



Explaining long-term trend patterns of precipitation over Europe

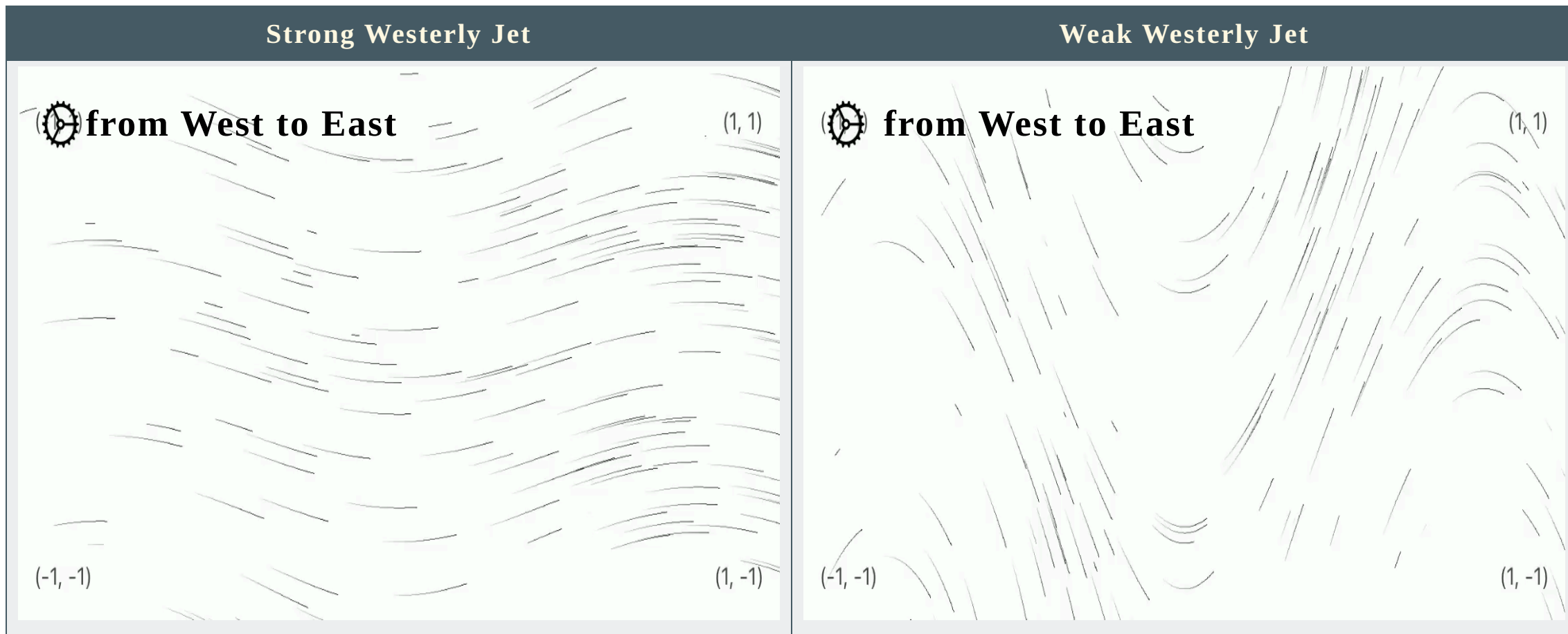
by **Peter Hoffmann**

Hydro-Climatic Risks





Changes in Atmosphere Dynamics at Midlatitudes



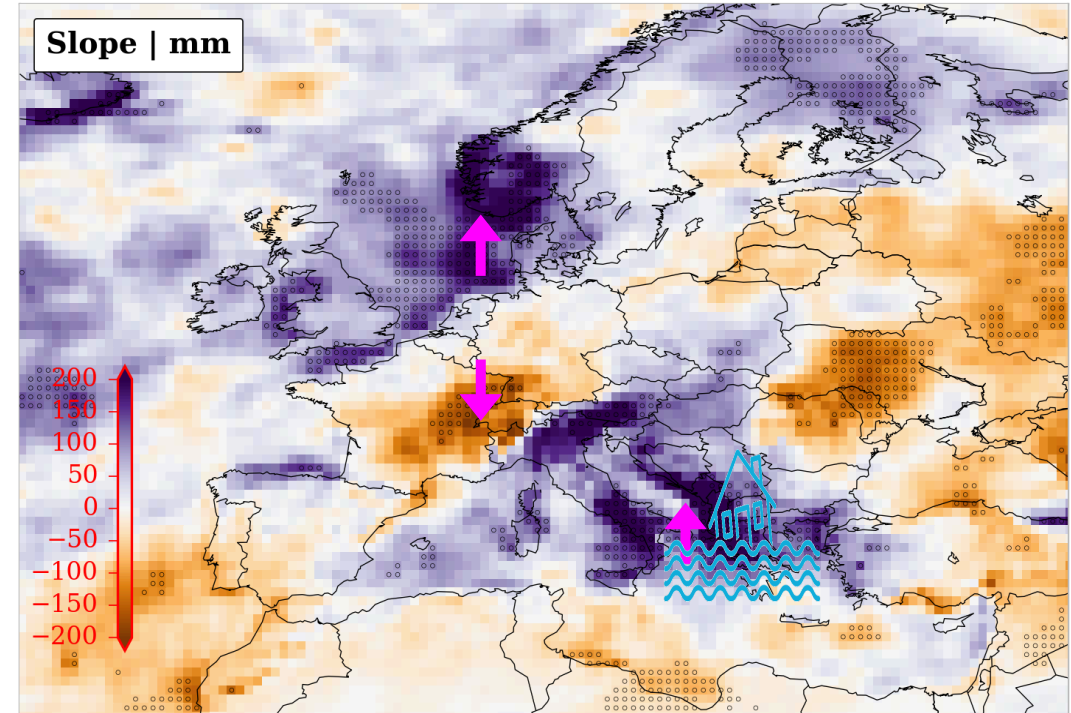
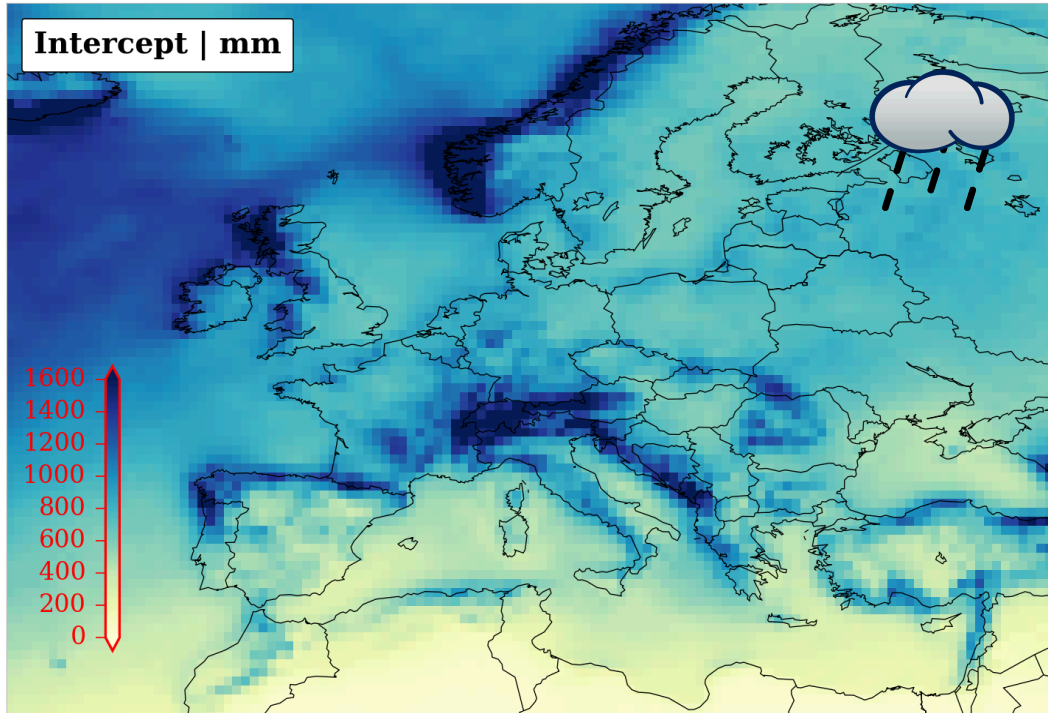
How rainfall patterns are effected beyond the temperature rise?

