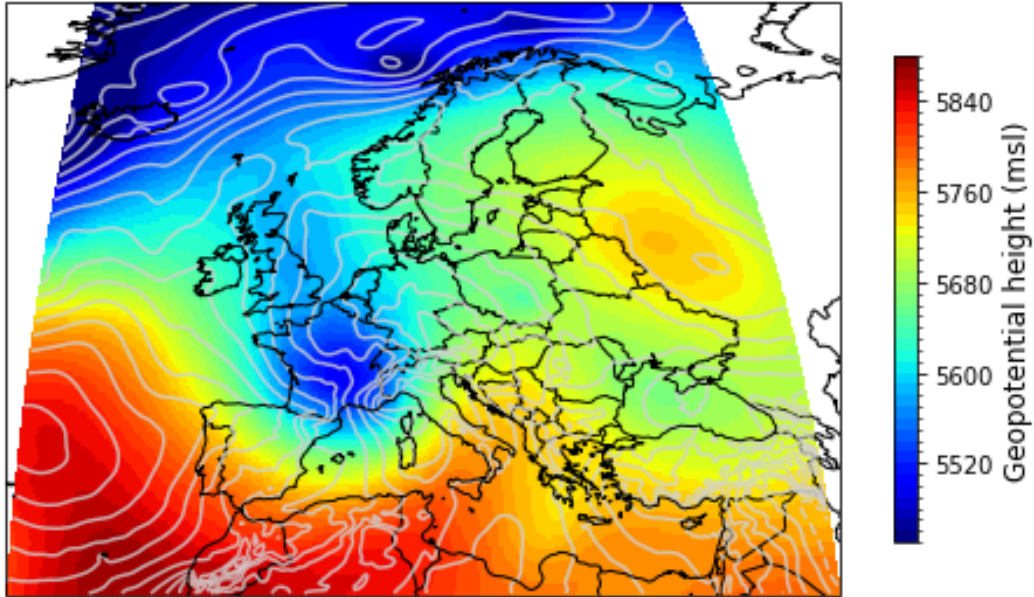
500hPa



July 2021 Rainfall event

2021-07-13 08h

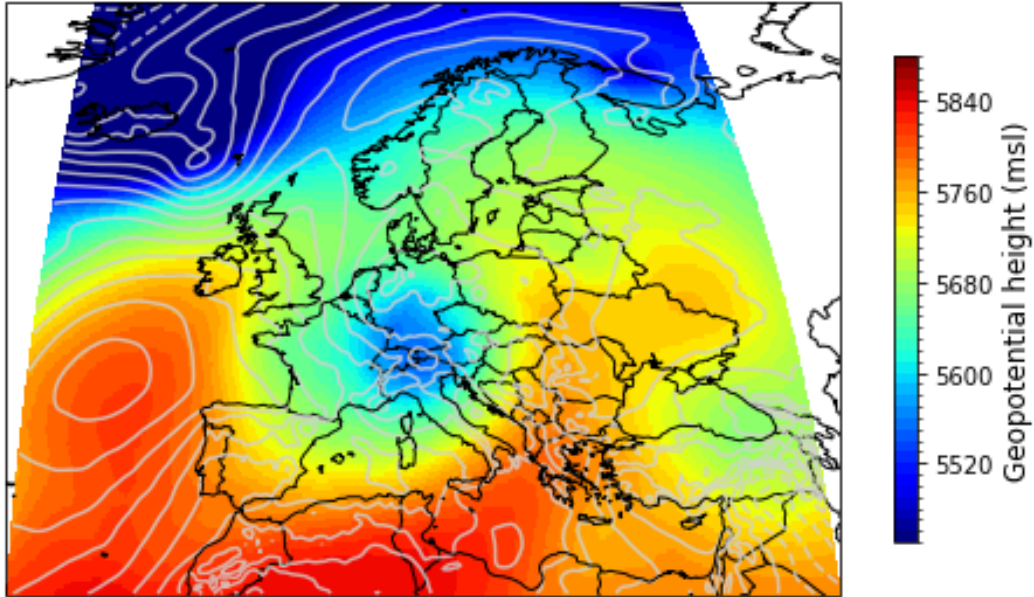
500hPa



July 2021 Rainfall event

2021-07-14 14h

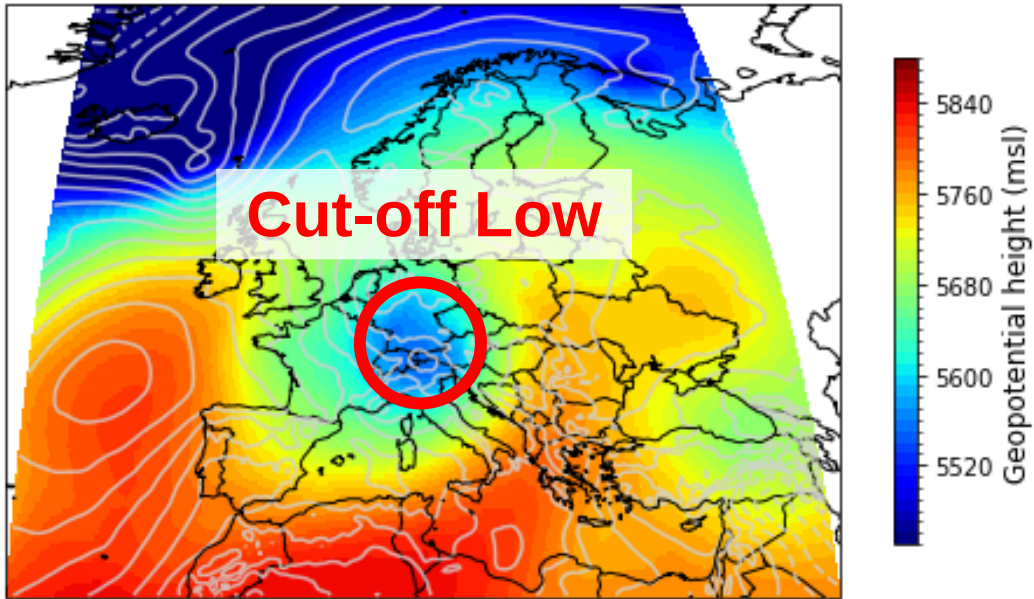
500hPa



July 2021 Rainfall event

2021-07-14 14h

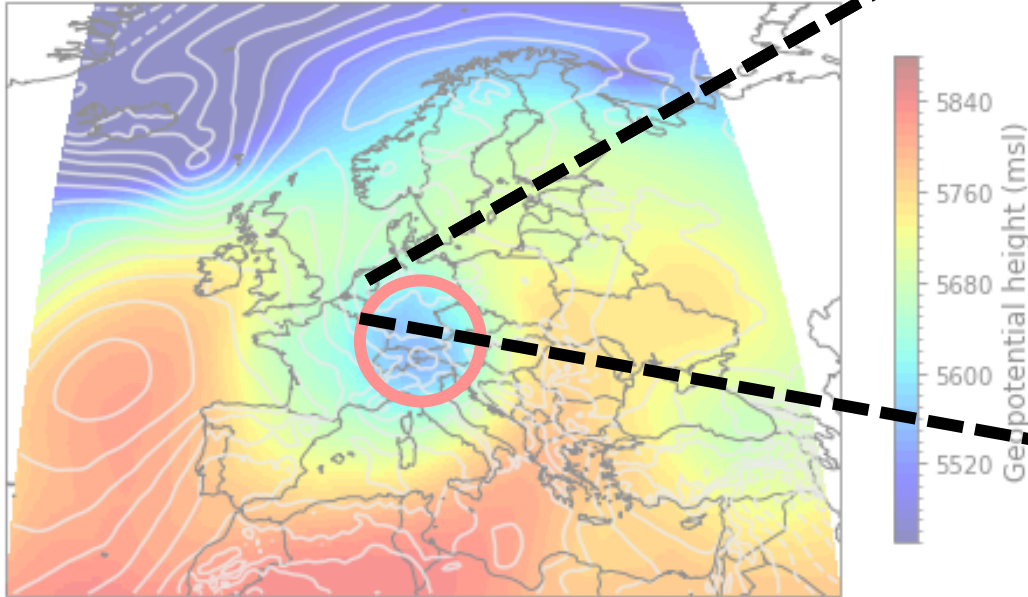
500hPa



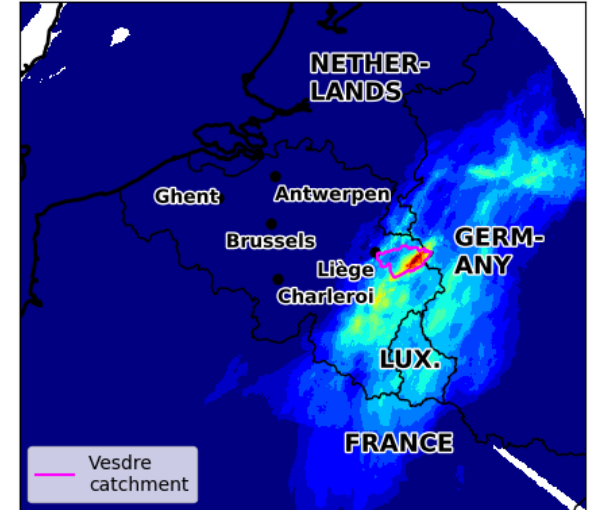
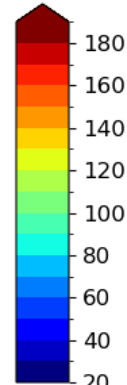
July 2021 Rainfall event

2021-07-14 14h

500hPa

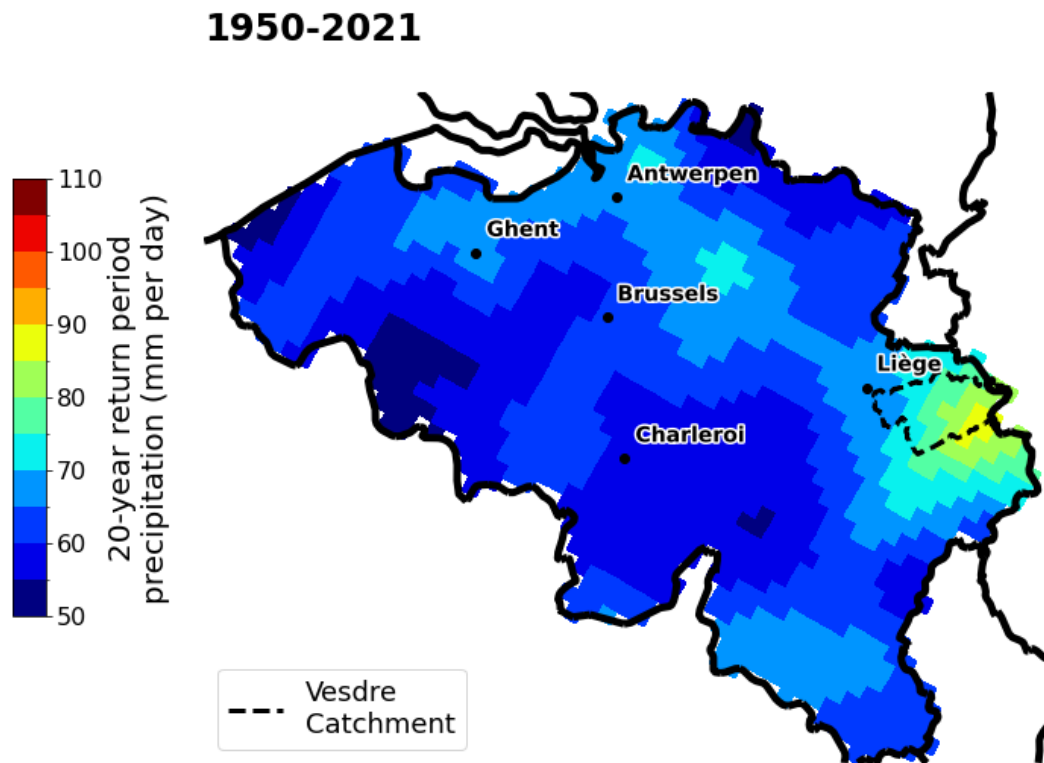


Precip on
14/07/2021
(mm)



~10-15% of the annual rainfall

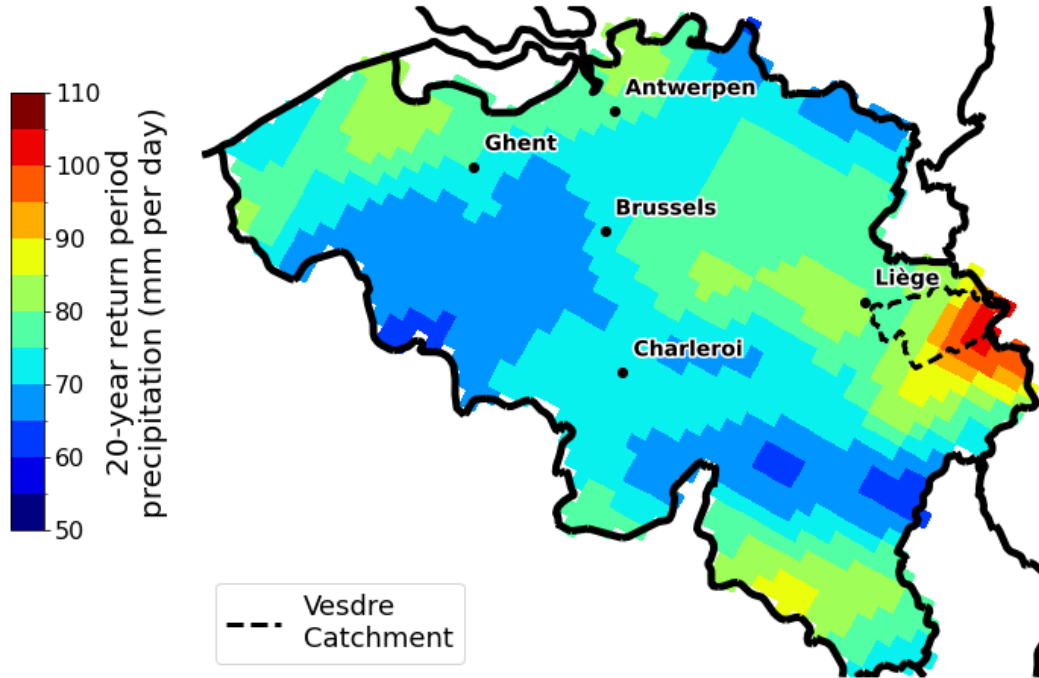
A bit more of context...



