Explaining long-term trend patterns of precipitation over Europe

by Peter Hoffmann

Hydro-Climatic Risks

Changes in Atmosphere Dynamics at Midlatitudes

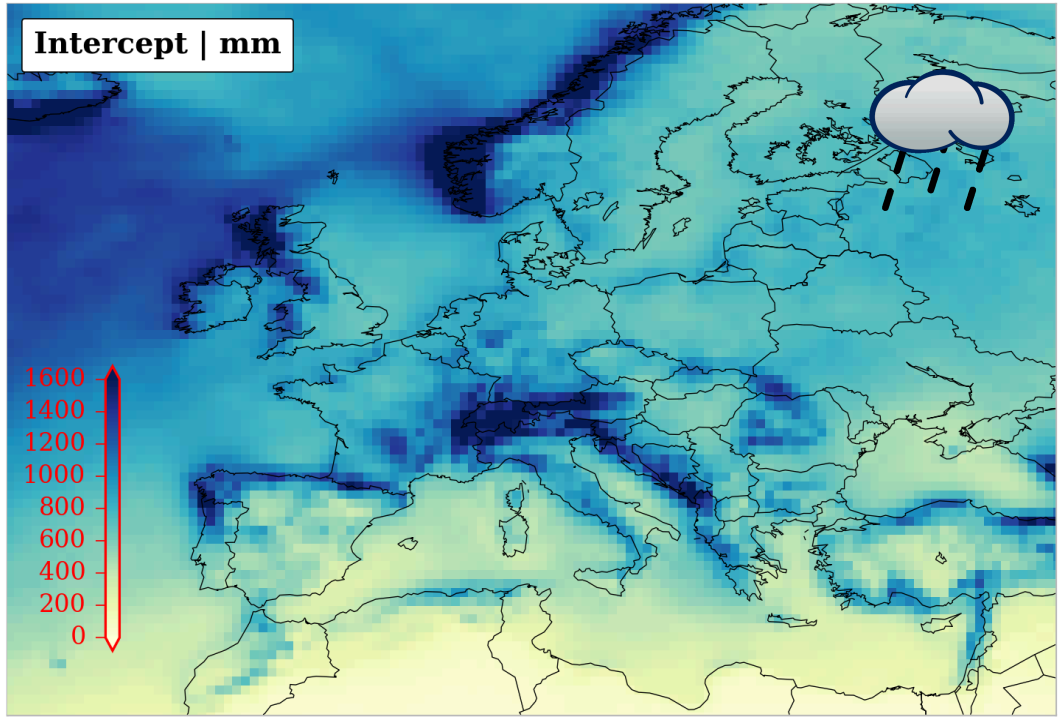
Strong Westerly Jet	Weak Westerly Jet
	

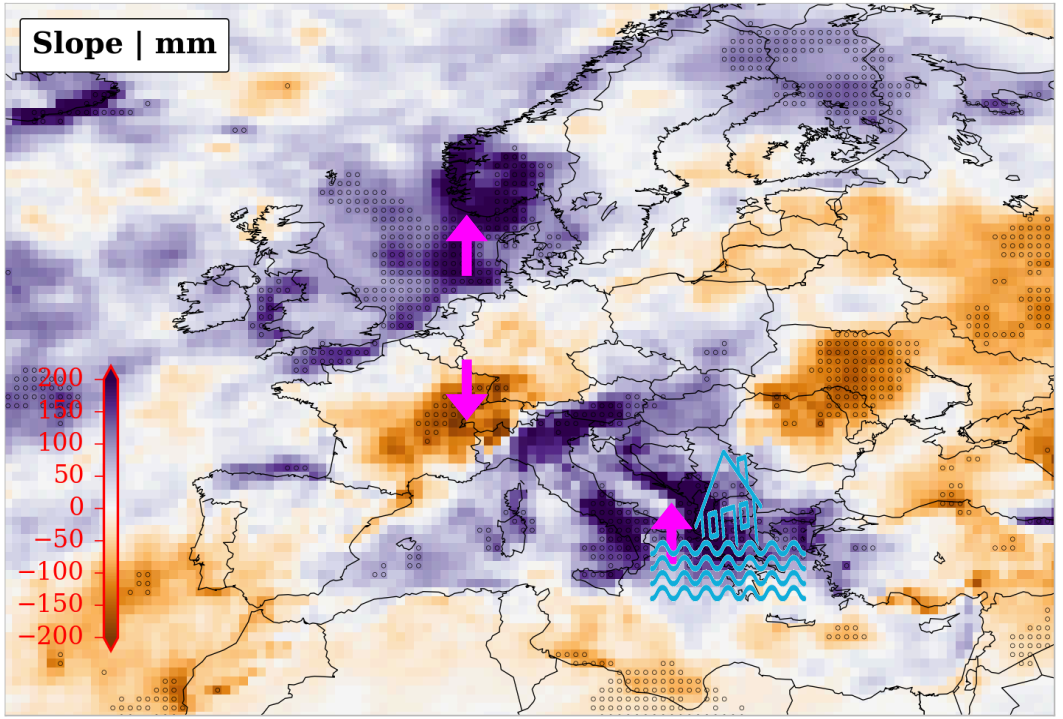
How rainfall patterns are effected by dynamic changes beyond the temperature rise?

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





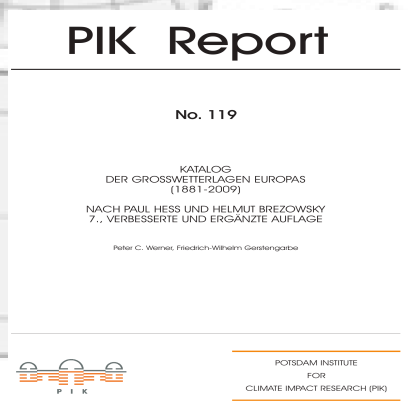
Decreasing trends over Western Europe and inceasing trends over the Mediterranean.