Arctic Amplifiction leads to a weakening of the Jet Stream



Total Annual Precipitation | PR

ERA5 | Annual Precipitation | 1981-2023 | Long-Term Trends
all: $a=0$ | $b=0$ | $p=1.00$



Decreasing trends over Western Europe and increasing trends over the Mediterranean.



Not all rain is the same

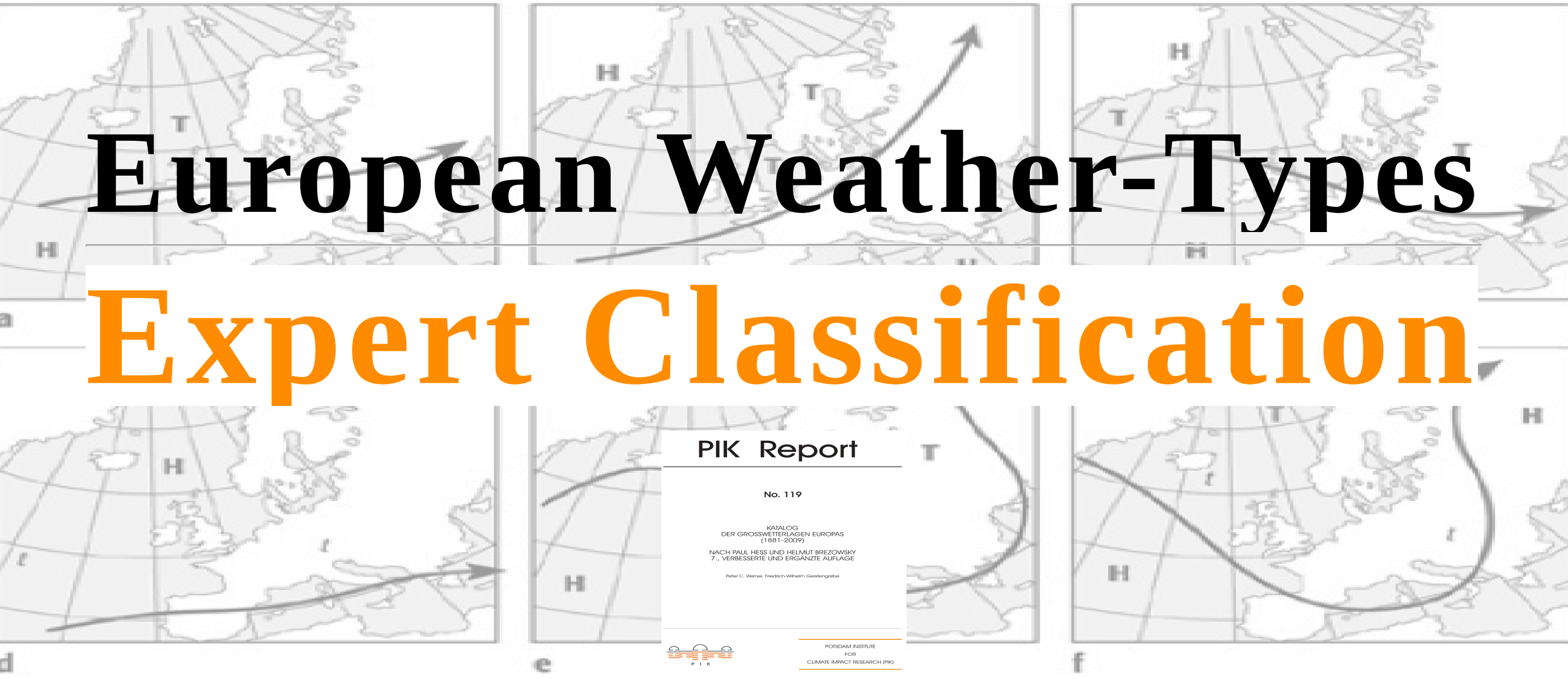
Every local rain event has a large-scale context





