Drivers of Cold Frontal Hourly Extreme Precipitation: A Climatological Study

Armin Schaffer, Tobias Lichtenegger, Heimo Truhetz, Albert Ossó, Douglas Maraun
Wegener Center for Climate and Global Change, University of Graz, Graz, Austria
Contact: armin.schaffer@uni-graz.at

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Introduction

In the mid-latitudes extreme precipitation is frequently related to atmospheric fronts. The most intense short-term precipitation is commonly related to cold fronts, which can lead to urban flooding and with the co-occurring squalls other large damages. Fronts are affected by a wide range of processes, operating across different scales. Our goal is to find the dominant processes which affect frontal extremes, by quantifying the strength of the impact of frontal characteristics on precipitation.

Methodology

We use ERA5 data from 1940-2021 for the front detection and the evaluation of their conditions [1]:

Fronts detection:

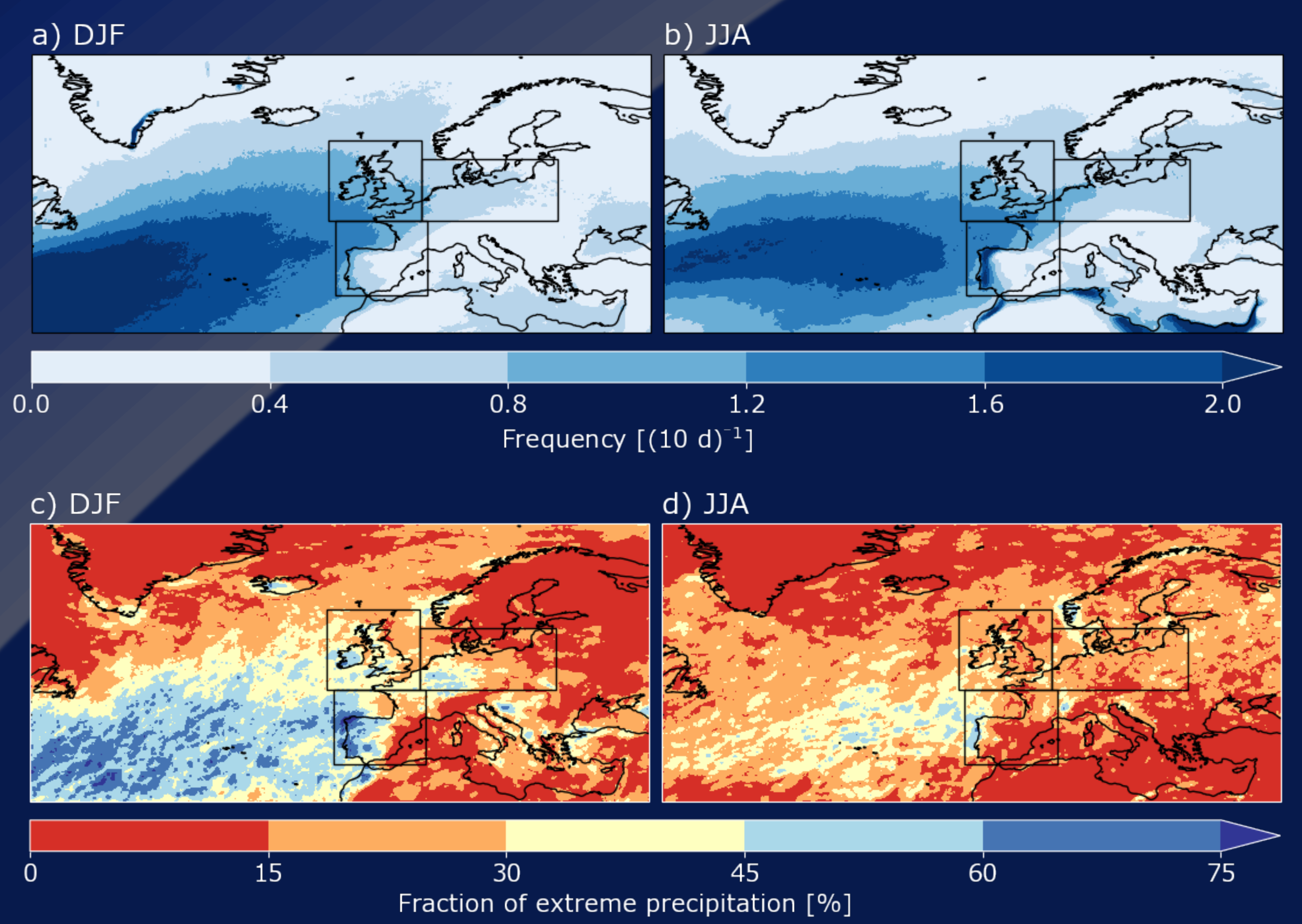
1. Using a spectral filter to smooth the equivalent potential temperature (Θ_e) field at 850 hPa [2]
2. Calculate the gradient of the Θ_e field ($\nabla\Theta_e$)
3. Apply thresholds to $\nabla\Theta_e$ and the cross-frontal wind speed and locate fronts at Thermal Front Parameter zero-contours
4. Classify warm and cold fronts based on the sign of the cross-frontal wind
5. Grouping frontal objects and apply length criterion (>500 km)

