TU WIEN TECHNISCHE UNIVERSITÄT WIEN

bfg Bundesanstalt für Gewässerkunde

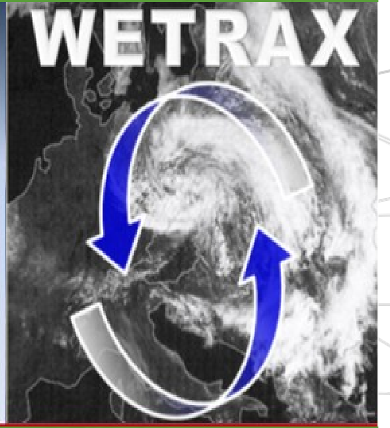
Bayerisches Staatsministerium für Umwelt und Verbraucherschutz

Bundesministerium Nachhaltigkeit und Tourismus

ZAMG

LEBENSMINISTERIUM BAYERN.DE

WETRAX+



Future changes in weather patterns and implications for low flow

Selina Thanheiser, Markus Homann, Christoph Beck, Andreas Philipp, Jucundus Jacobeit

Institute of Geography, University of Augsburg, Germany

UNI A

Agenda

1. **Background**
2. **Data and Methods** for determining weather patterns/circulation types
3. **Drought relevant Circulation Types** for the winter and the summer half year
4. **Implications for Low Flow** in the Isar river
5. **Future Changes** in frequencies, persistence and within-type characteristics of circulation types
6. **Summary and Conclusions**

1 Background

WETRAX^{+} Project - Weather Patterns, Cyclone Tracks and related precipitation Extremes

Effects of climate change on extreme areal precipitation and drought periods in southern central Europe

Main contributions of University of Augsburg:

- determination of circulation types that are important for extremes
- estimation of future changes in frequencies and characteristics of relevant types

2 Data for determining weather patterns/circulation types

Observational-, reanalysis- and climate model data

Data	Variable	Time period	Resolution	Name
Observational data	Gridded Precipitation data [mm] „Target variable“	1961-2015	24 hours / 6x6km	Central Institute for Meteorology & Geodynamics Austria
Reanalysis data	Mean sea level pressure [hPa], Relative humidity [%]*, U-component of wind [m/s]*, V-component of wind [m/s]*, Vertical velocity [hPa/h]* Geopotential [gpm]** Temperature [K]*** Determination of circulation types	1958-2017	6 hours / 1.25°	JRA55 – Japanese 55-year Reanalysis (Japan Meteorological Agency)
Regional climate model data	Mean sea level pressure [hPa], Temperature [K]*** Precipitation [mm] Projection of circulation types	1971-2100	24 hours / 0.11°	EURO-CORDEX (Coordinated Downscaling Experiment – European Domain)

* 700 hPa Niveau ** 500 hPa Niveau *** 2 m

2 Methods for determining weather patterns/circulation types

Regionalisation of gridded precipitation data

In a first step, regions with similar precipitation variability between 1961-2017 on a yearly scale were determined by using an s-mode principal component analysis.

The result are six regions of similar precipitation variability. The precipitation data enters the classification as a target variable in the form of **six time series, one for each region of similar precipitation variability**.