European Weather-Types

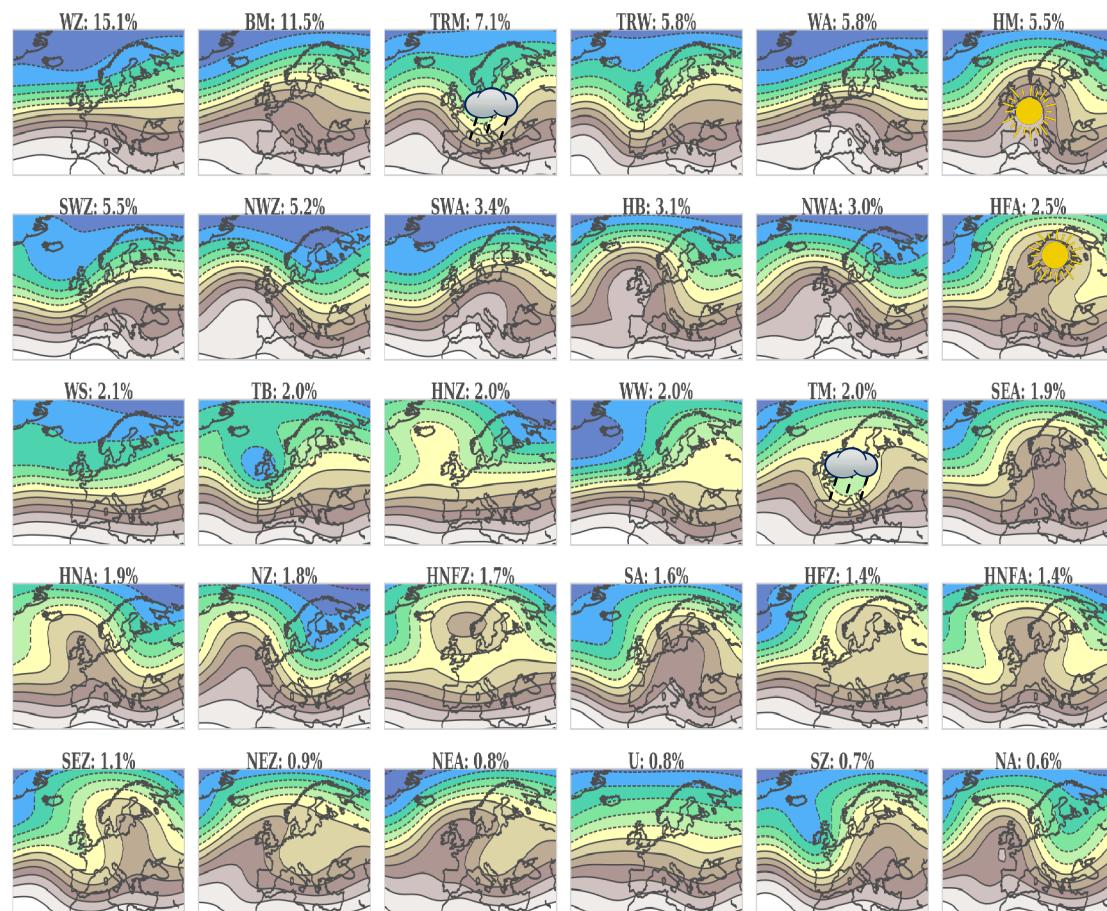
Expert Classification





European Weather-Type Sequences

Simplification of the large-scale Weather Variability by using Categorical Data



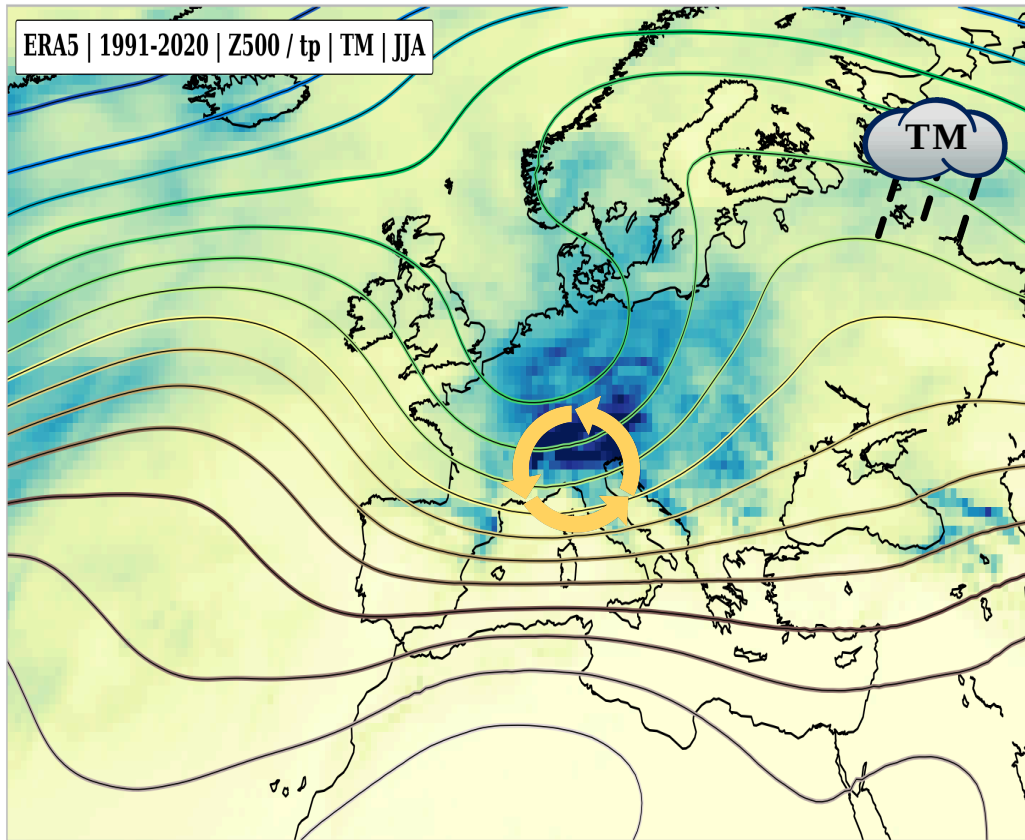
Example: Ahrtal Catastrophe

Year	Month	Day	GWL	CE
2021	7	10	TRW	
2021	7	11	TRW	
2021	7	12	TRW	
2021	7	13	TRM	☔☔☔
2021	7	14	TRM	☔☔☔
2021	7	15	TRM	☔☔☔
2021	7	16	NEZ	
2021	7	17	NEZ	
2021	7	18	NEZ	



Causal Linkage between large-scale Circulation and Rainfall Patterns

Composite Pattern for Low Pressure over Central Europe (TM)



Cause

- large-scale transport of air masses
- patterns are recurring and classifiable

Effect

- local weather phenomena: wet | dry
- location of instabilities (fronts)

Cause-Effect

- linkage: weather-type and weather phenomena



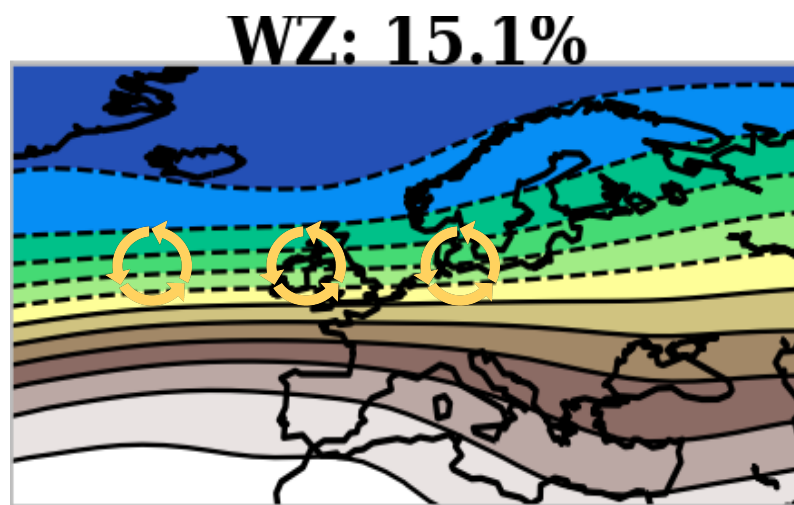
Weather-Type Specific Total Precipitation