(Brajkovic et al., 2025)

A bit more of context...

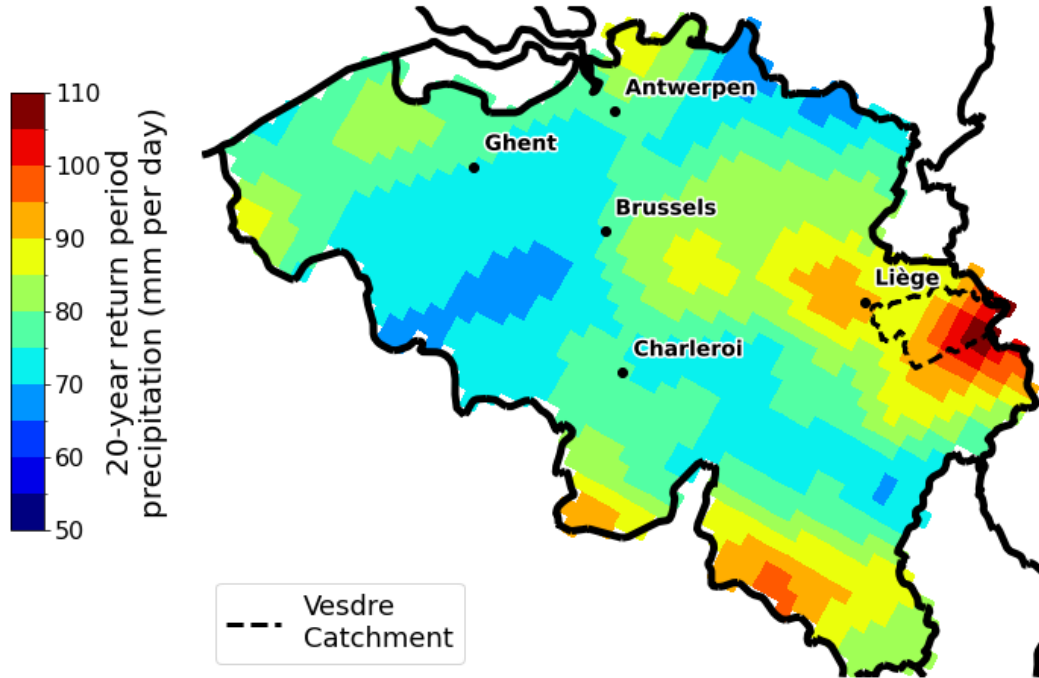
SSP1-2.6 ~ Paris Agreement



(Brajkovic et al., 2025)

A bit more of context...

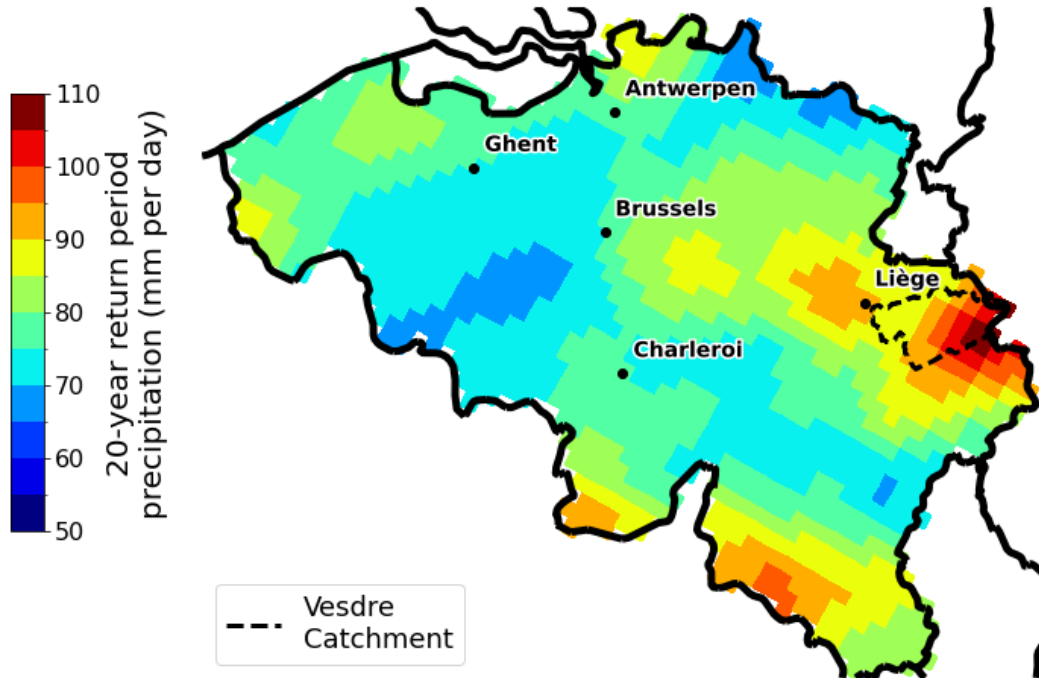
SSP5-8.5 - Business as usual



(Brajkovic et al., 2025)

A bit more of context...

SSP5-8.5 - Business as usual

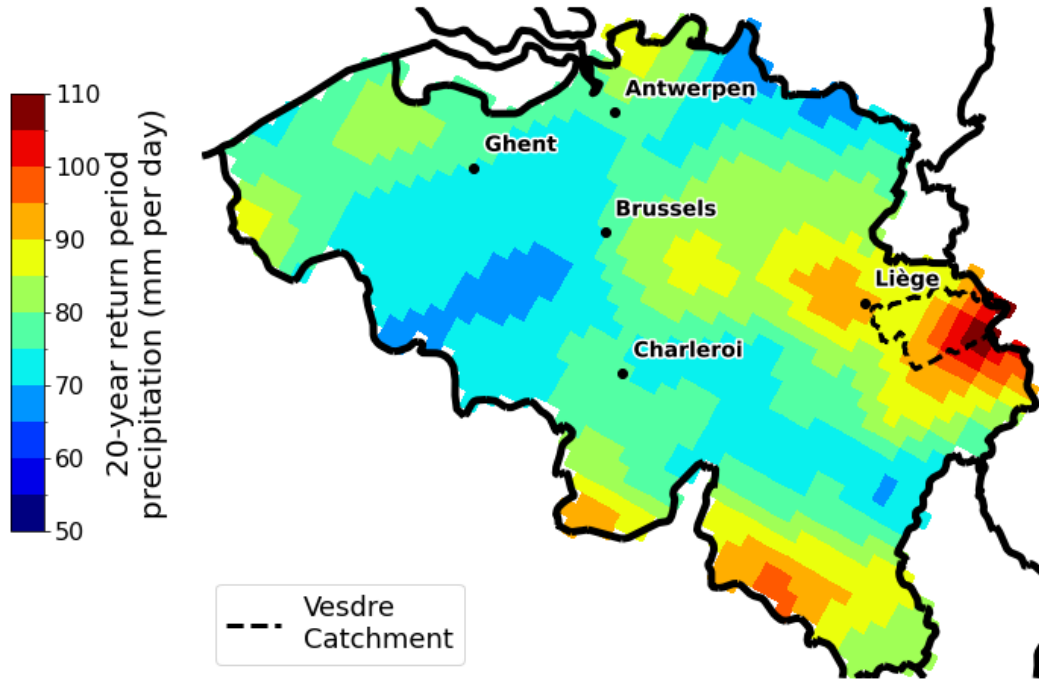


(Brajkovic et al., 2025)

- Based on 6 downscaled IPCC model projections

A bit more of context...

SSP5-8.5 - Business as usual

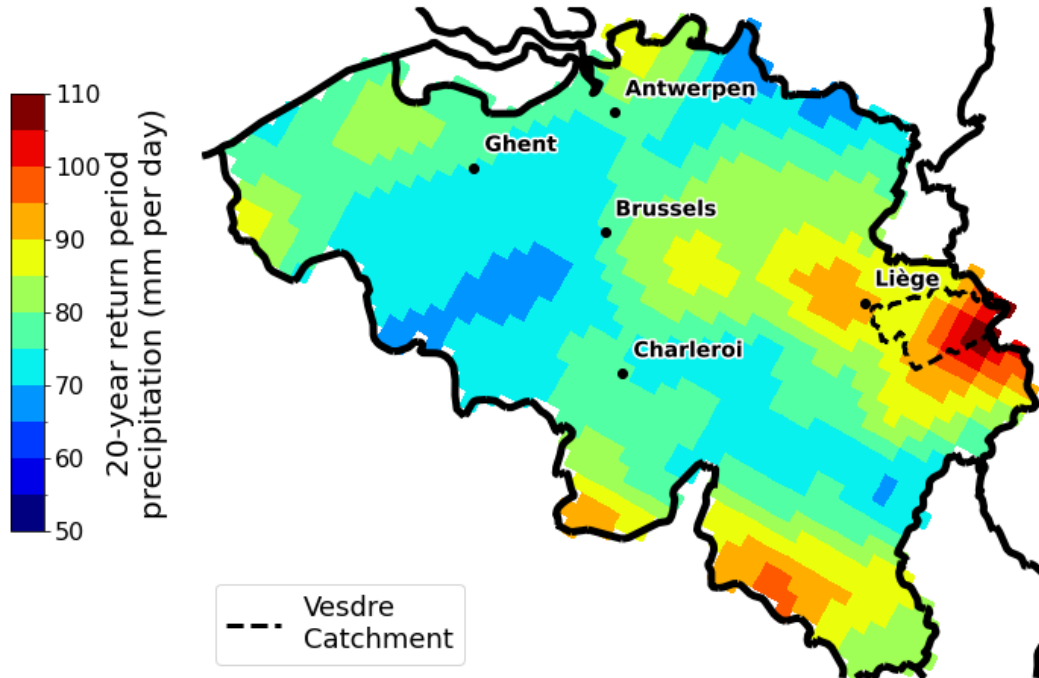


(Brajkovic et al., 2025)

- Based on 6 downscaled IPCC model projections
- Regional Climate Model MAR

A bit more of context...