Not all rain is the same

Every local rain event has a large-scale context

European Weather-Types

Expert Classification


PIK Report

No. 119

KATALOG
DER GROSSWETTERLAGEN EUROPAS
(1881-2009)

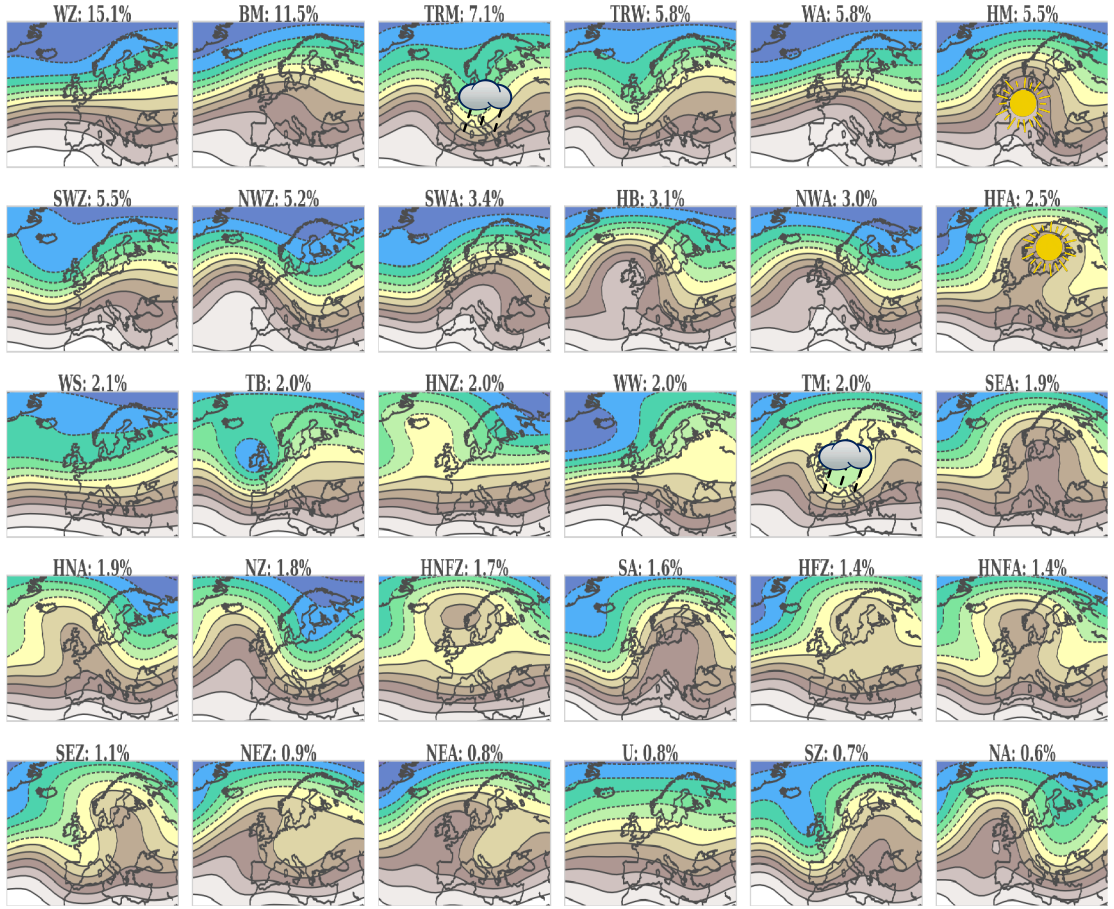
NACH PAUL HESS UND HELMUT BREZOWSKY
7., VERBESSERTE UND ERGÄNZTE AUFLAGE

Peter C. Werner, Friedrich-Wilhelm Gerstengarbe

POTSDAM INSTITUTE
FOR
CLIMATE IMPACT RESEARCH (PIK)