Evaluation of the frontal characteristics:

- Hourly precipitation within a 150 km radius
- Atmospheric conditions at 850 hPa at 0, 100, 200 and 300 km ahead and behind the front (Θ, Θ_e, humidity, gradients and wind speed)
- Dynamic fields are split into synoptic and meso-scale using spectral filter

Quantifying the strength of the relation of precipitation and front characteristics:

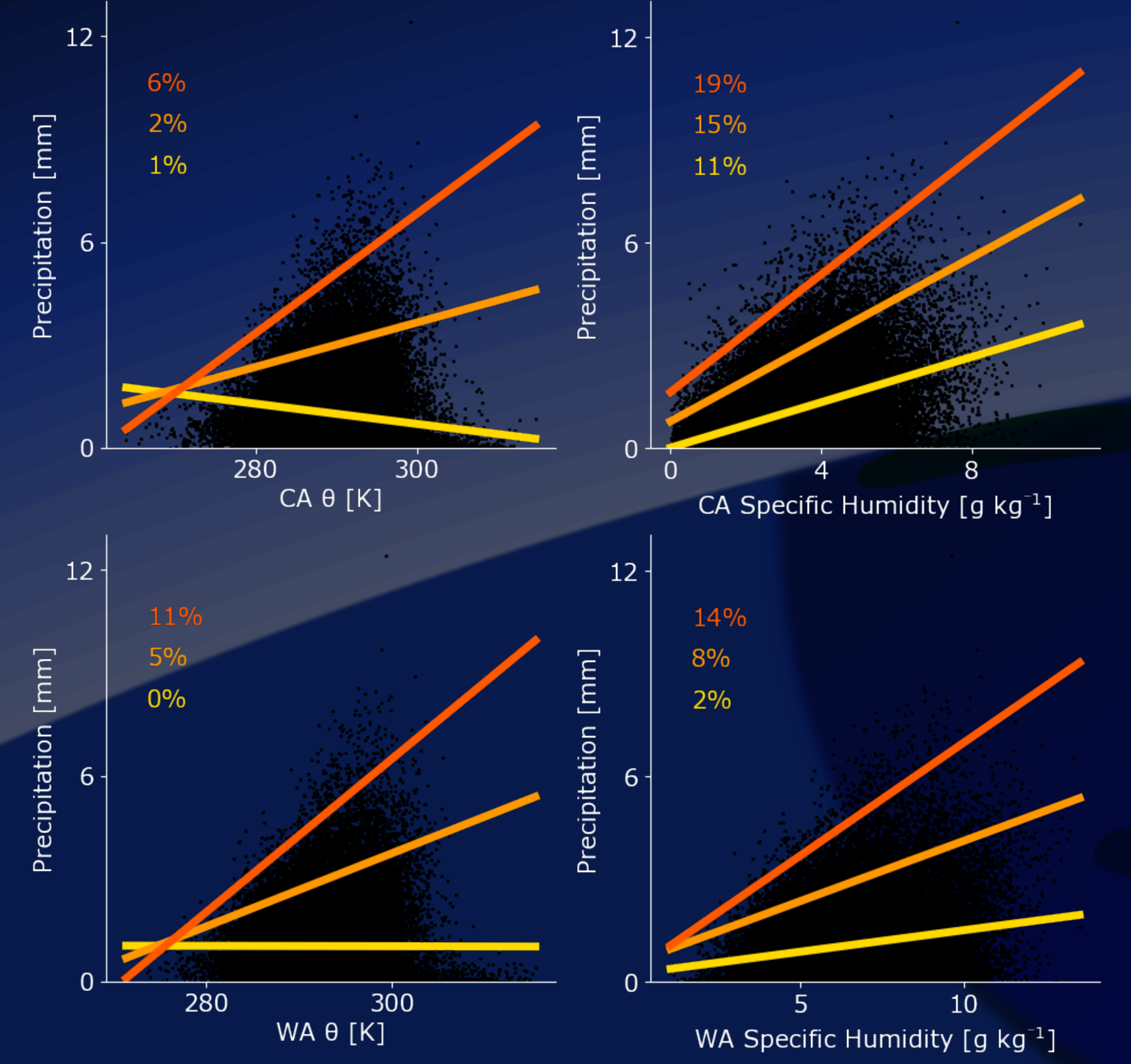
- Quantile regression (QR) models of 99th, 90th and 50th percentile [3]
- Quantile Verification Skill Score (QVSS) as measure of the goodness of fit [4]