SSP5-8.5 - Business as usual



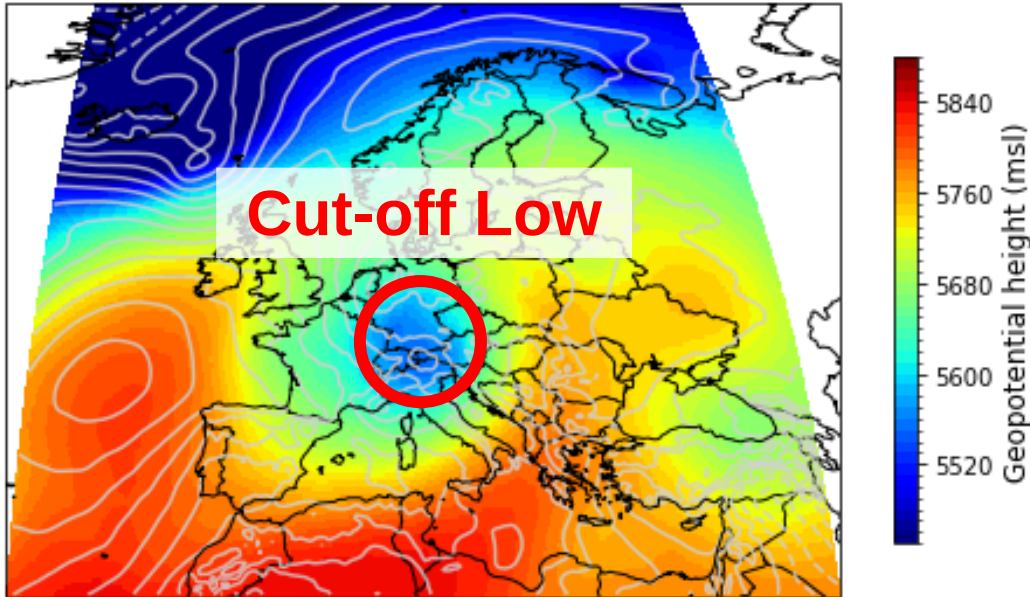
(Brajkovic et al., 2025)

- Based on 6 downscaled IPCC model projections
- Regional Climate Model MAR
- High inter-model variability !?

Role of the Cut-off lows (COLs) ?

2021-07-14 14h

500hPa

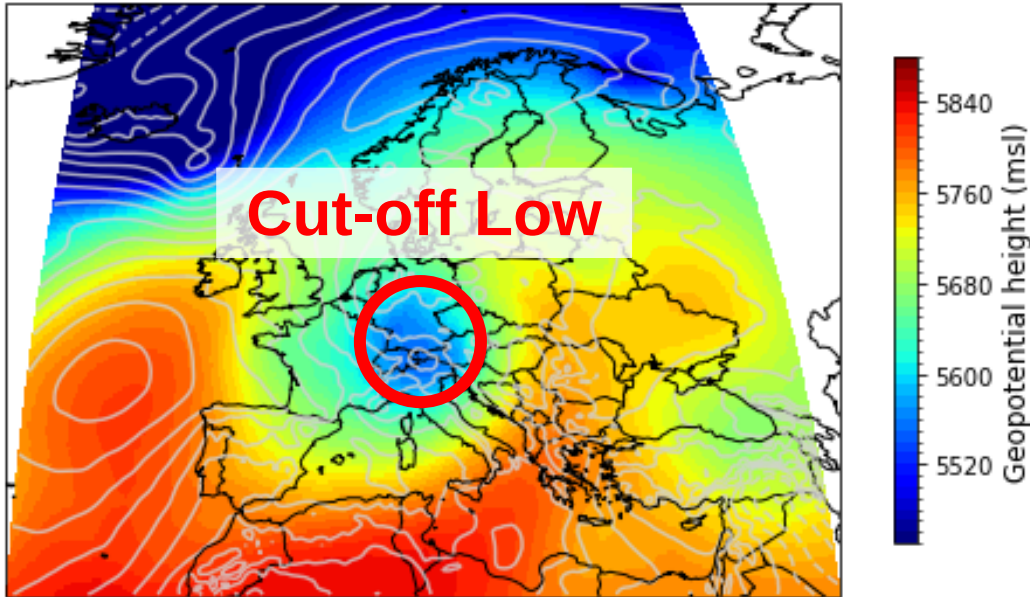


- COL frequency is slightly increasing over Europe (Munoz et al. 2020)

Role of the Cut-off lows (COLs) ?

2021-07-14 14h

500hPa



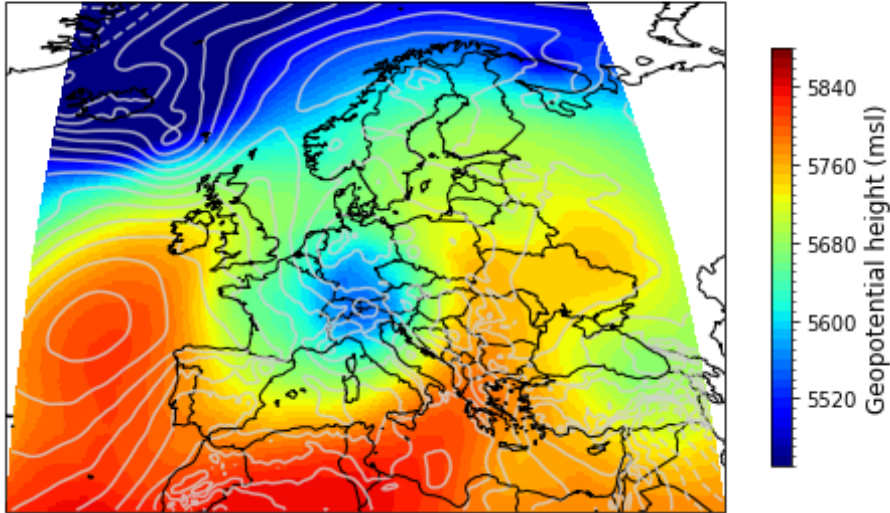
- COL frequency is slightly increasing over Europe (Munoz et al. 2020)
- How have they impacted Europe and Belgium in terms of extreme precipitation?

To address this : 2 datasets...

ERA5 Reanalyses (1940-2025)

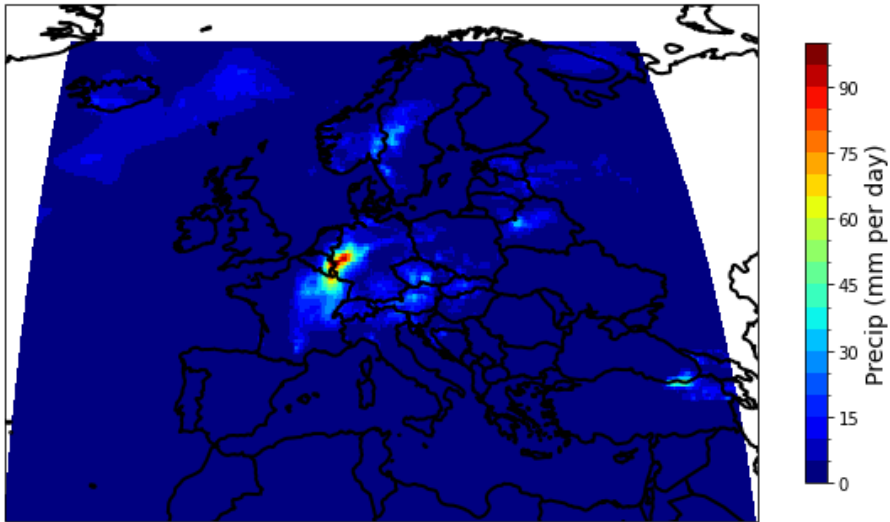
2021-07-14 14h

500hPa



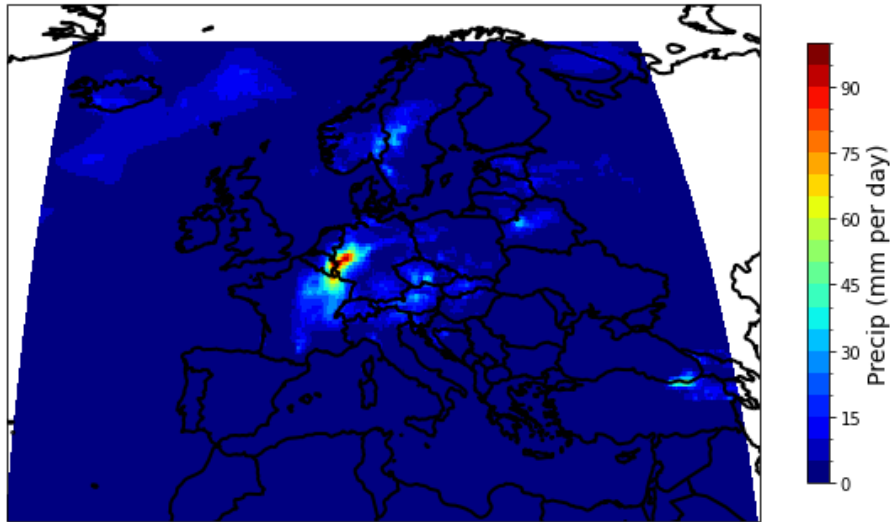
To address this : 2 datasets...

ERA5 Reanalyses (1940-2025)

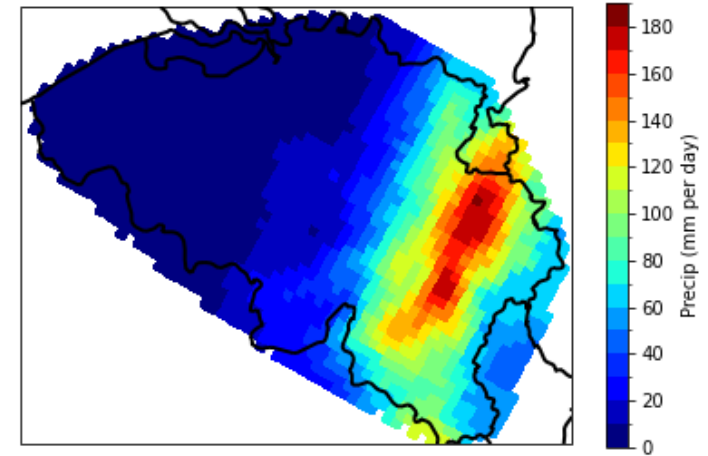


To address this : 2 datasets...

ERA5 Reanalyses (1940-2025)



Bias-adjusted MAR-ERA5 data (1940-2023)

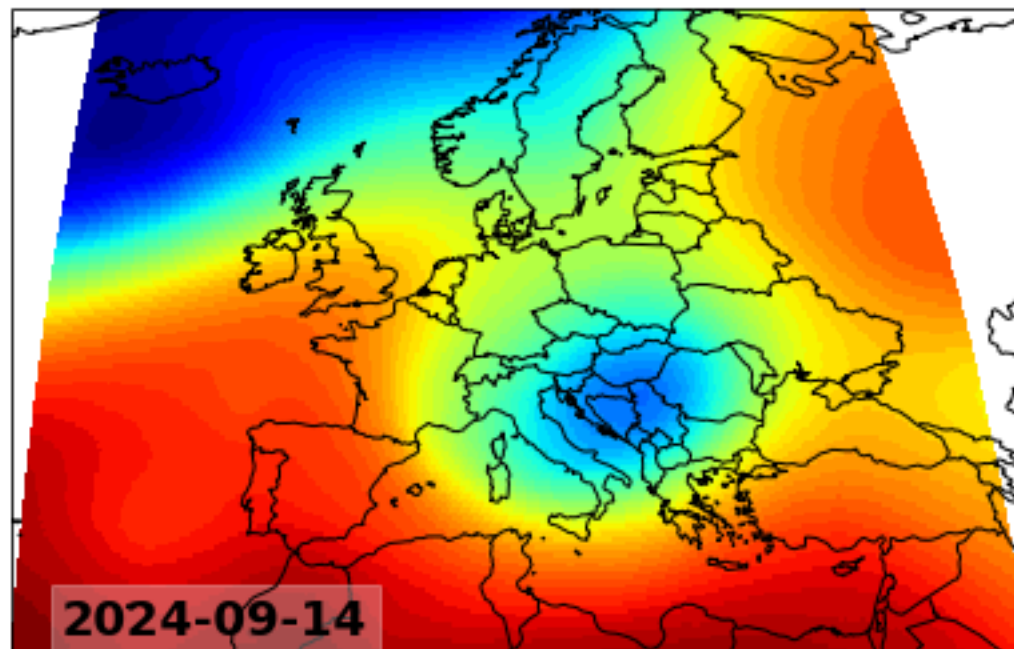


(Brajkovic et al., 2025)

Attribution algorithm

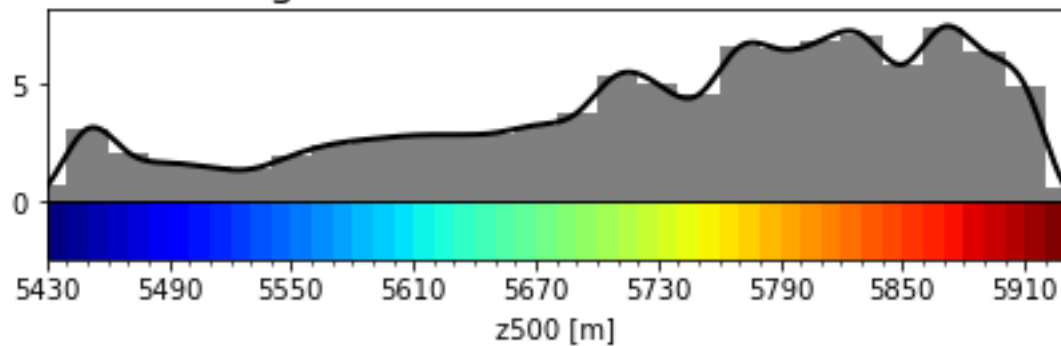


a)



b)