Long-Term Trend Pattern



Westerly Cyclonic (W)

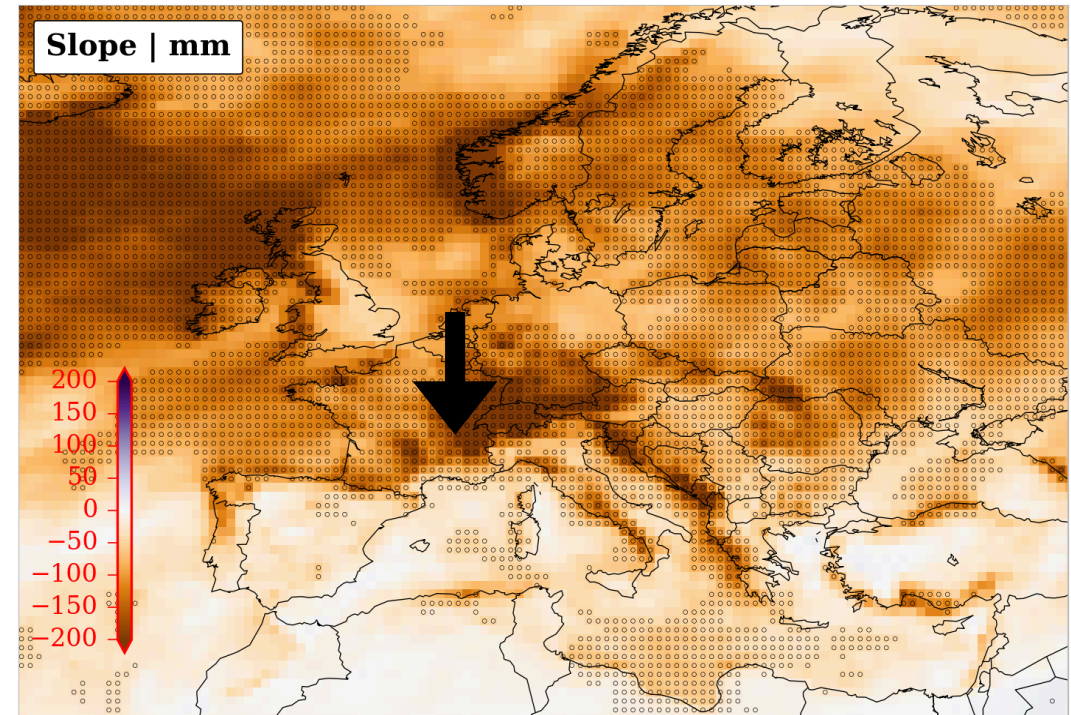
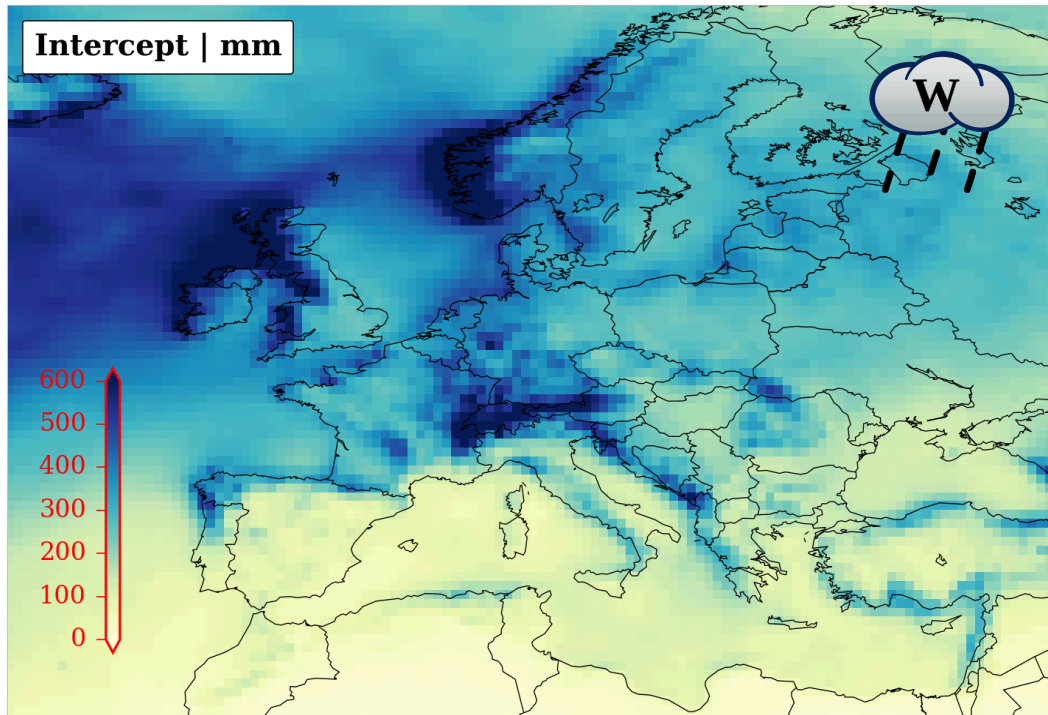
Low-Pressure Systems from the North-Atlantic





Total Annual Precipitation | PR_W

ERA5 | Annual Precipitation | 1981-2023 | Long-Term Trends
W: $a=109$ | $b=-33$ | $p=0.01$



Frequency and Total Precipitation in most parts of Europe is decreasing.