European Weather-Type Sequences

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



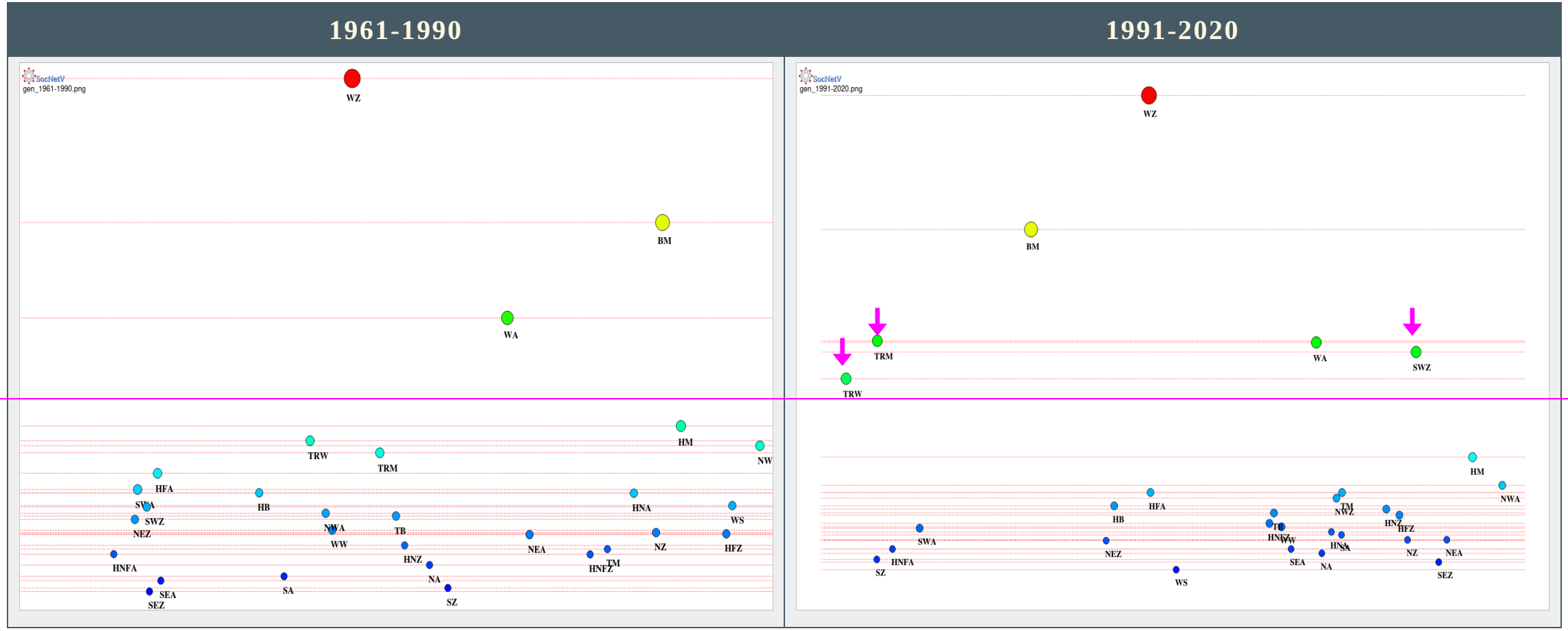
Example: Ahrtal Catastrophe

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	

every day is allocated to one of these 30 synoptic patterns

Changes in European Weather-Type Sequences

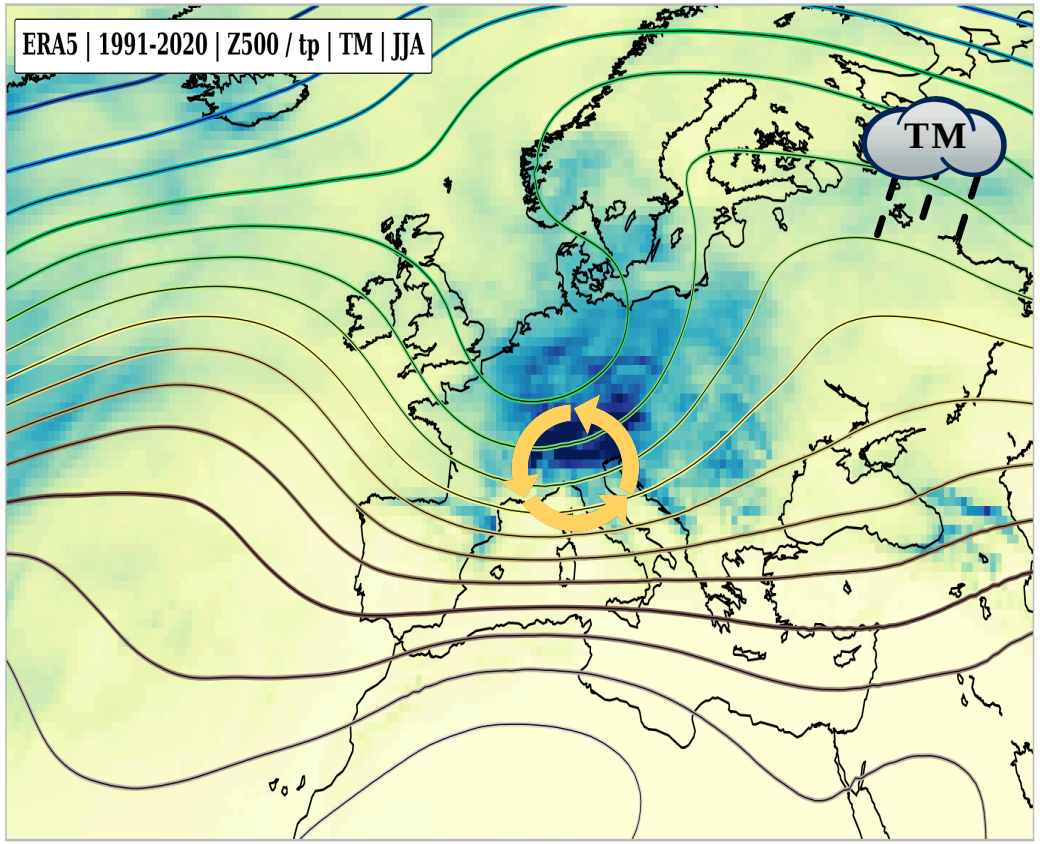
New dominant Weather-Types explain the present weather variability



TRM, TRW, SWZ are often associated with extreme weather events

Causal Linkage between large-scale Circulation and Rainfall Patterns

Composite Pattern for Low Pressure System 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

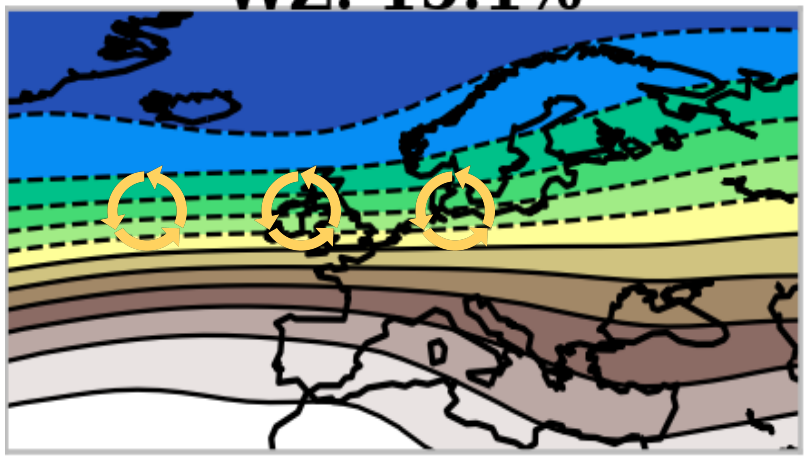
Weather-Type Specific Total Precipitation

Long-Term Trend Pattern

Westerly Cyclonic (W)