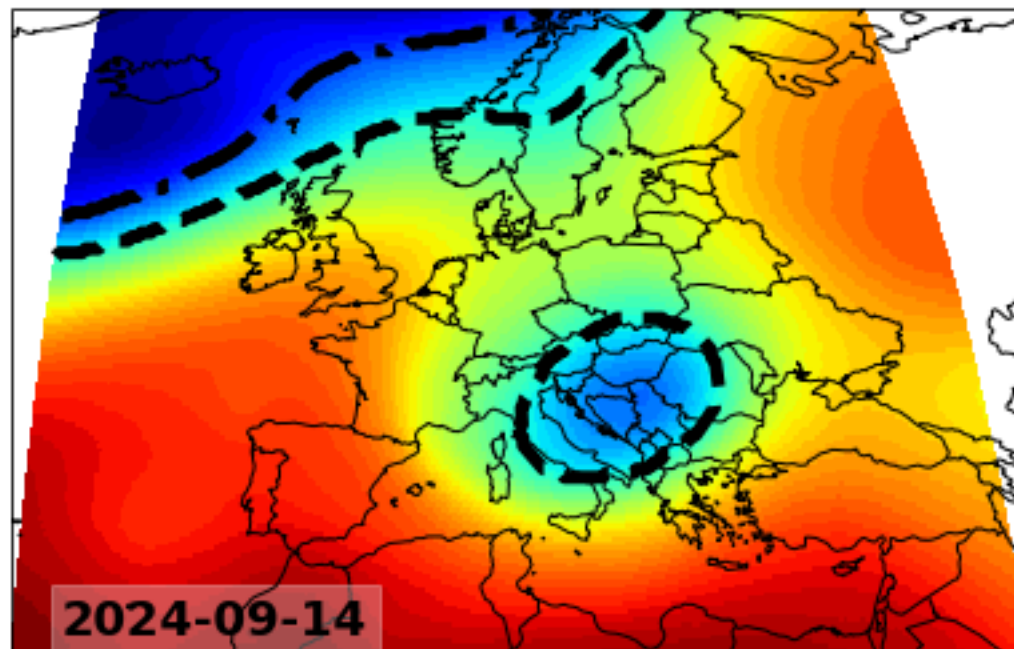
z500 histogram



Attribution algorithm

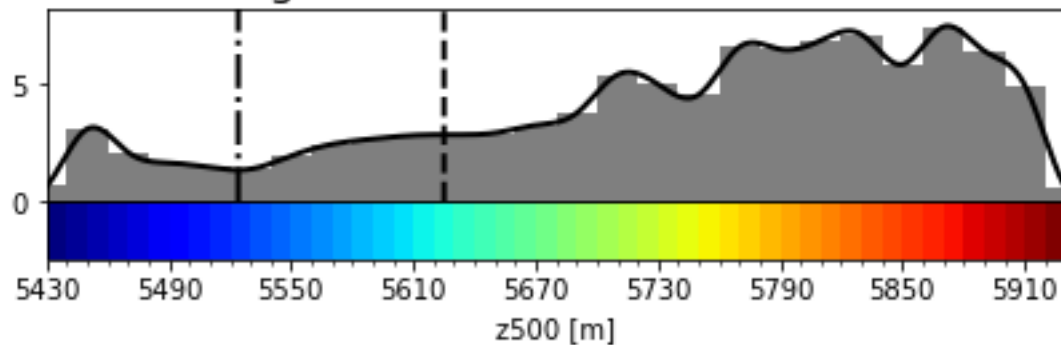
—• Lower threshold
-- Upper threshold

a)

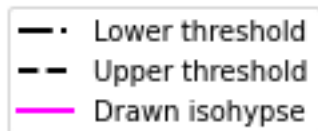


b)

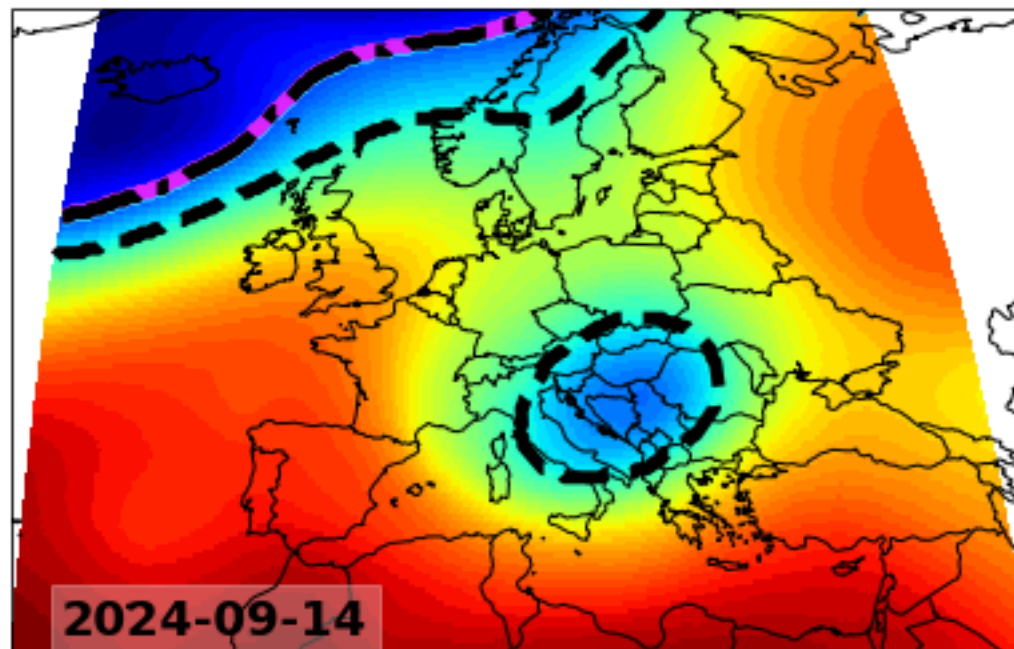
z500 histogram



Attribution algorithm

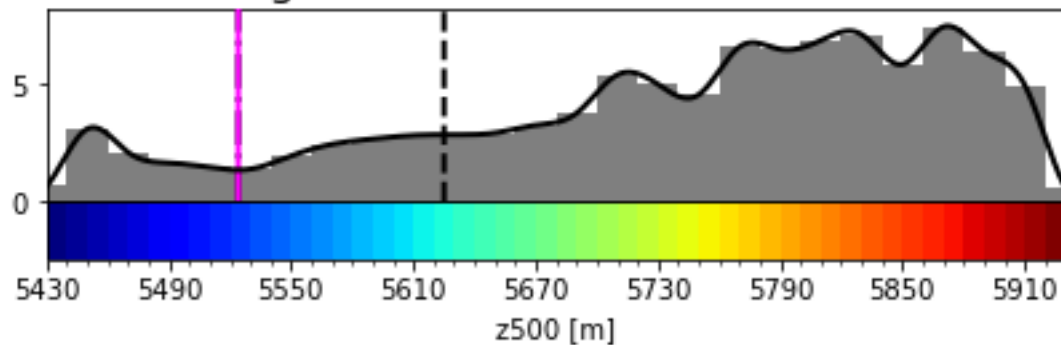


a)

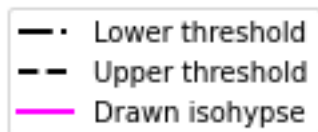


b)

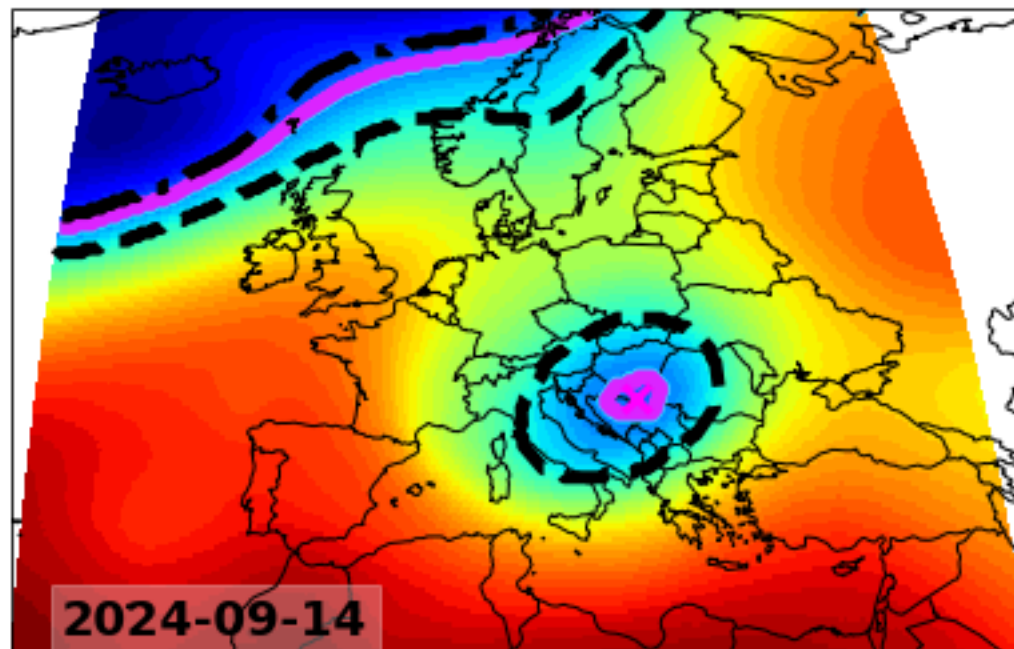
z500 histogram



Attribution algorithm

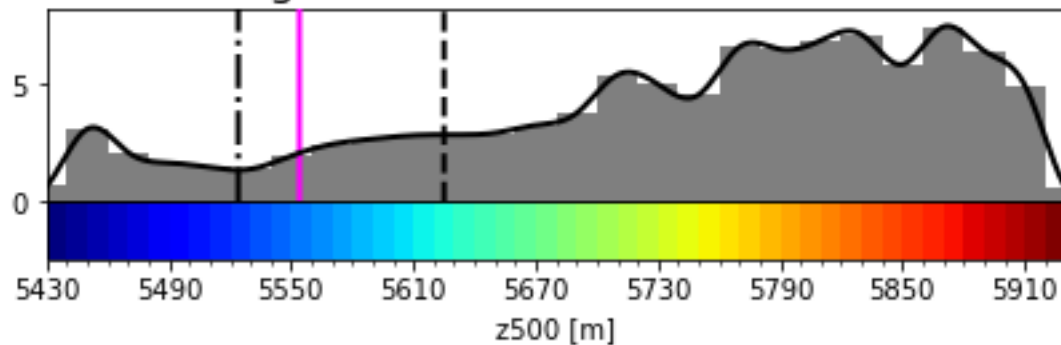


a)



b)

z500 histogram

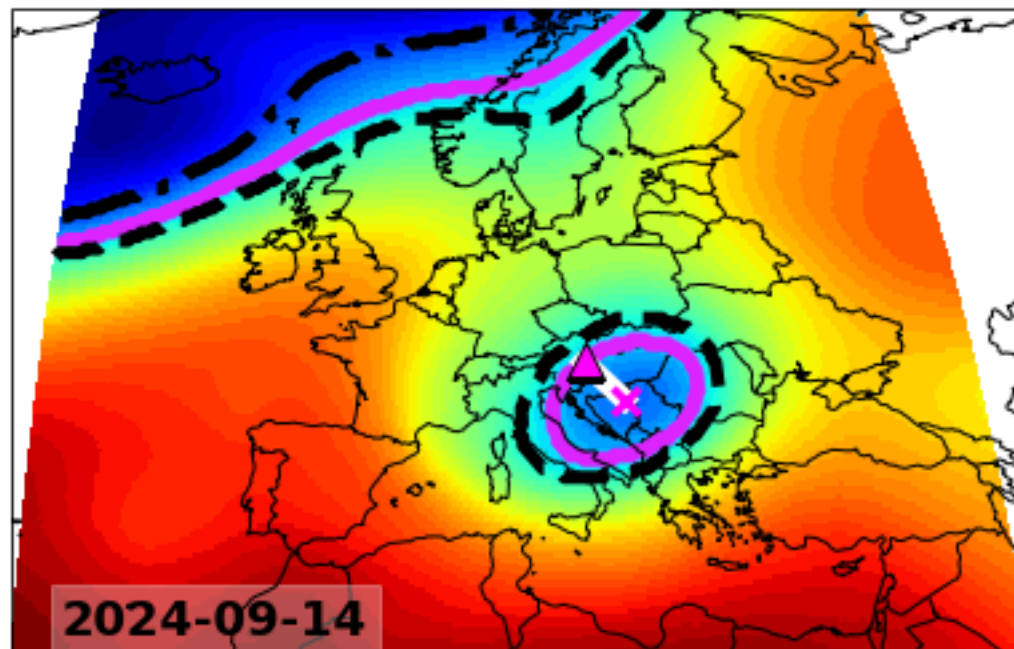


Attribution algorithm

a)