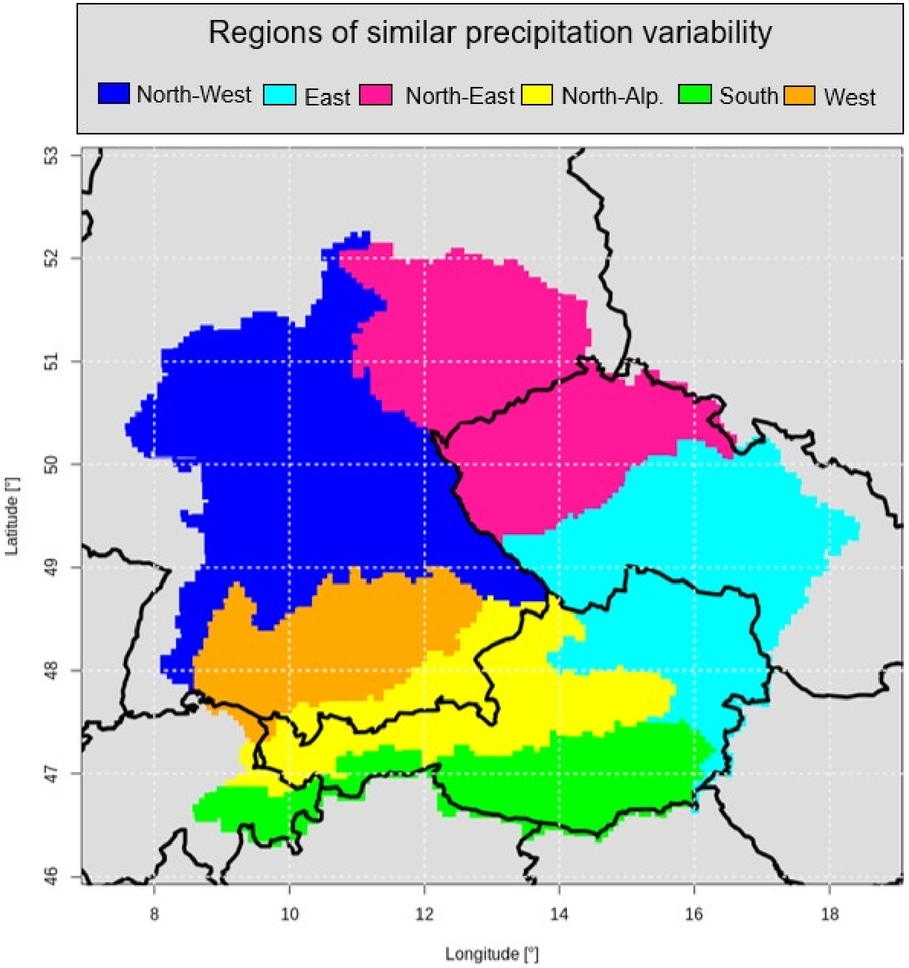


Figure 1: Regions of similar precipitation variability in the study area resulting from s-modal principal component analysis on a monthly basis with gridded WETRAX+ precipitation dataset (1961-2017).

2 Methods for determining weather patterns/circulation types

Weather/circulation typing

Software

Cost733class is a FORTRAN software package for developing and evaluating weather and circulation type classifications.

(Philipp et al. 2010)

Classification

Non-hierarchical cluster analysis: SANDRA (simulated annealing and diversified randomization) for an optimal division of classes.