Changes in Weather-Type Frequency

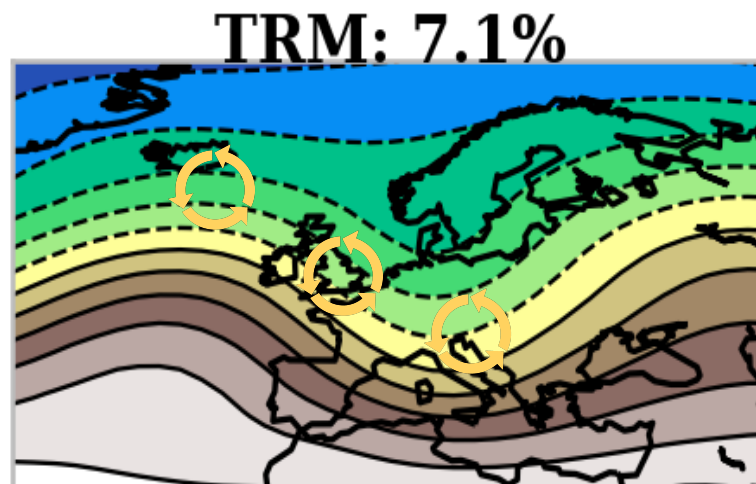
W: (112|-40) BM: (46|-11) SW: (28|+8) NW: (28|+2) TRM: (25|+13) TRW: (16|+8)

New Dominant Weather-Types



Trough over Central Europe (TRM)

Low-Pressure Systems with Moisture Transport from the Mediterranean

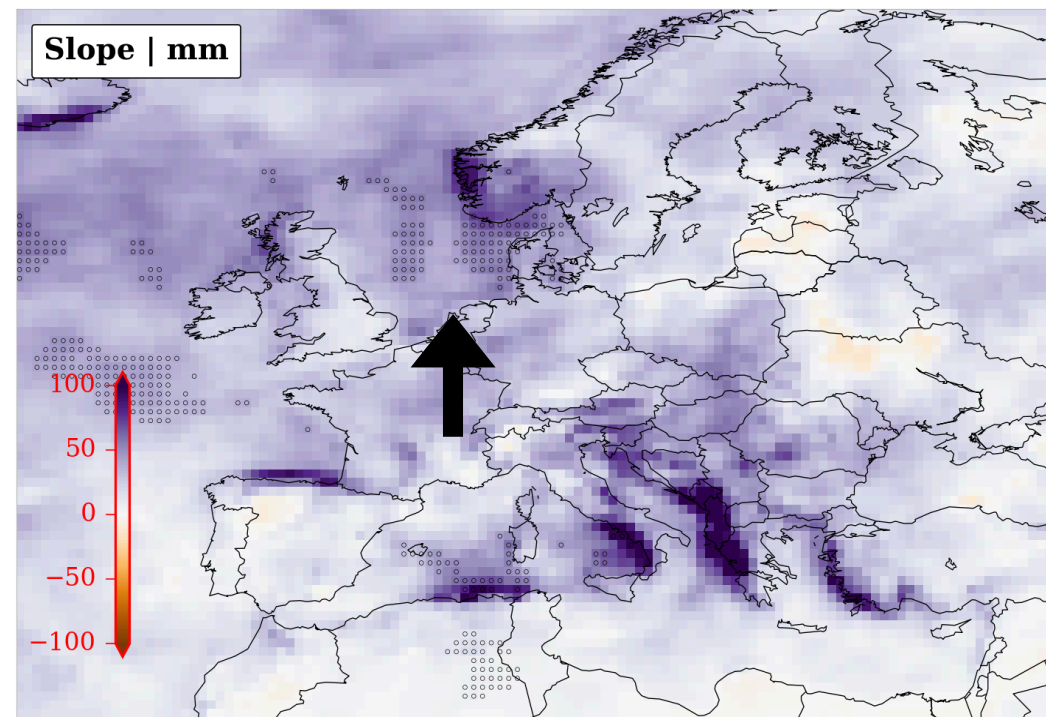
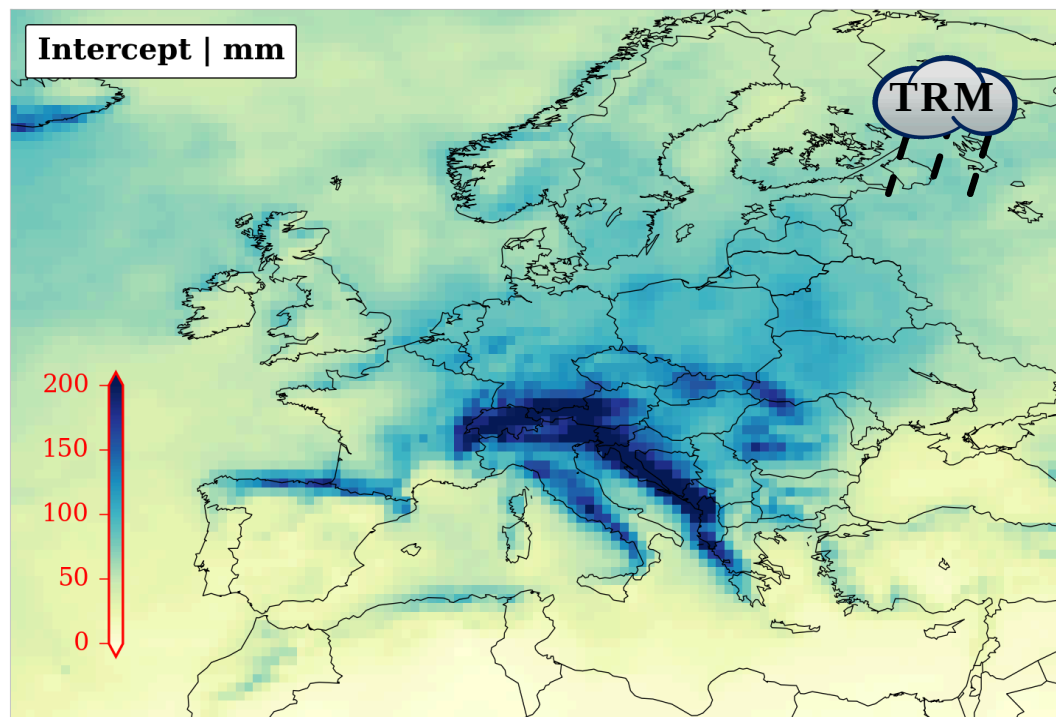




Total Annual Precipitation | PR_{TRM}

ERA5 | Annual Precipitation | 1981-2023 | Long-Term Trends

TRM: $a=27$ | $b=9$ | $p=0.28$



Frequency and Total Precipitation increasing especially over the Mediterranean.