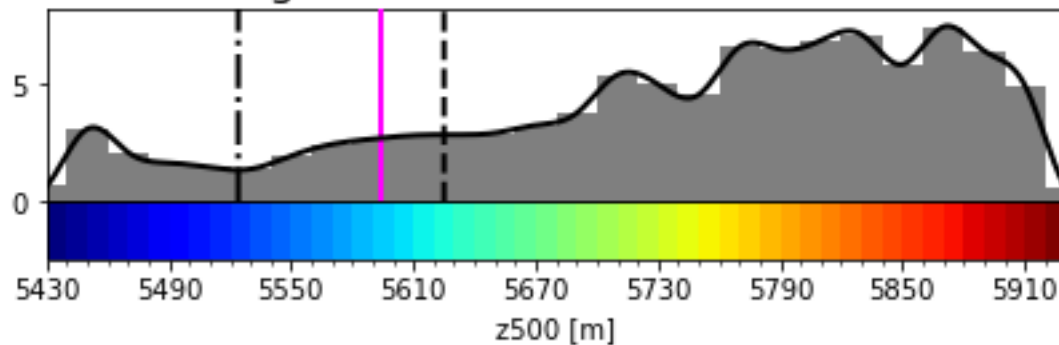
—•— Lower threshold
--- Upper threshold
— Drawn isohypse

✕ COL center
▲ Closest precipitation pixel



b)

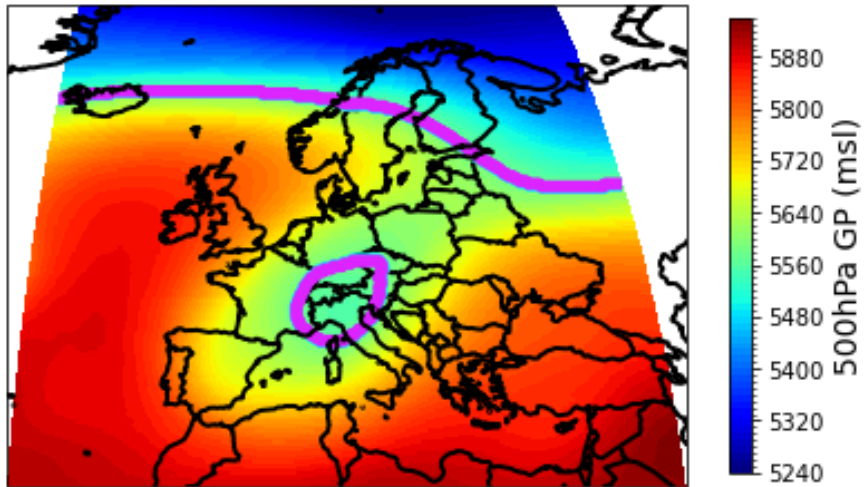
z500 histogram



Working at the scale of Europe

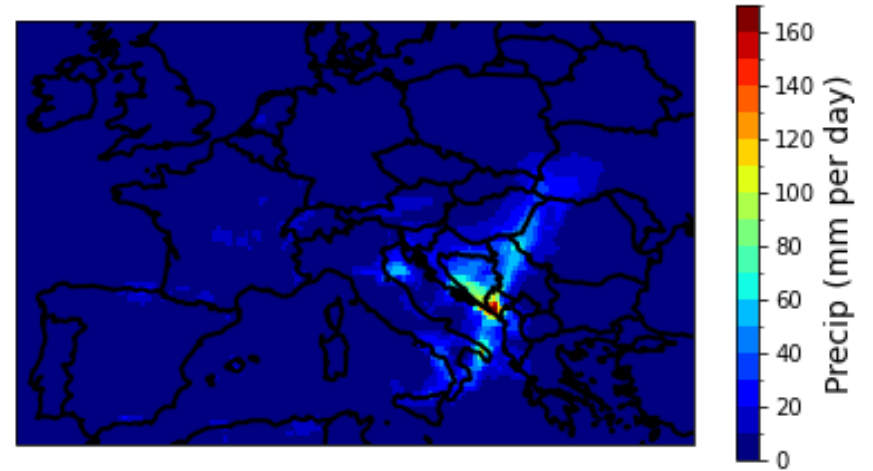
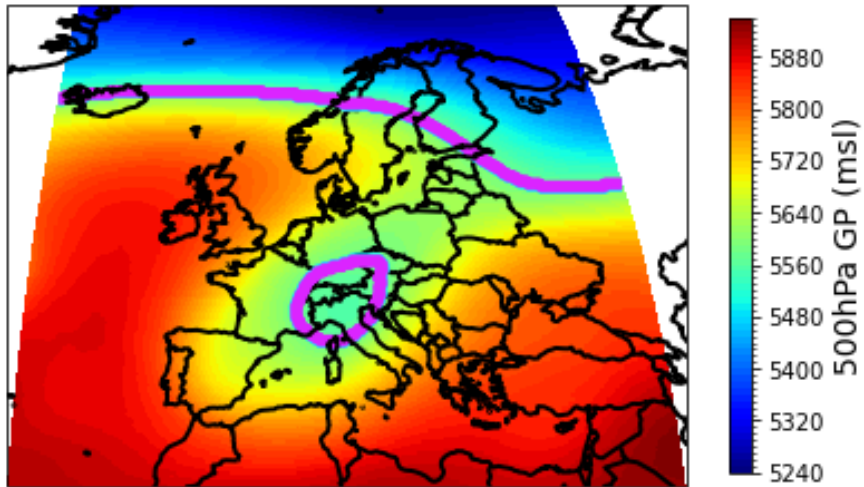
Some identified cases

1988-09-15



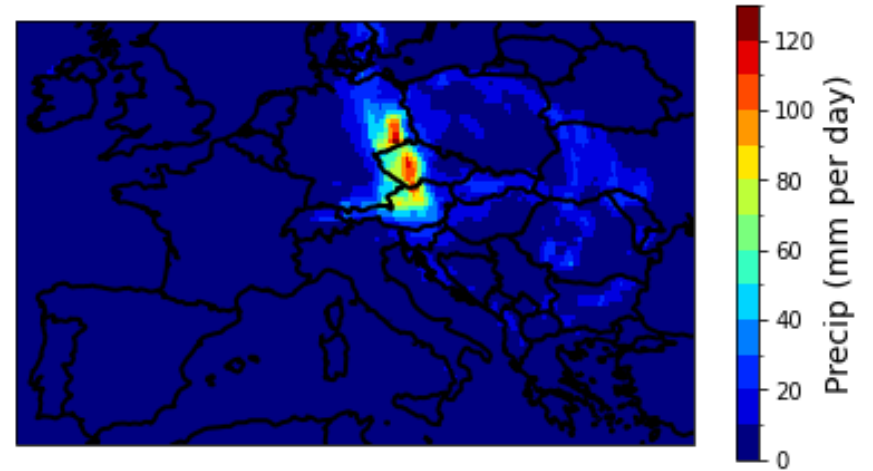
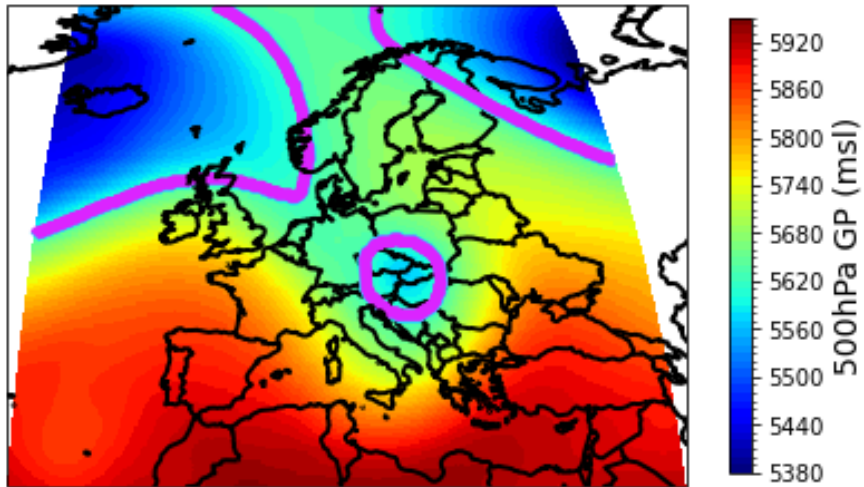
Some identified cases

1988-09-15



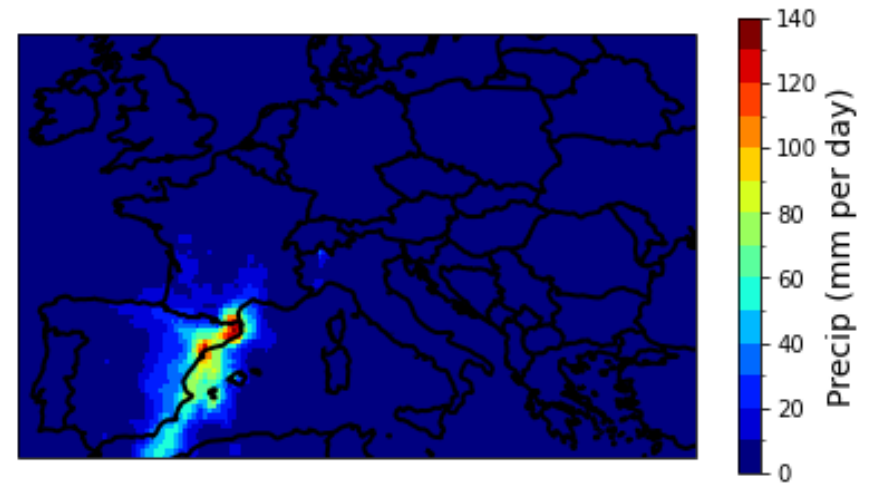
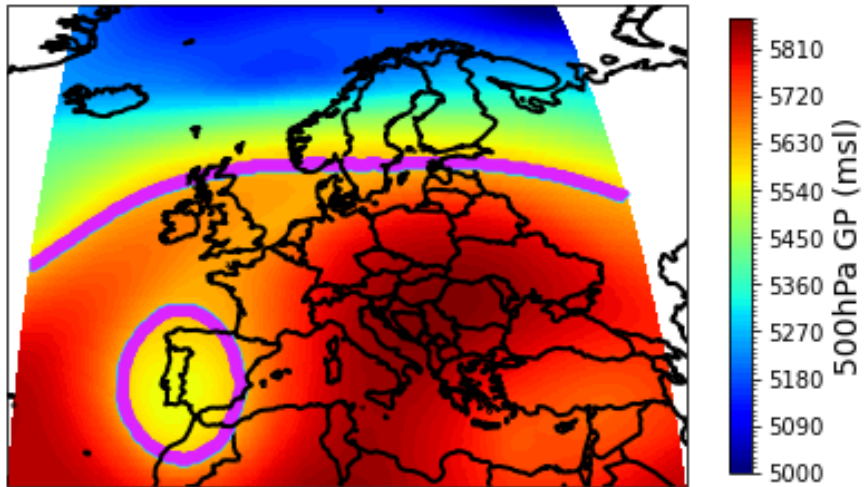
Some identified cases