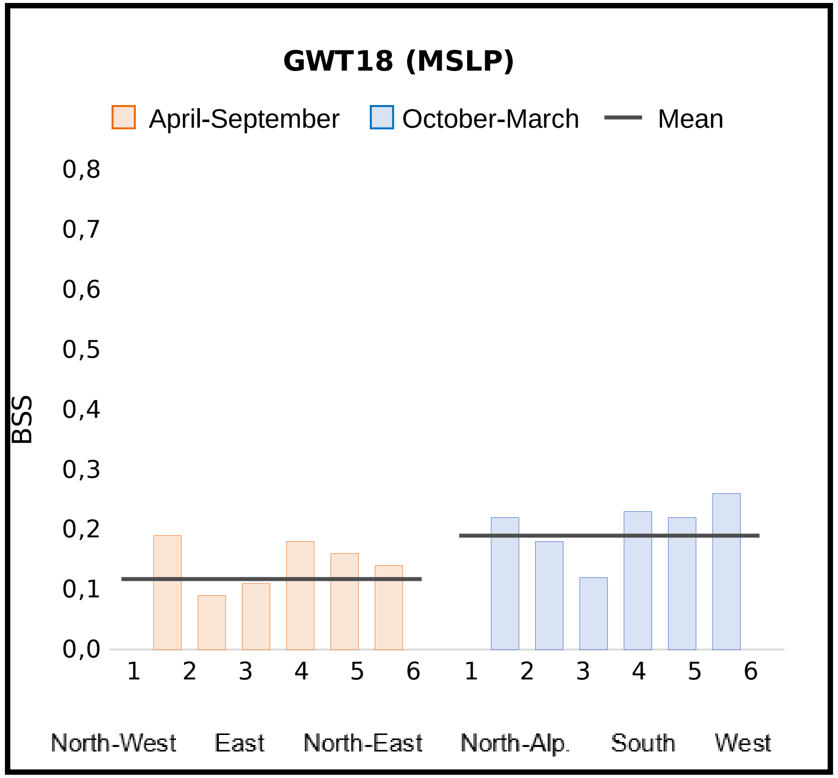
Evaluation

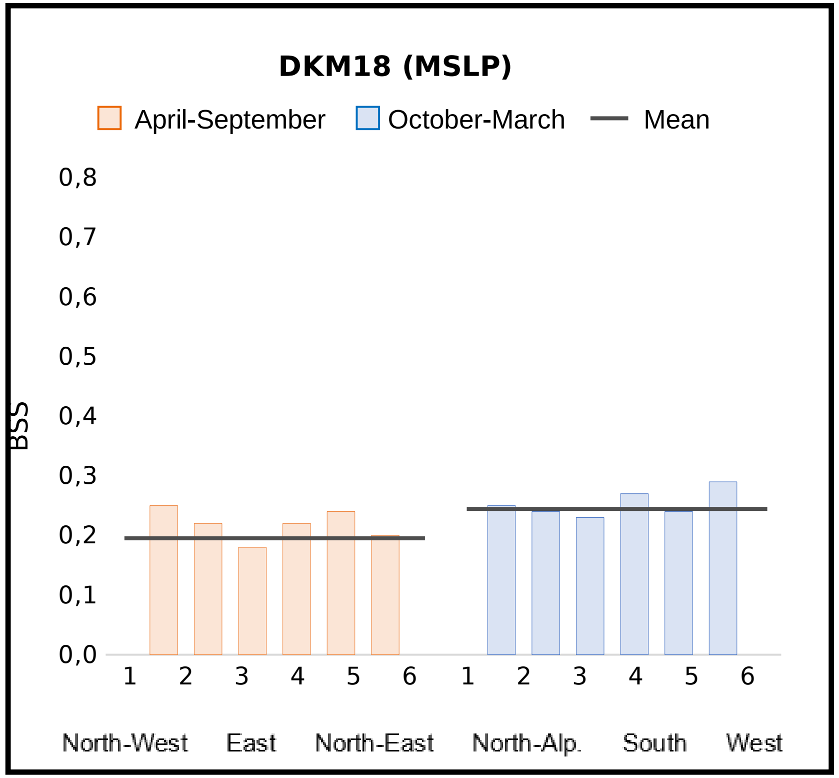
The Brier-Skill-Score (BSS) is based on the Brier Score (BS), a statistical index which can be used to validate probability forecasts.

Aim → optimizing the synoptic skill of the classification
(discriminatory power for target variable precipitation)