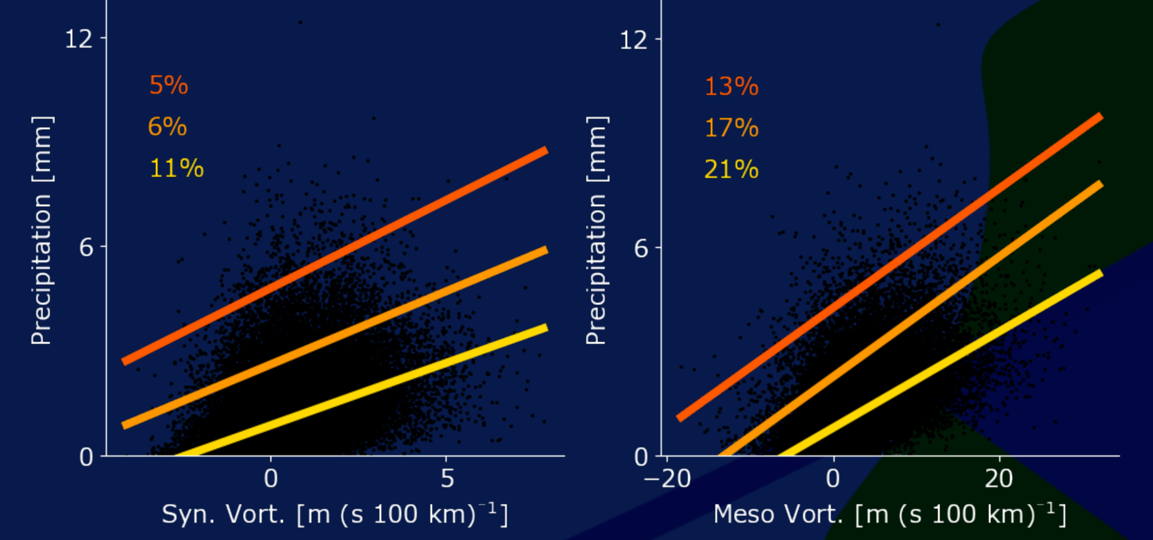
Cold front frequency for (a) DJF, (b) JJA and cold frontal extreme precipitation fraction of all extreme precipitation for (c) DJF, (d) JJA. Extreme precipitation is defined as the 99.9th percentile of all hourly precipitation. Precipitation is classified as frontal if a front is located within a 150 km radius. Black boxes indicate regions where the relation of precipitation and the frontal conditions are evaluated.