2002-08-12



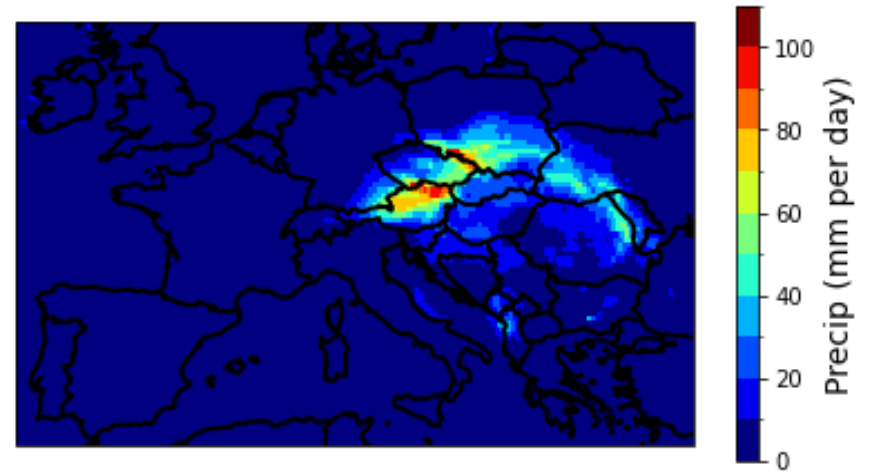
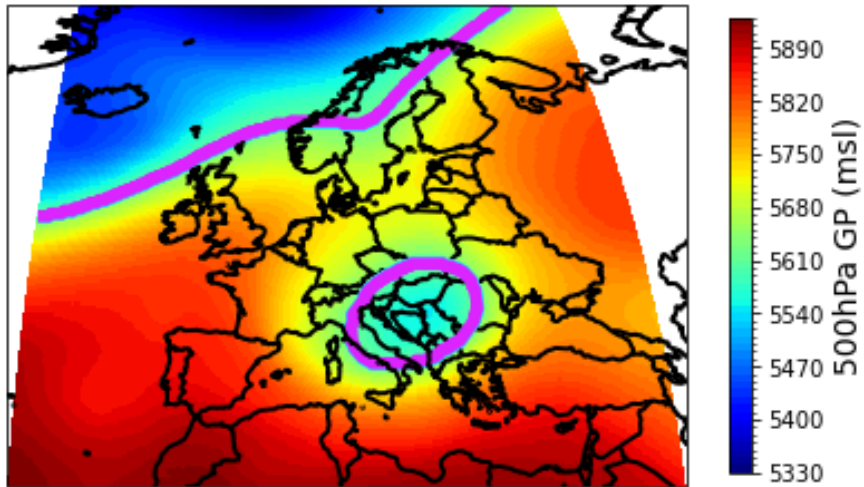
Some identified cases

2019-10-22

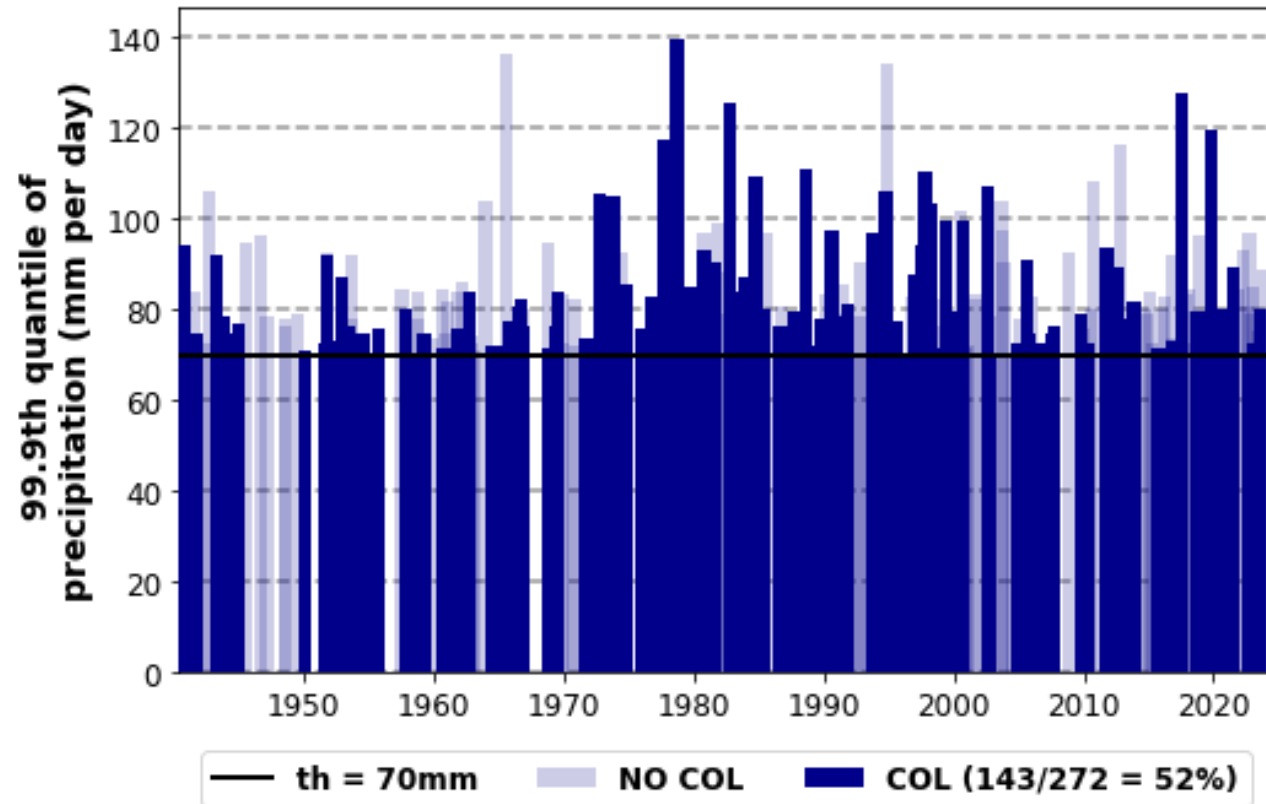


Some identified cases

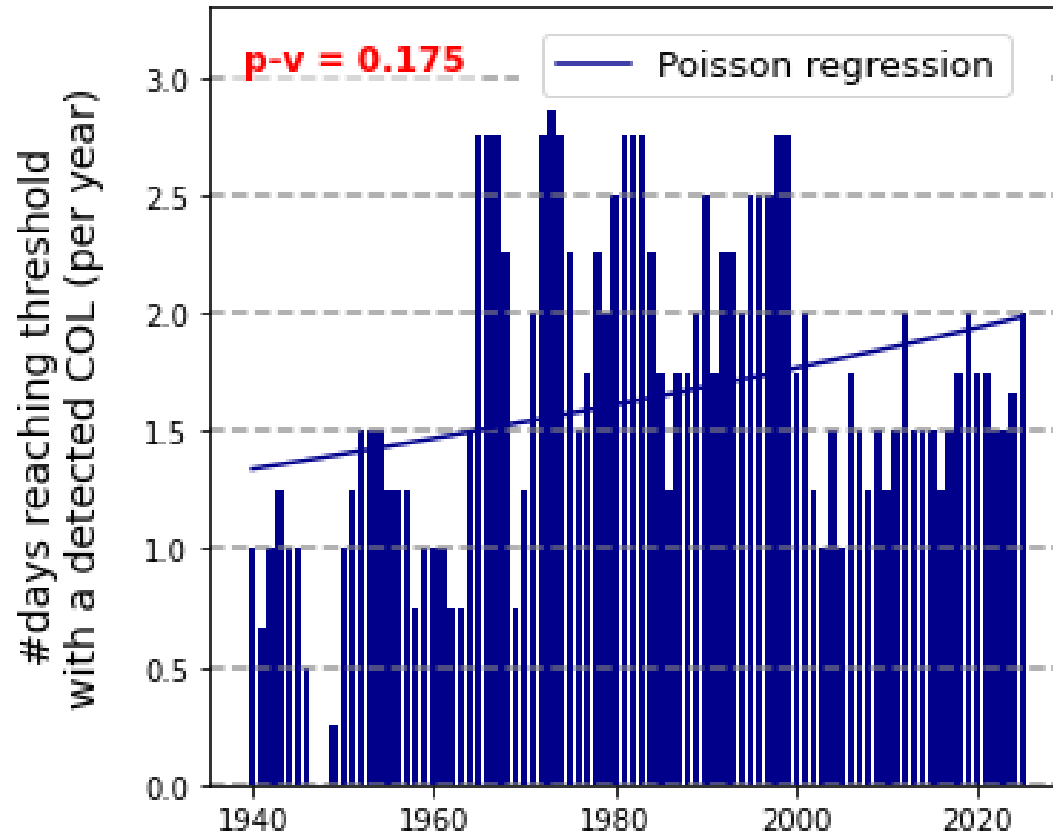
2024-09-14



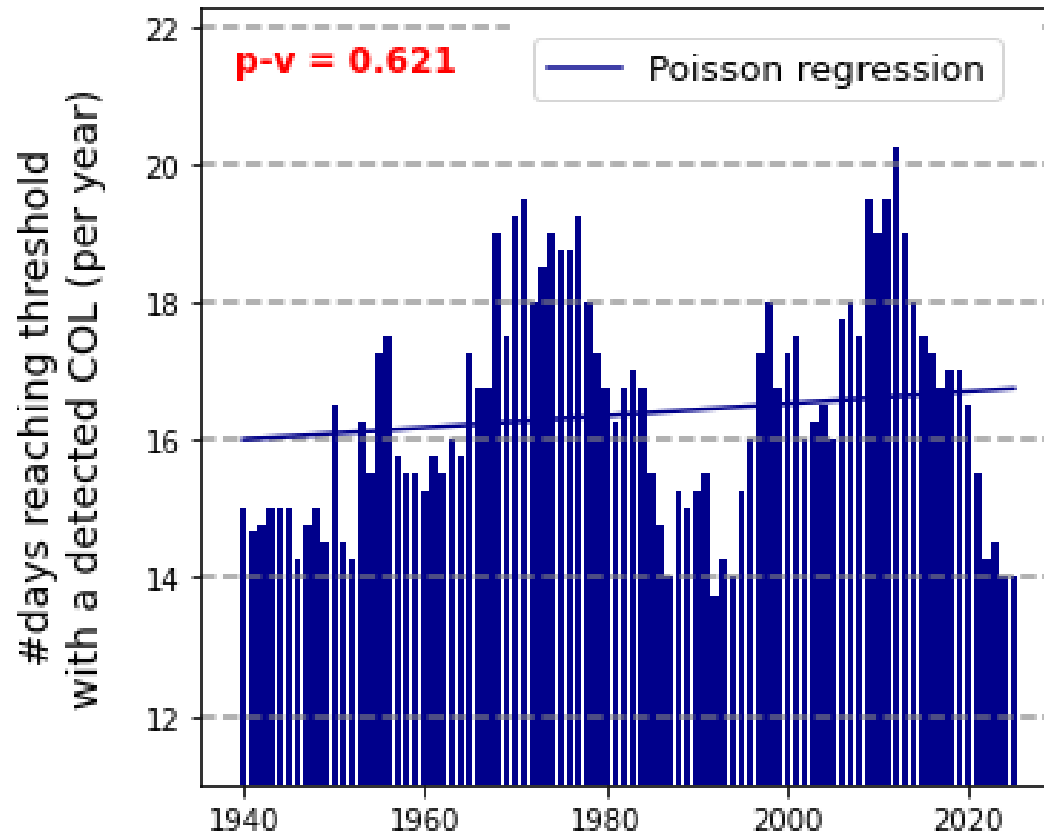
Detection over 1940-2024



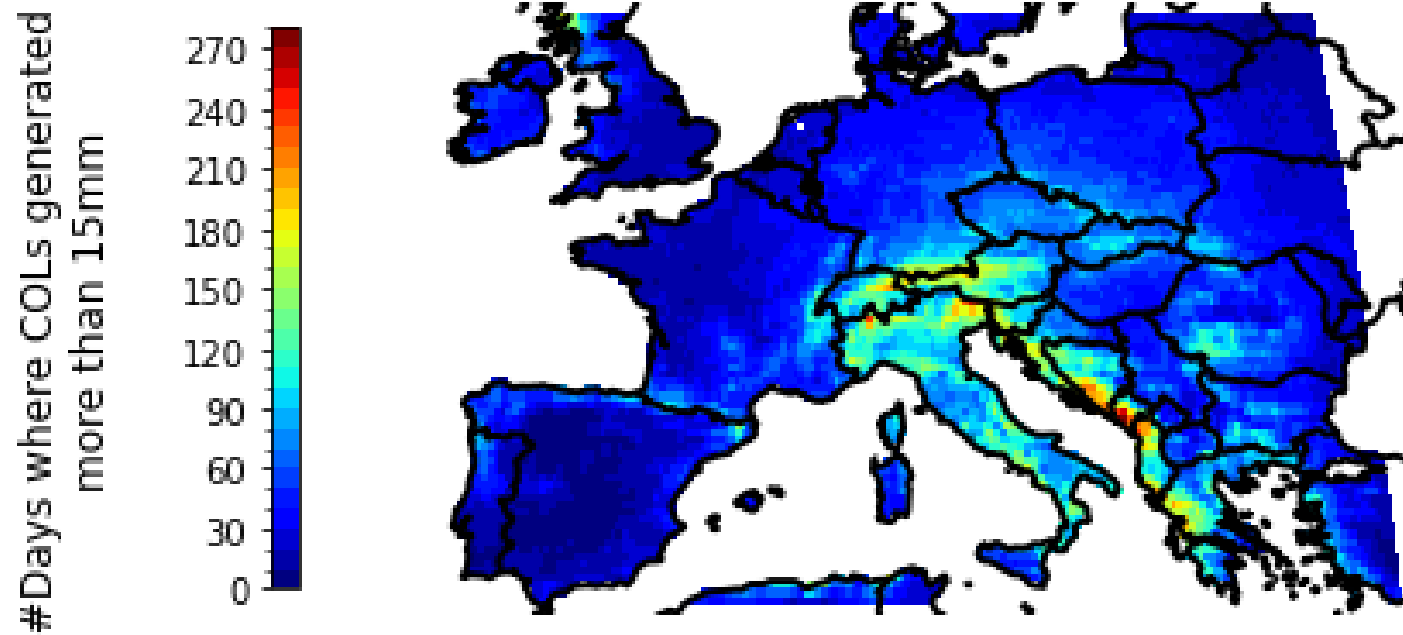
Observed trend (threshold = 70 mm per day)