2 Methods for determining weather patterns/circulation types

Optimized circulation type classification: **GWT vs. DKM – MLSP only**





Increasing synoptic skill

from

semi-objective

to

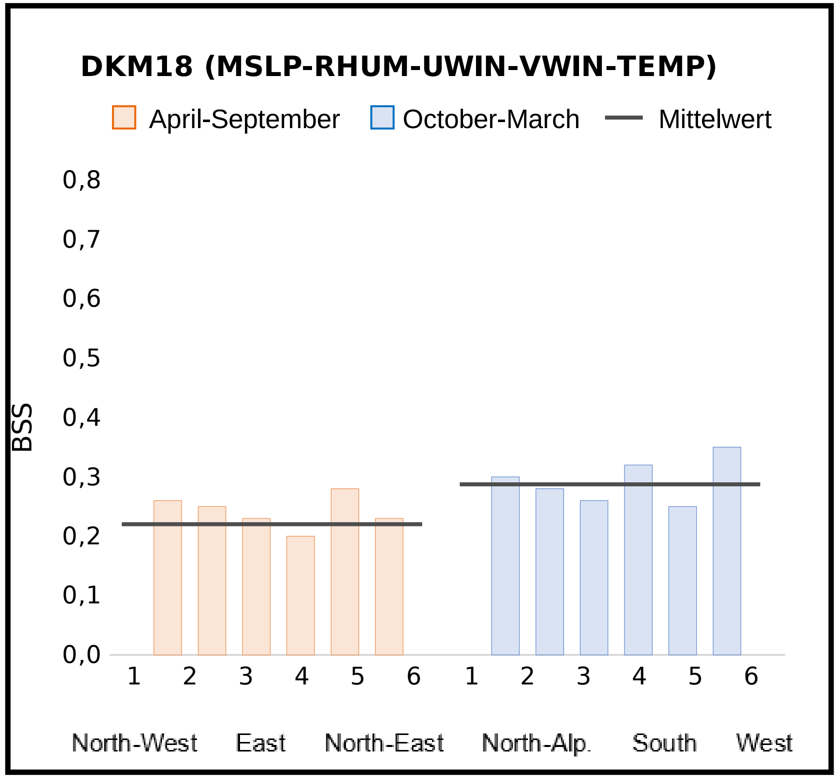
objective

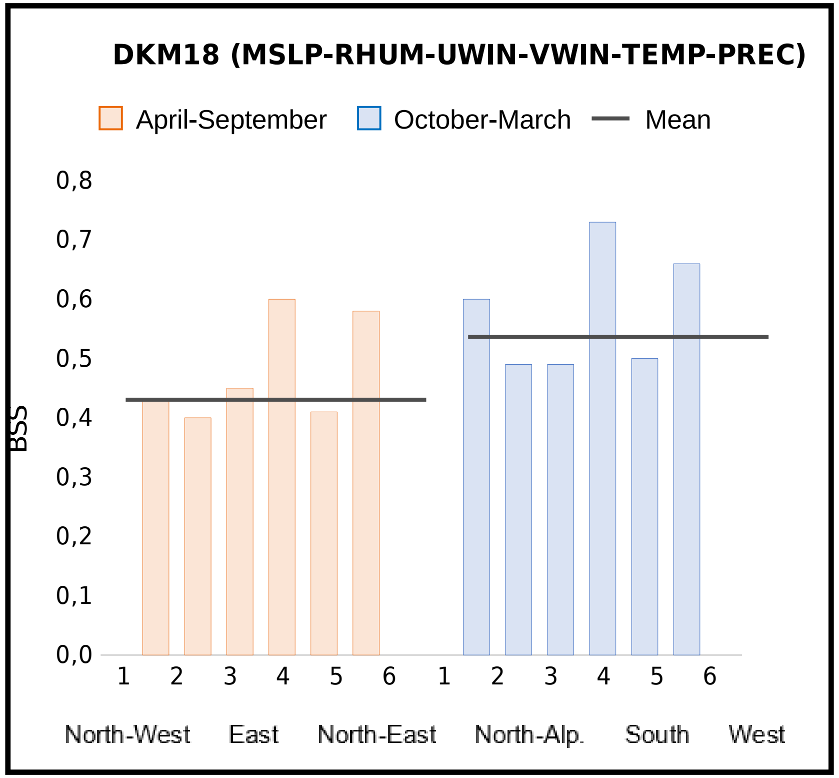
classifications

Region-specific Brier skill score (BSS) for April-September and October-March using GWT and DKM classification with 18 classes for mean sea level pressure in hPa (MSLP). The black horizontal line is mean BSS of all regions.

2 Methods for determining weather patterns/circulation types

Optimized circulation type classification: **DKM18 all Variables vs. all Variables with PREC**





Increasing synoptic skill

by means of

multi-parameter

and

„conditional“

classifications

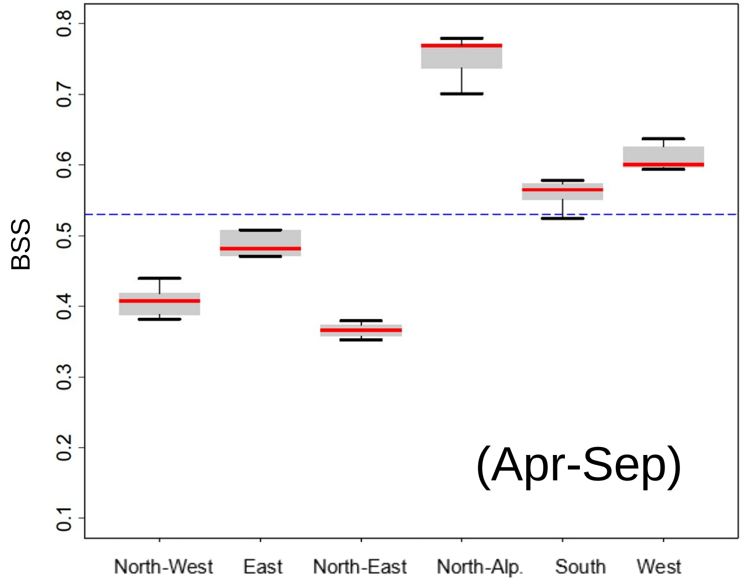
Region-specific Brier skill score (BSS) for April-September and October-March using DKM classification with 18 classes and the weighted parameters MSLP (1), RHUM700 (2), U-Wind700 (1), V-Wind700 (1), TEMP (3), and DKM classification conditioned on the target variable PREC (18). The black horizontal line is the mean BSS of all regions.