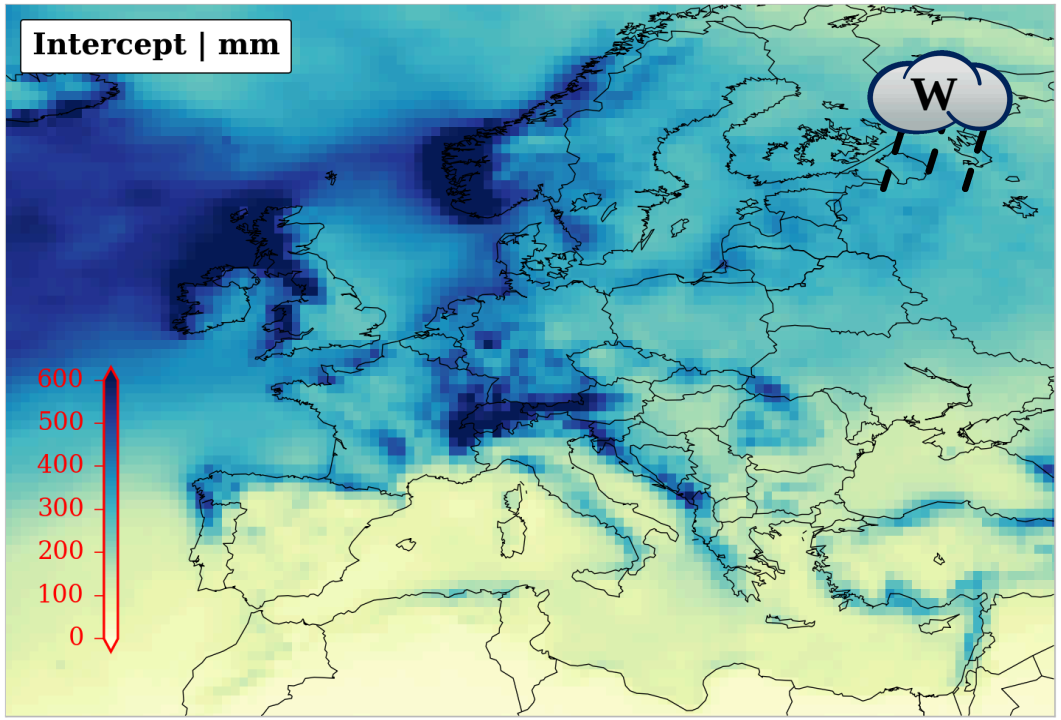
Low-Pressure Systems from the North-Atlantic

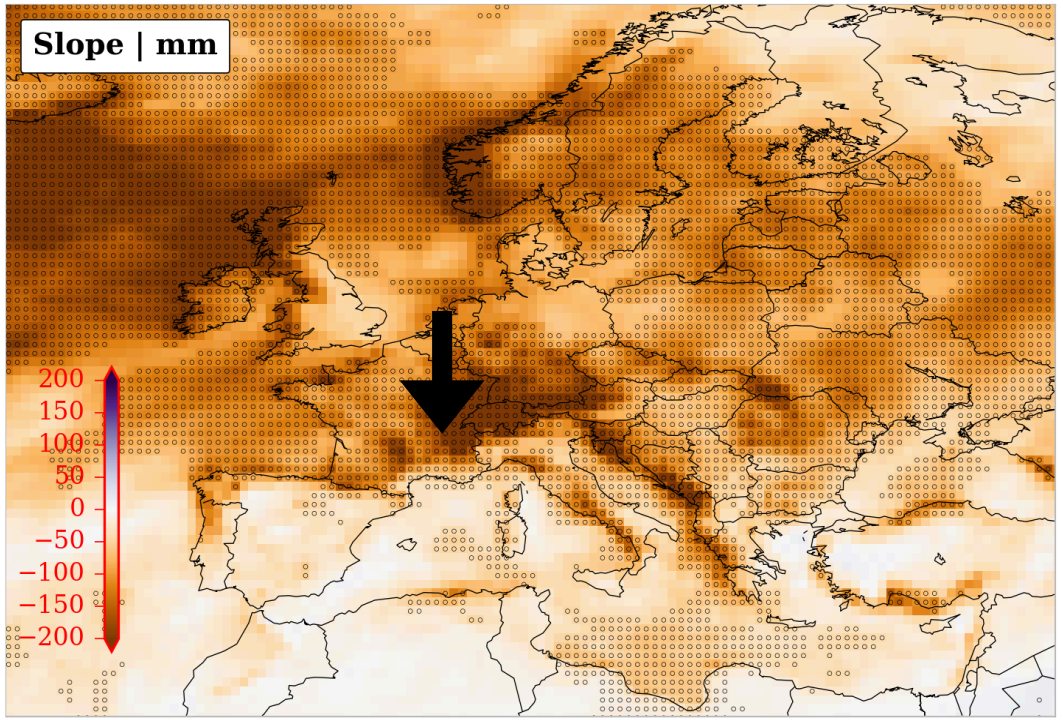
WZ: 15.1%



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

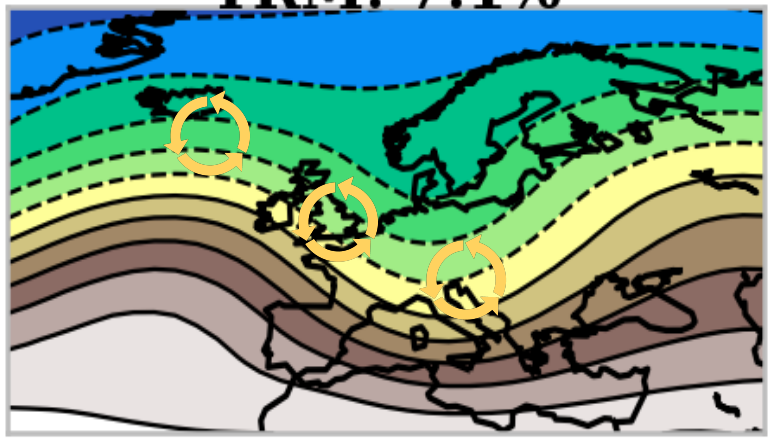
W: (112|-40) BM: (46|-11) SW: (28|+8) NW: (28|+2) TRM: (25|+13) TRW: (16|+8)

New Dominant Weather-Types

Trough over Central Europe (TRM)