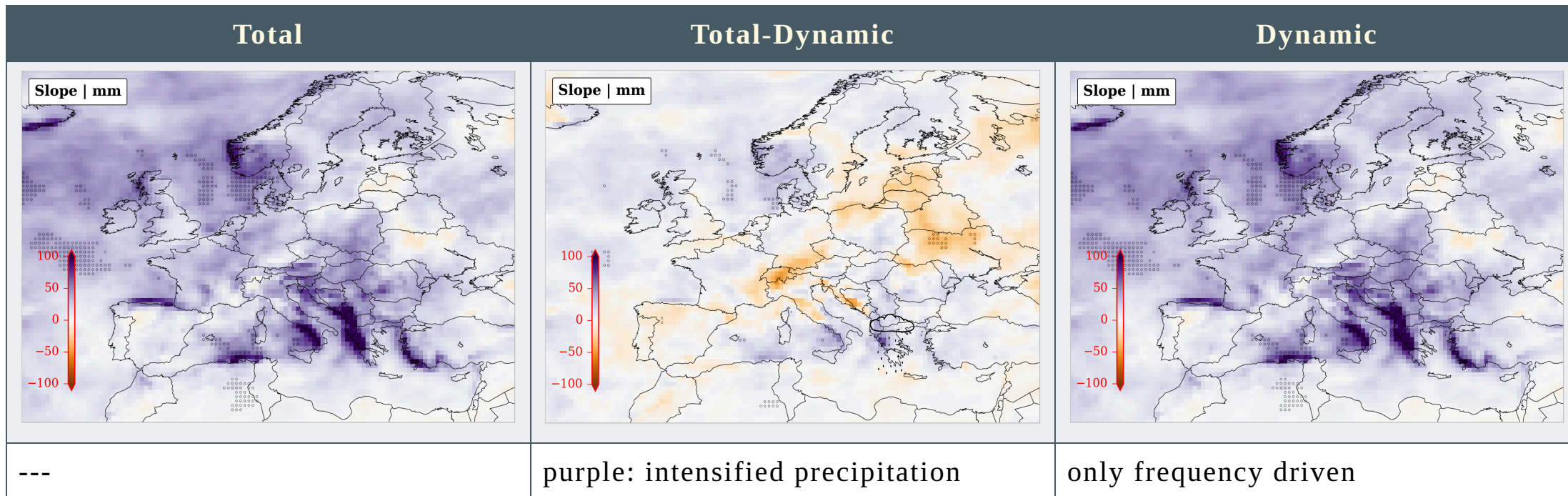
Is this only explained by the Frequency Change?

Extraction of the Dynamic Factor



Total Annual Precipitation | Total vs Dynamic | PR_{TRM}

Long-Term Trends



Dynamic Factor?

observed daily precipitation is replaced by long-term monthly means per weather-type (here TRM)



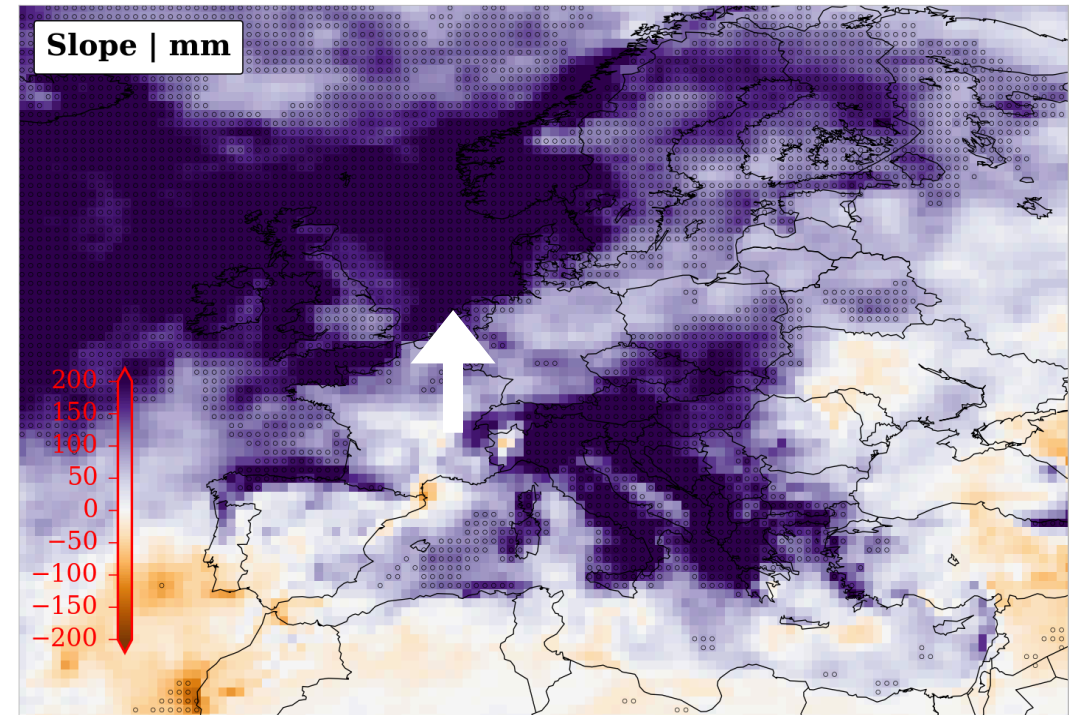
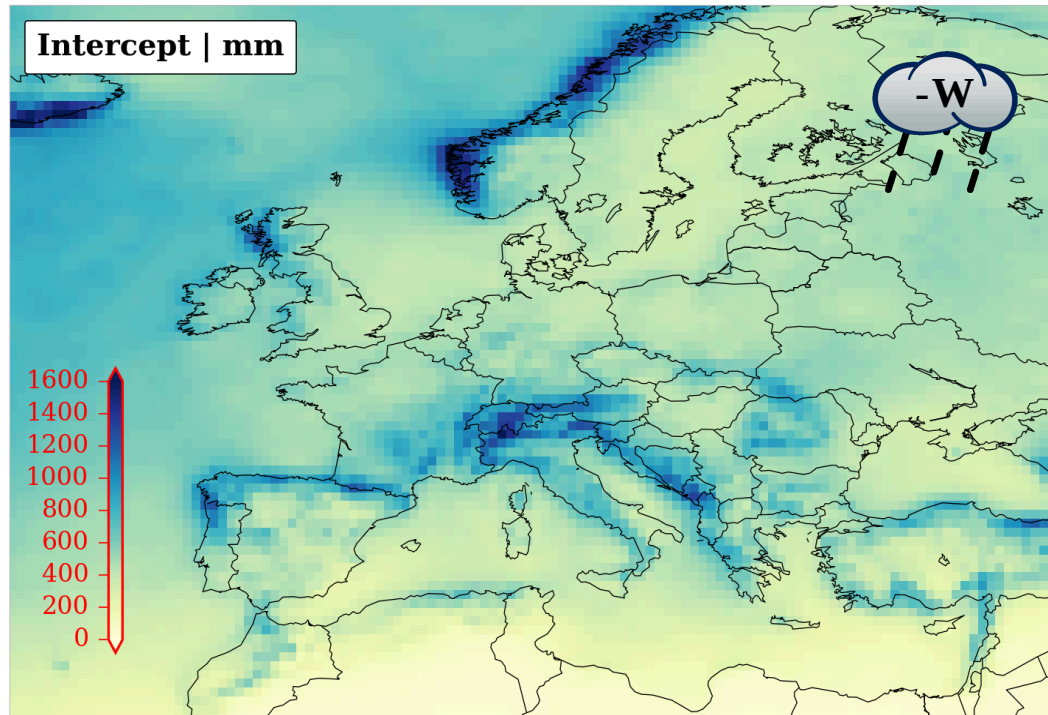
Does the changing Weather-Types explain the Trend Patterns?