Observed trend (threshold = 30 mm per day)



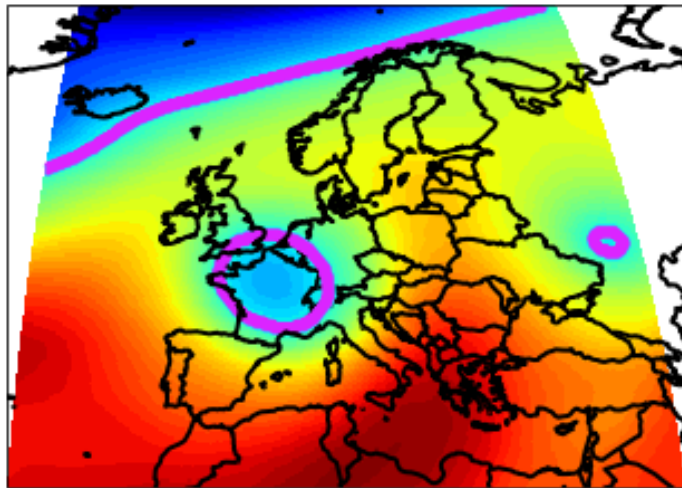
Regional disparities



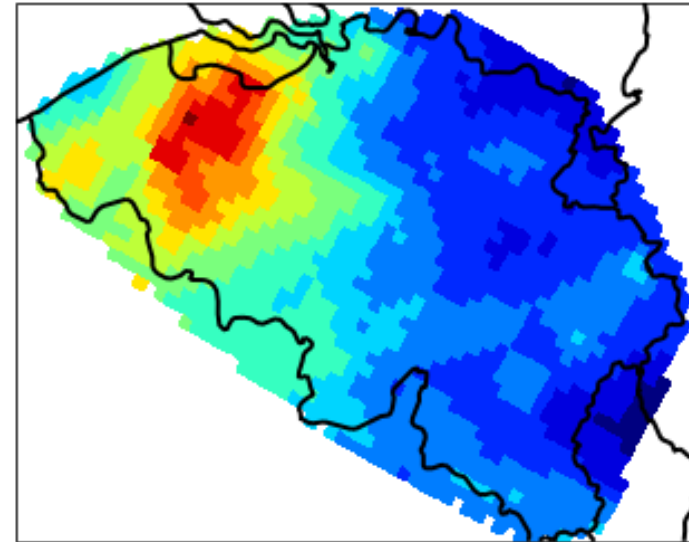
Working at the scale of Belgium

Some identified cases

1945-08-09



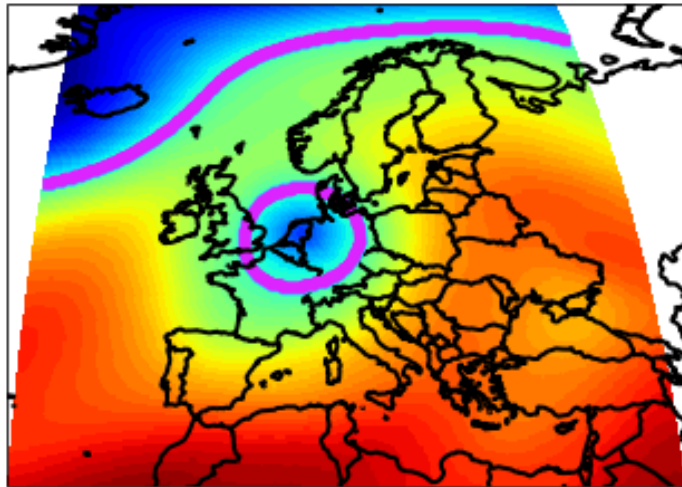
5950
5890
5830
5770
5710
5650
5590
5530
5470
5410
500hPa GP (msl)



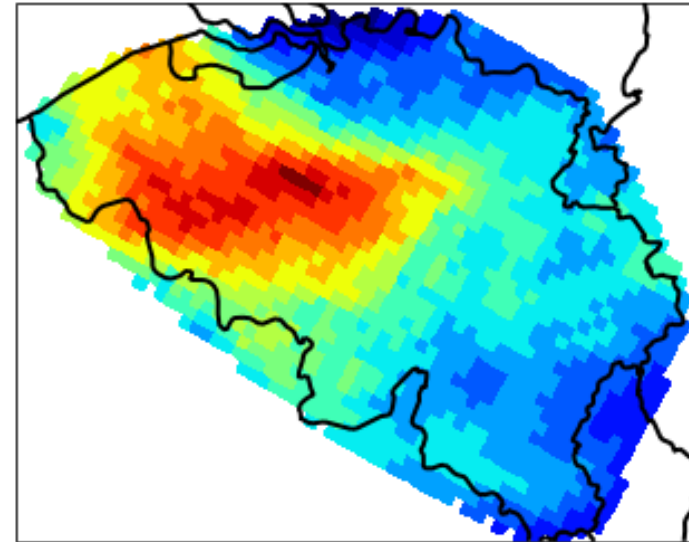
130
110
90
70
50
30
10
Precip (mm per day)

Some identified cases

1996-08-29



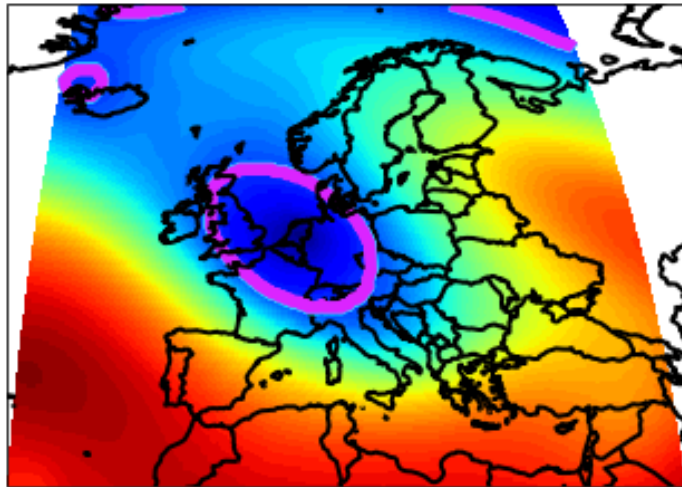
5880
5820
5760
5700
5640
5580
5520
5460
5400
500hPa GP (msl)



150
130
110
90
70
50
30
10
Precip (mm per day)

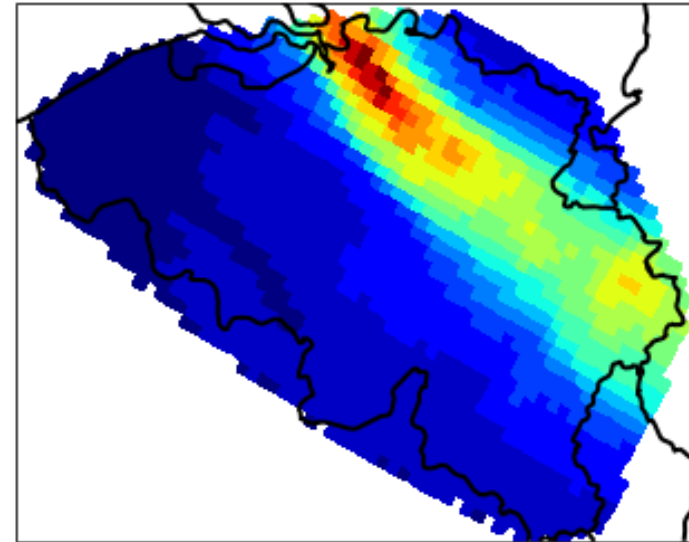
Some identified cases

1998-09-13



5930
5860
5790
5720
5650
5580
5510
5440
5370
5300

500hPa GP (msl)

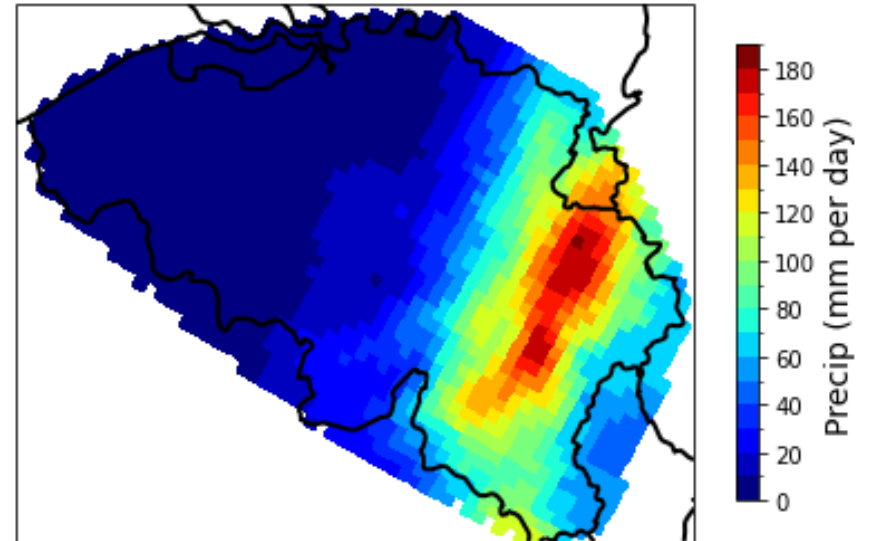
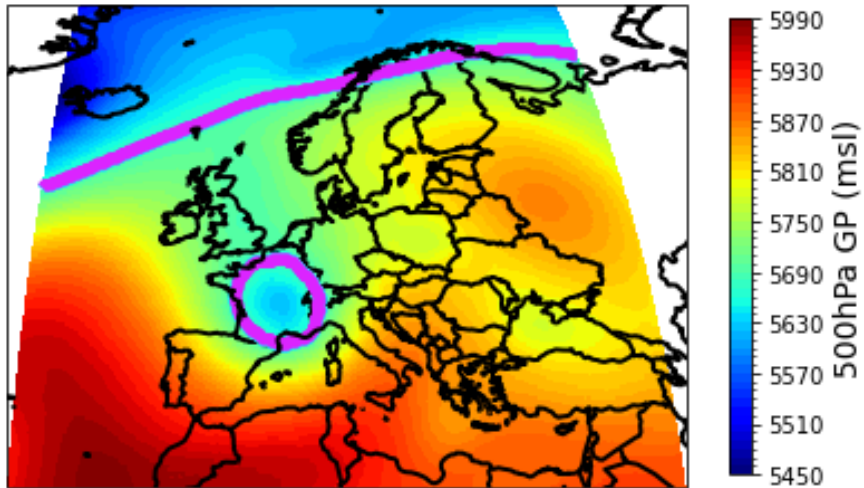