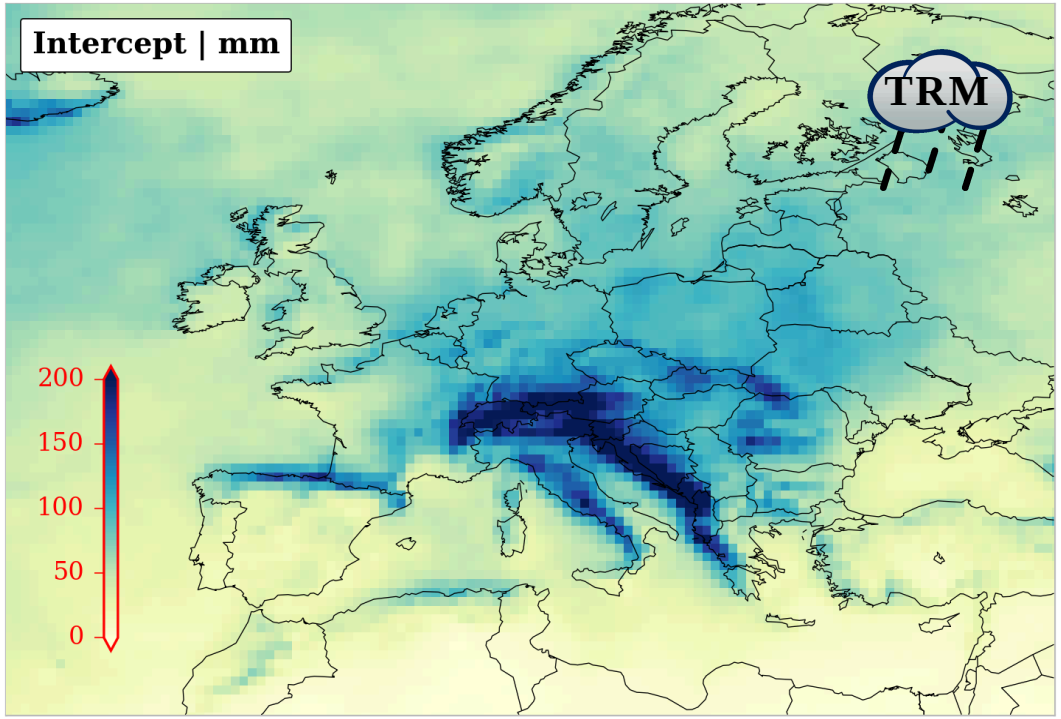
Low-Pressure Systems with Moisture Transport from the Mediterranean

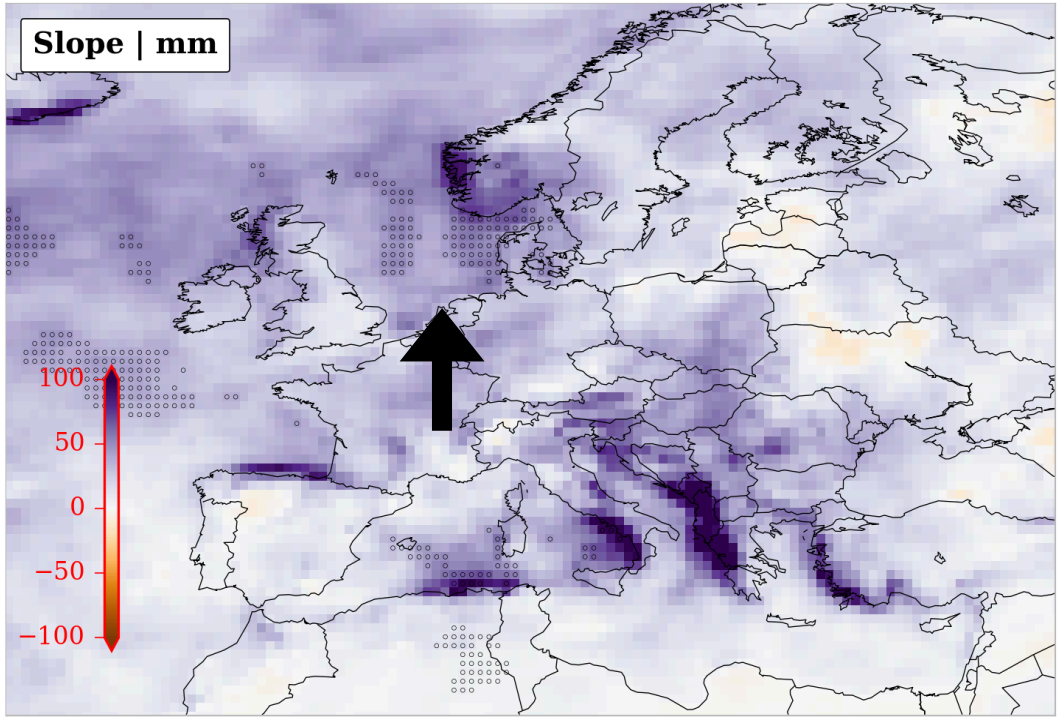
TRM: 7.1%



Total Annual Precipitation | PR_{TRM}

ERA5 | Annual Precipitation | 1981-2023 | Long-Term Trends
TRM: a=27 | b=9 | p=0.28





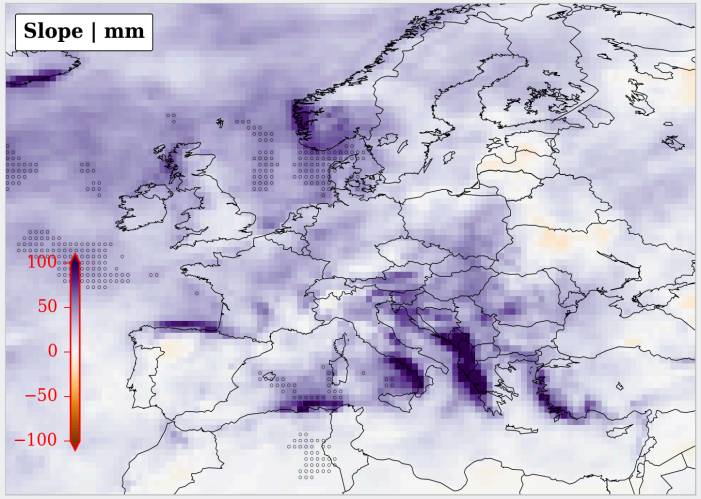
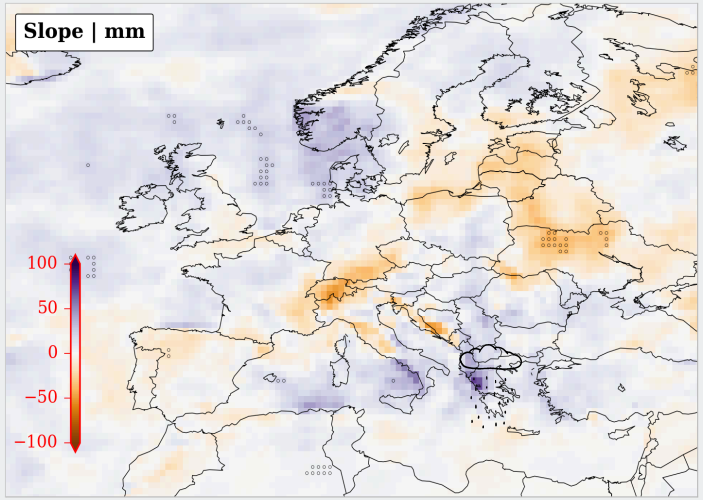
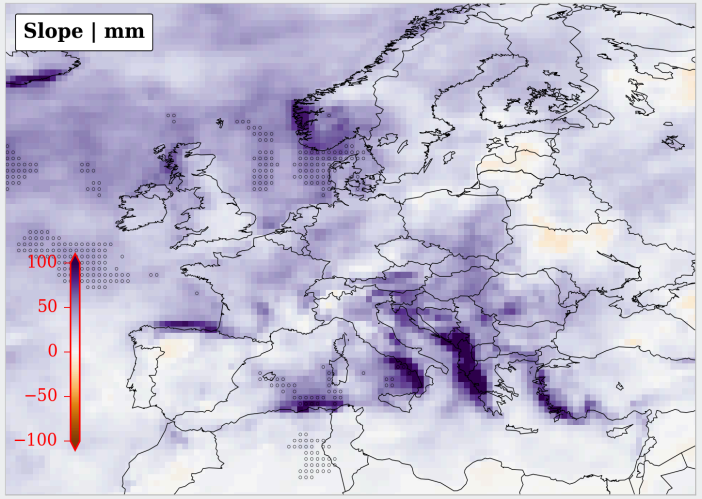
Frequency and Total Precipitation increasing especially over the Mediterranean.