Results

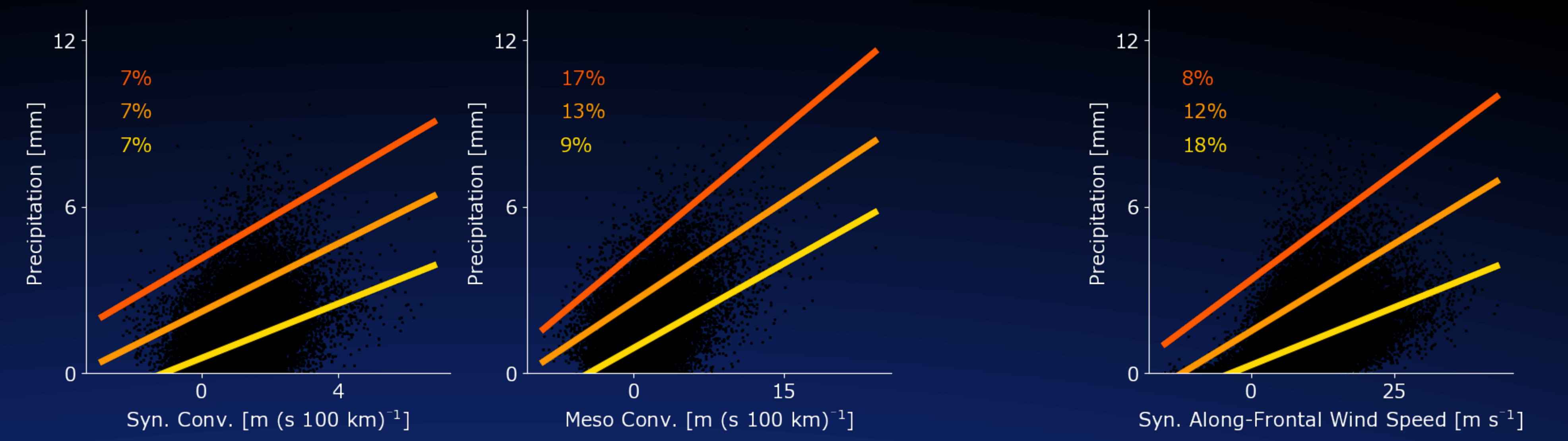
Figures show the relation of precipitation and selected frontal parameters. Each black dot indicates the mean values of the 10 strongest precipitating frontal points of one front. Only fronts with the highest precipitation in a 24 h time window are used, to reduce the dependency of time consecutive detection. The colored lines represent the QR for the 99th, 90th and 50th percentile with the corresponding QVSS values colored accordingly. Higher values indicate a stronger impact of the parameter on the precipitation intensity percentile.



- Temperature in the warm air sector (WA) has a stronger impact than in the cold air sector (CA), caused by Clausius-Clapeyron relation and latent heat release. This further indicates that the temperature gradient has an impact on precipitation.
- Humidity in CA has a stronger impact than in the WA



- Synoptic vorticity: proximity to and intensity of the associated cyclone, and secondary frontogenesis
- Meso-scale vorticity: frontal trough, related to latent heat release and ageostrophic circulation



- Synoptic convergence: Cold & Dry Conveyor Belt flow into the Warm Conveyor Belt
- Meso-scale convergence: ageostrophic frontal circulation related to baroclinicity

- Synoptic along-frontal wind speed quantifies the speed of the Warm Conveyor Belt
- Related to moisture transport towards the front

Main Messages

- Processes impacting cold frontal extreme precipitation are identified and quantified
- More precipitation variance can be explained in DJF/SON than in JJA/MAM
- ERA5 may not resolve all relevant processes
- These results may be the basis for model evaluation, to study the biases and added value of a hierarchy of climate models

References

1. Hersbach H, Bell B, Berrisford P, et al. (2020). The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146 (730), 1999–2049. doi: 10.1002/qj.3803
2. Denis, Bertrand & Côté, Jean & Laprise, René. (2002). Spectral Decomposition of Two-Dimensional Atmospheric Fields on Limited-Area Domains Using the Discrete Cosine Transform (DCT). Monthly Weather Review, 130(7), 1812-1829. doi: 10.1175/1520-0493(2002)130<1812:SDOTDA>2.0.CO;2
3. Koenker, R. (2005). Quantile Regression. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511754098
4. Koenker, R., & Machado, J. A. F. (1999). Goodness of Fit and Related Inference Processes for Quantile Regression. Journal of the American Statistical Association, 94 (448), 1296–1310. Retrieved 2023-07-19, doi: 10.1080/01621459.1999.10473882