Lets remove the most dominate Weather-Type W



Total Annual Precipitation | PR_w

ERA5 | Annual Precipitation | 1981-2023 | Long-Term Trends
all: a=0 | b=0 | p=1.00



Trend Pattern of Total Precipitation without the most dominant Weather-Type show inceased trends.



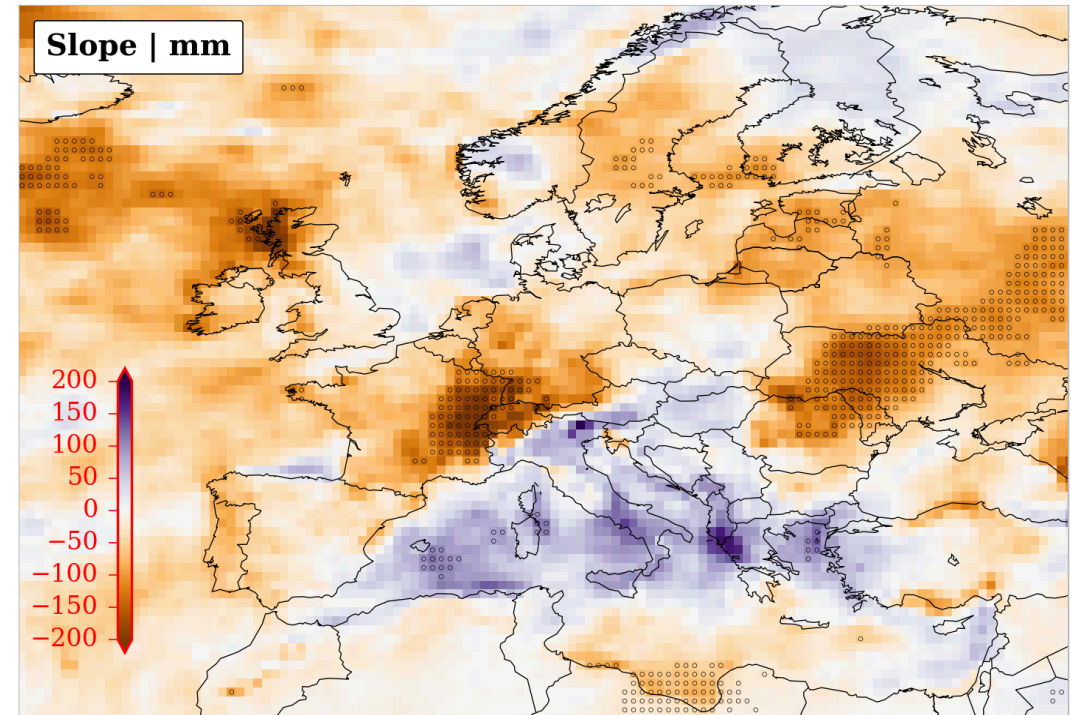
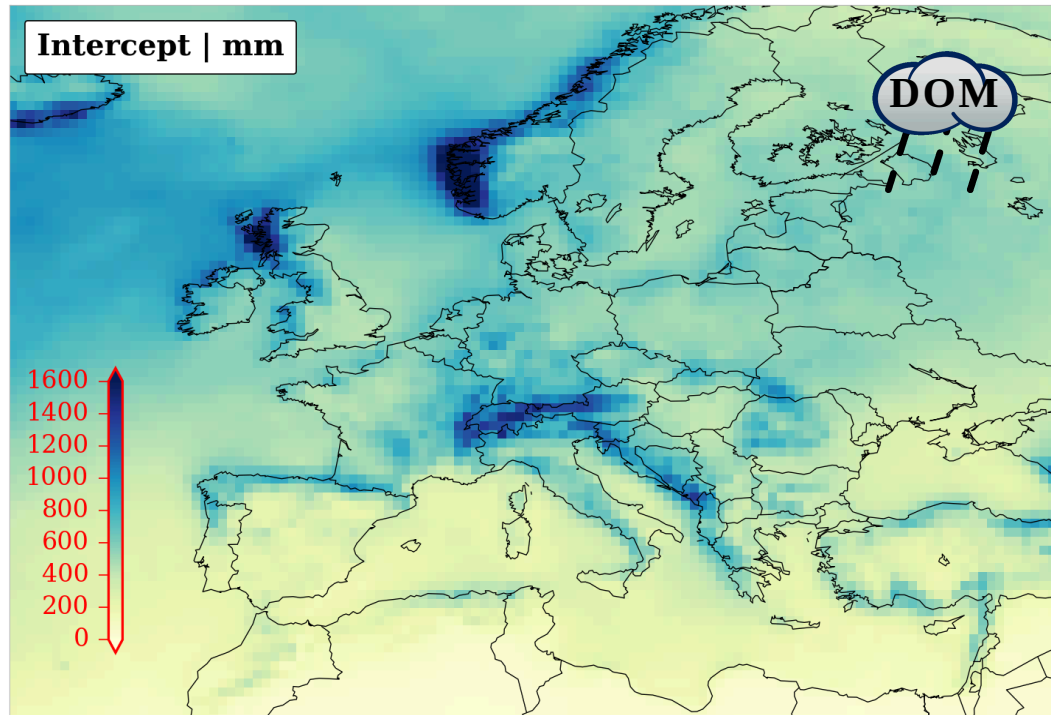
Reconstructing Total Precipitation Patterns

only using the dominant Weather-Types: W | TRM | TRW | NW | NE | BM



Total Annual Precipitation | PR_{DOM}

ERA5 | Annual Precipitation | 1981-2023 | Long-Term Trends
all: $a=0$ | $b=0$ | $p=1.00$



Only a few dominant Weather-Types explain most of the trend features in total precipitation.