Is this only explained by the Frequency Change?

Extraction of the Dynamic Factor

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

Long-Term Trends

Total	Total-Dynamic	Dynamic
		
---	purple: intensified precipitation	only frequency driven

Dynamic Factor?

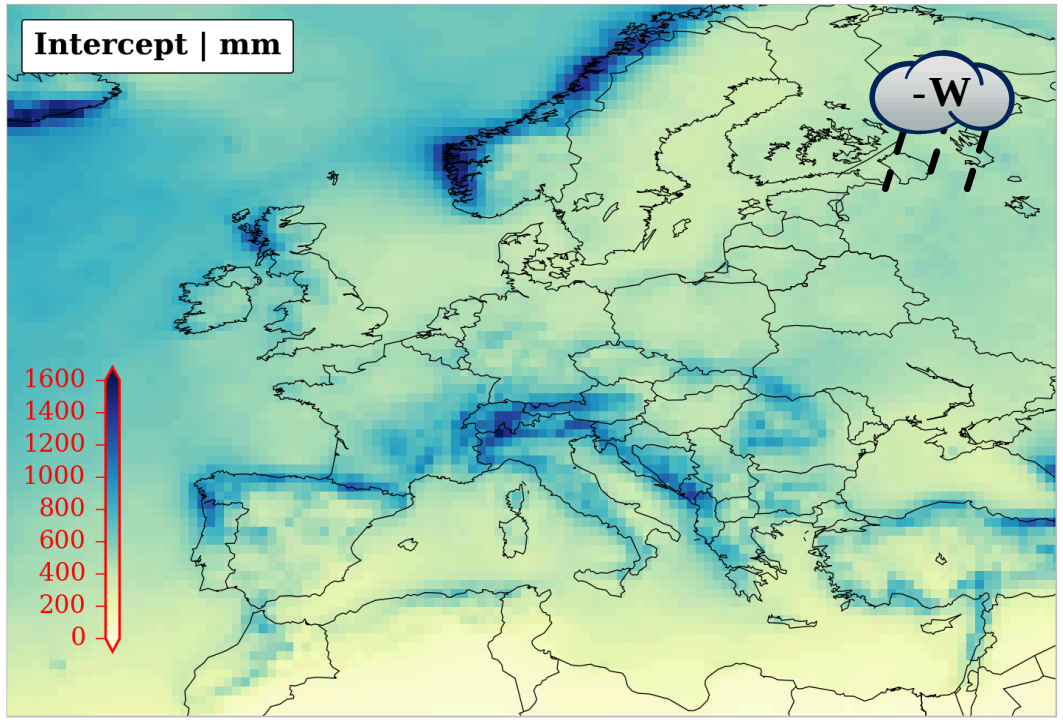
observed daily precipitation is replaced by long-term monthly means per weather-type (here TRM)

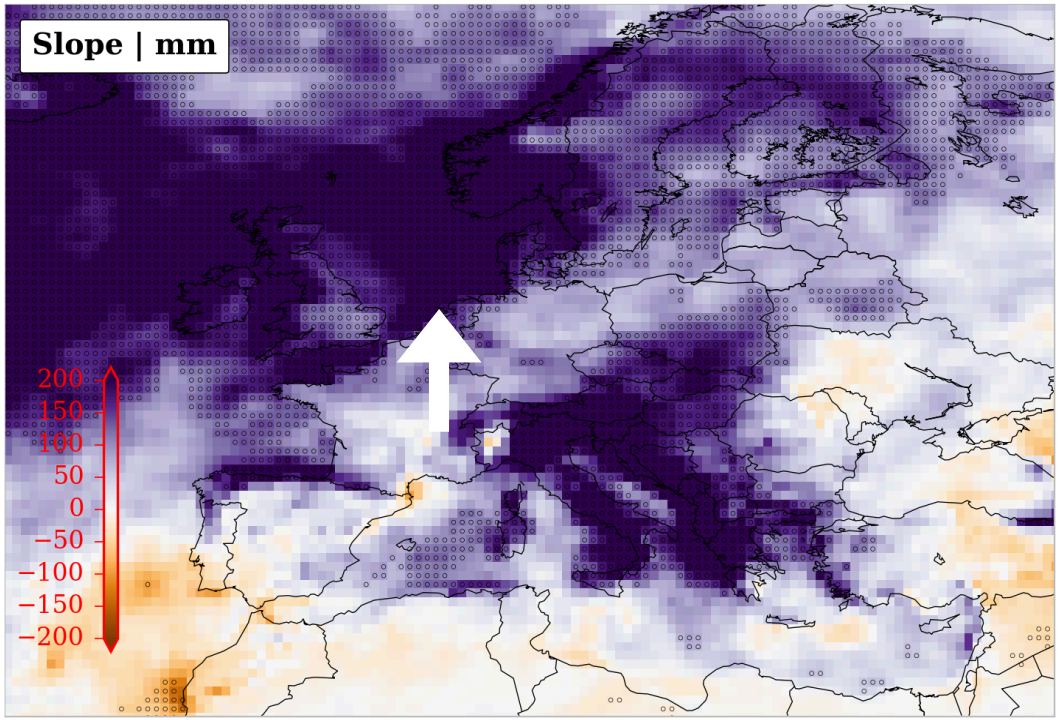
Does the changing Weather-Types explain the Trend Patterns?