160
140
120
100
80
60
40
20
0

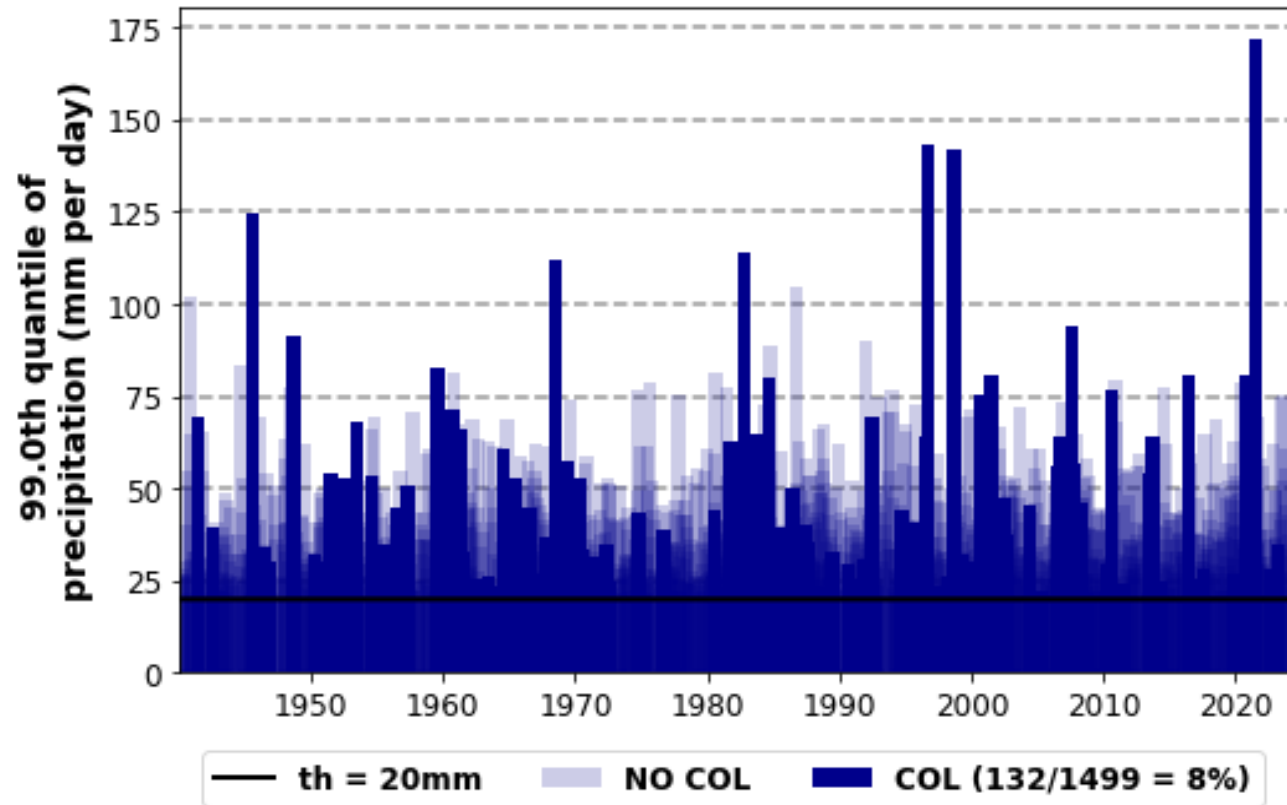
Precip (mm per day)

Some identified cases

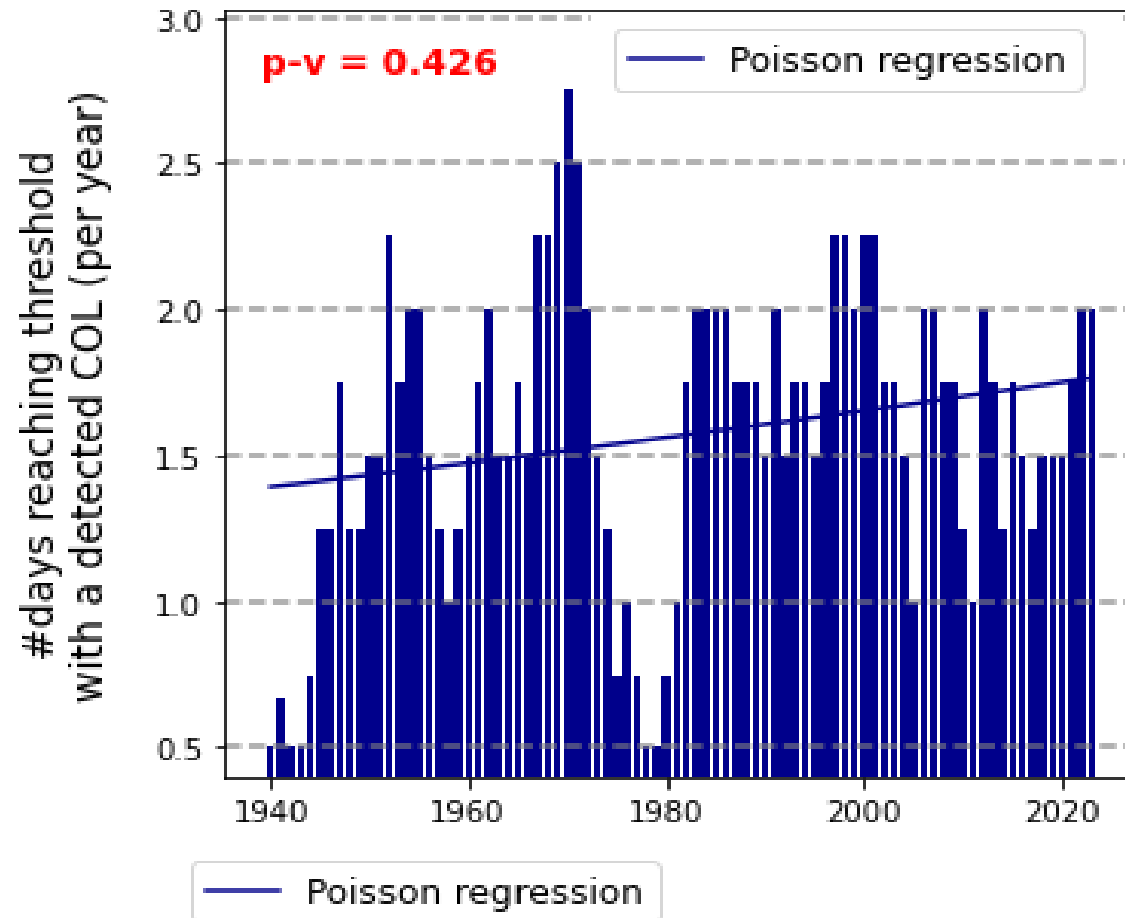
2021-07-13



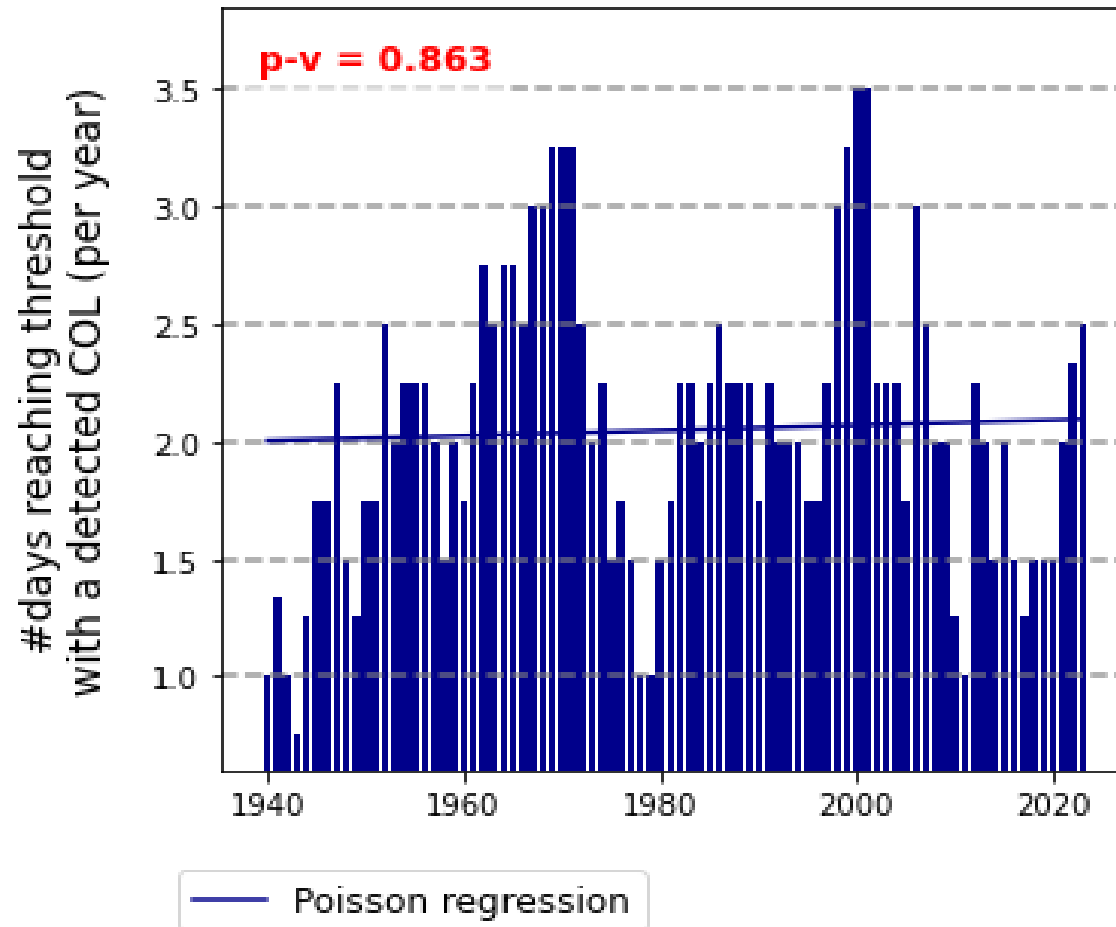
Detection over 1940-2023



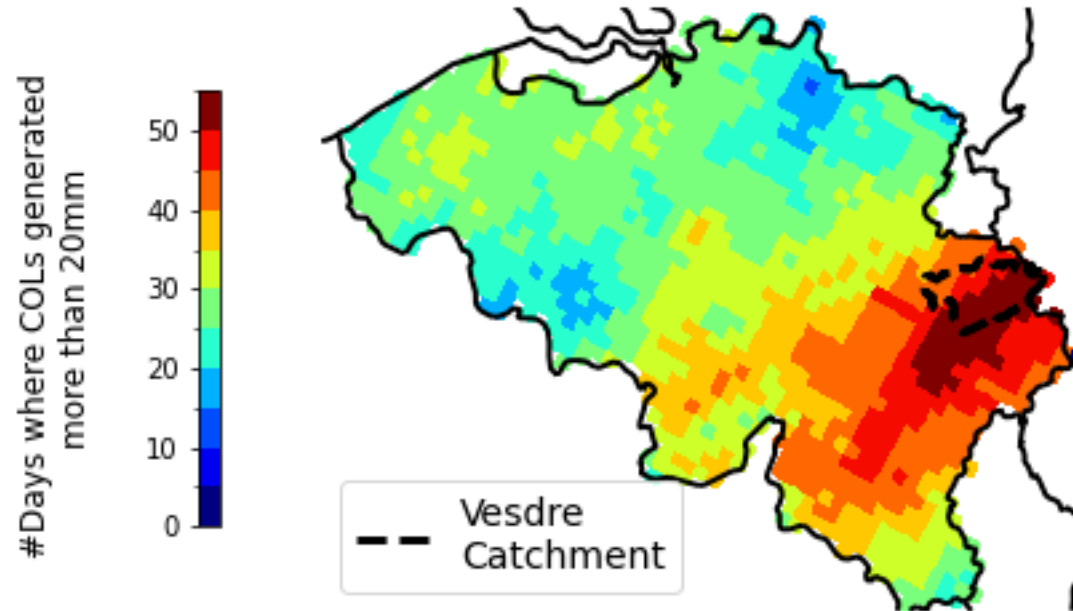
Observed trend (threshold = 20 mm per day)



Observed trend (threshold = 10 mm per day)



Regional disparities



At both scales:

- Around a half/tenth (Europe/Belgium) of extreme precipitation events are COL-induced (proportion is threshold dependant)
- Trends are not significant for COL-induced events
 - Natural variability in the climate system
 - Random timing
- Topography as a key-role

Take-home message

- Understanding COL impacts evolution is critical
 - large amount of events in **distribution tails**
- COLs have **always had massive impacts** at European and Belgian scales
- Climate change makes **those impacts only worse**
- Changes in Extreme precipitation intensity thermodynamically driven **rather than dynamically** (Schoofs et al., 2025; Brajkovic et al., 2025)

Thank you all! 😊

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Cited references

Brajkovic, J., Fettweis, X., Noël, B., Vyver, H. V. D., Ghilain, N., Archambeau, P., Piroton, M., and Doutreloup, S. (2025). Increased intensity and frequency of extreme precipitation events in belgium as simulated by the regional climate model MAR. *Journal of Hydrology: Regional Studies*, 59:102399.

Muñoz, C., Schultz, D., and Vaughan, G. (2020). A midlatitude climatology and interannual variability of 200- and 500-hpa cut-off lows. *Journal of Climate*, 33(6):2201–2222.

Schoofs, J., Vandelanotte, K., Van de Vyver, H., Van Der Sichel, L., Vandersteene, M., Serras, F., van Lipzig, N. P. M., and Van Schaeybroeck, B. (2025). Dynamic and thermodynamic contributions to future extreme-rainfall intensification: a case study for belgium.