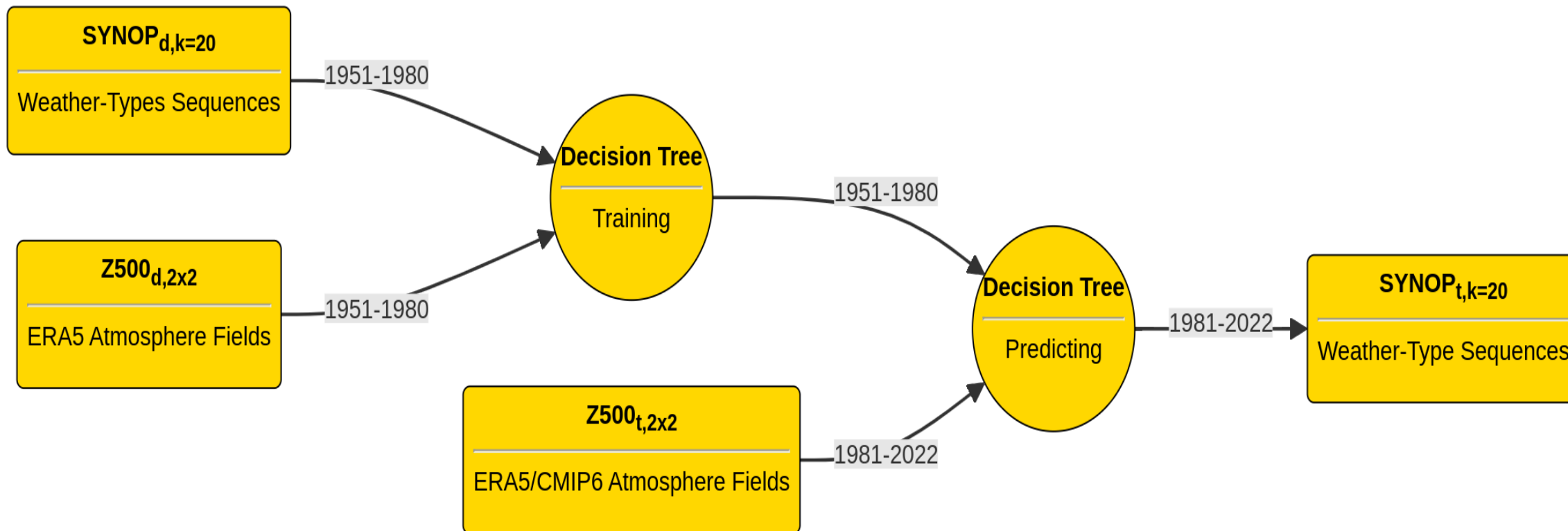
A very high demand on Climate Models

What can we expect from climate scenarios?



Re-Identification of Weather-Types in Climate Models

from Atmosphere Fields to Categorical Data of Synoptic Patterns

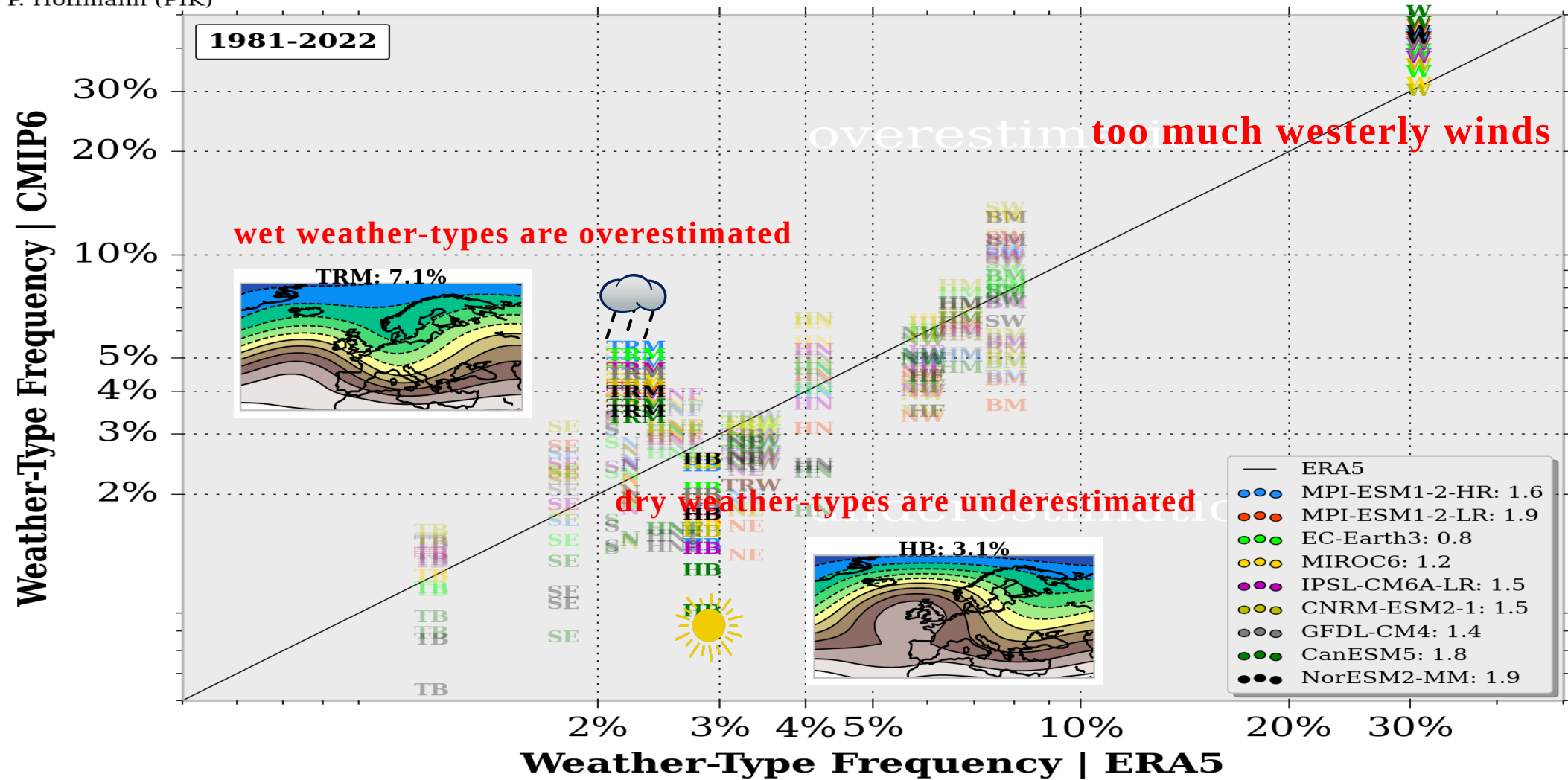


objective classification of existing Weather-Types using Z500 atmospheric fields over Europe from ERA5 and CMIP6.



European Weather-Type Frequency in Climate Scenarios

© P. Hoffmann (PIK)



EC-Earth3: the best performing model



Final Remarks

- Dynamic Changes explain Trend Features in Total Precipitation over Europe (new dominant meridional weather-types)
- Decreasing Trends of Total Precipitation from the North-Atlantic with a westerly wind context
- The lower the influence from the North-Atlantic the more extreme the resulting Precipitation Patterns
- Climate Models overestimate the westerly wind context, underestimate dry and overestimate wet Weather-Types
- A few signs of dynamic changes in Climate Model Scenarios
- **Recommendation:**
 - not all biases can be adjusted (dynamical bias)
 - because the simulated weather variability follows slightly other rules
 - bias adjustments should only consider the respective large-scale context