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





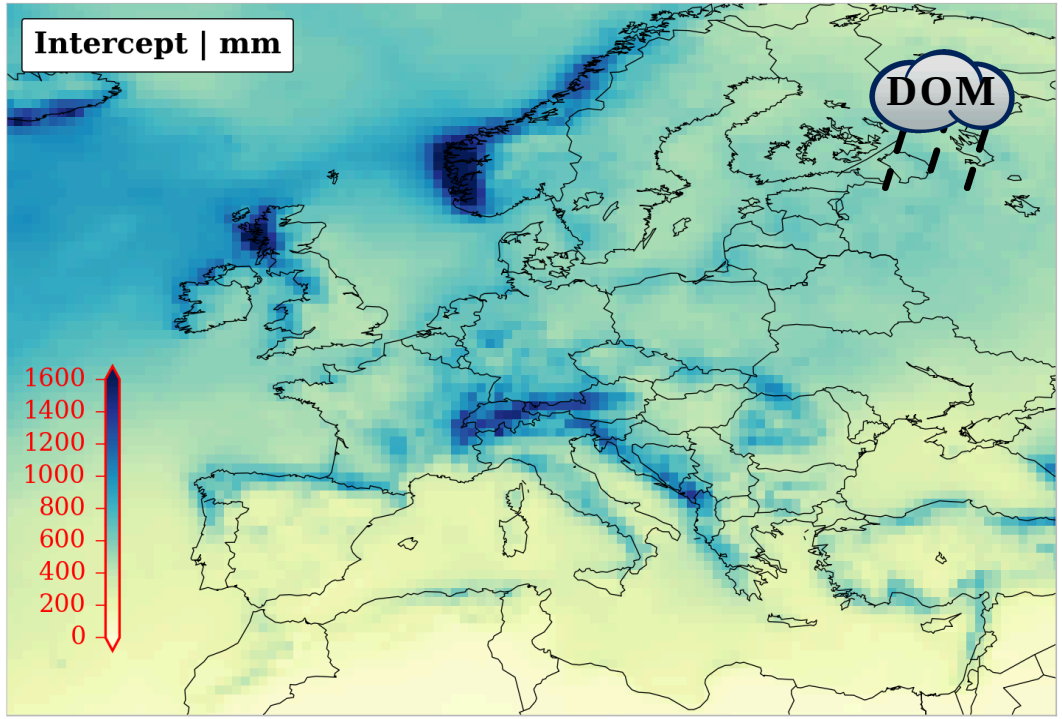
Trend Pattern of Total Precipitation without the most dominant Weather-Type show inceasing trends.

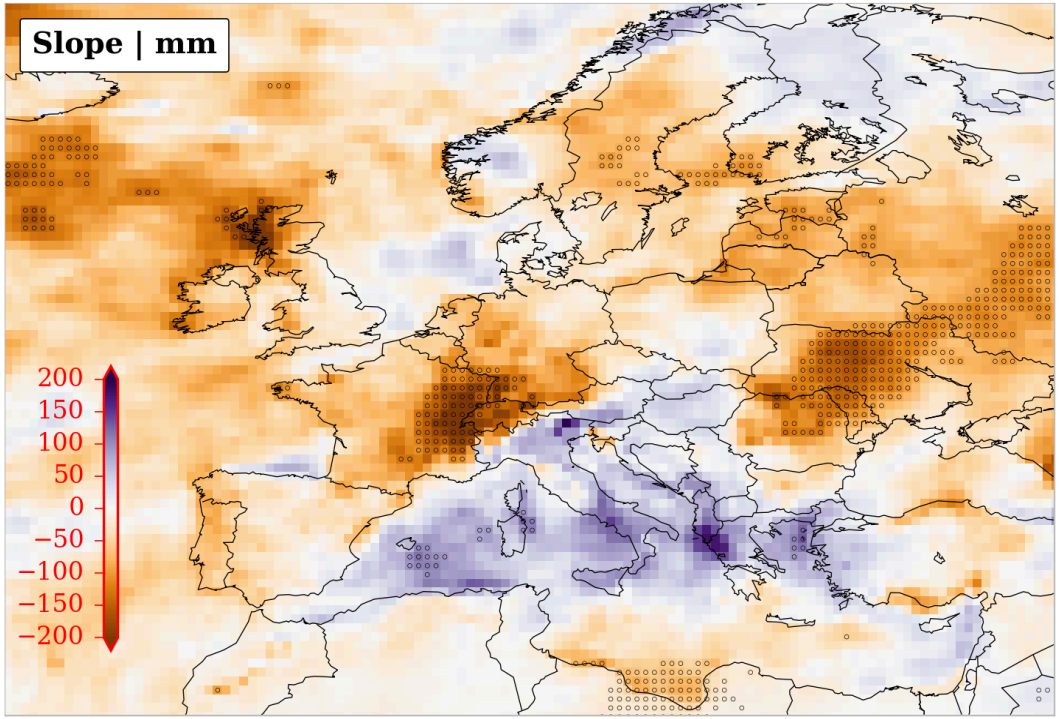
Recontructing Total Precipitation Patterns

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





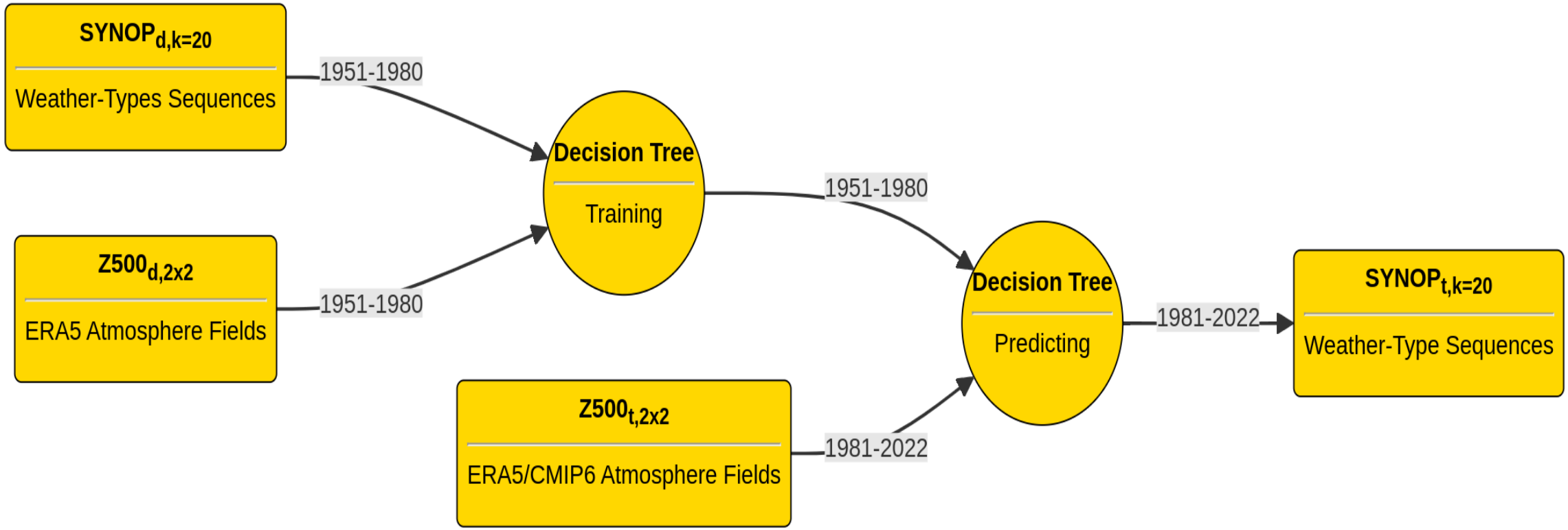
Only a few dominant Weather-Types explain most of the trend features in total precipitation.

A very high demand on Climate Models

What can we expect from climate scenarios?

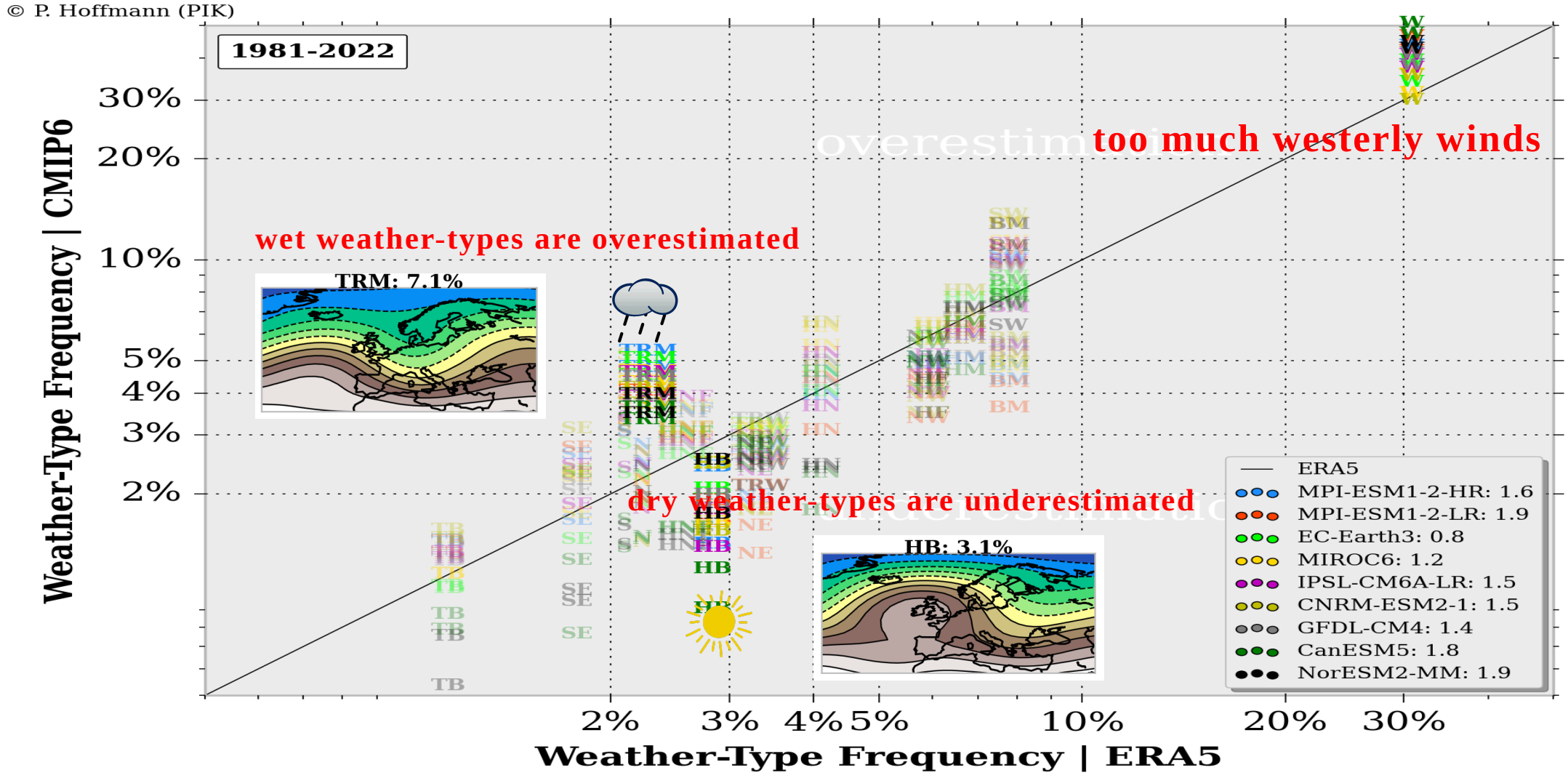
Re-Identification of Weather-Types in Climate Models

from Atmosphere Fields to Synoptic Patterns by training a Decision Tree



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

European Weather-Type Frequency in Climate Scenarios



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
- **Recommedation:**
  - 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

Comparison of observed and simulated Trends

Annual Precipitation: 1981-2023

ERA5	Euro-Cordex