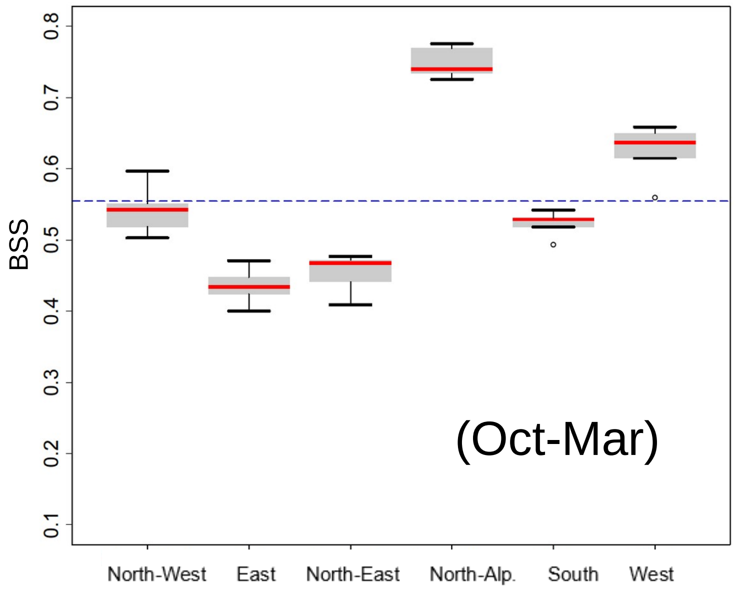
2 Methods for determining weather patterns/circulation types

Optimized circulation type classification

Final variables and weights – Classification (SAN18) **drought** (Apr-Sep, Oct-Mar)

Variable	Mean sea level pressure	Relative humidity	U-component of wind	V-component of wind	Temperature	Precipitation
Unit	hPa	%	m/s	m/s	K	mm
Level		700 hPa	700 hPa	700 hPa	2 m	
Weight	**1**	**2**	**1**	**1**	**3**	**18**





Brier skill scores (BSS) of classifications with respect to dryness. MSLP(1), RHUM700(2), UCW700(1), VCW700(1), TEMP(3), PREC(18). Mapping performance of circulation type classification with respect to precipitation in terms of Brier Skill Score (BSS) according to Schiemann & Frei (2010) (y-axis) in the six regions of similar precipitation variability (x-axis), boxplots: BSS range across validation periods.

3 Drought relevant circulation types

Percentage of circulation type (CT) days April-September and October-March associated with **drought** in regions of similar precipitation variability

April-September

	North-West	East	North-East	North Alp.	South	West
CT 1	0.00	2.17	1.21	0.00	0.48	0.00
CT 2	0.32	0.96	1.60	0.64	0.64	0.32
CT 3	8.89	21.85	18.61	21.76	13.98	5.74
CT 4	0.00	0.00	0.00	0.00	0.00	0.00
CT 5	0.00	0.20	0.20	0.00	0.00	0.00
CT 6	4.07	1.83	8.55	0.00	0.00	0.81
CT 7	0.00	0.00	0.00	0.00	0.00	0.00
CT 8	3.54	1.86	6.11	0.00	0.80	1.06
CT 9	0.00	0.00	0.00	0.00	1.03	0.00
CT 10	0.00	0.00	0.00	0.00	0.00	0.00
CT 11	0.69	0.69	3.45	0.00	0.00	0.00
CT 12	27.97	22.74	22.85	24.70	29.05	17.19
CT 13	0.32	0.00	0.95	0.00	0.00	0.00
CT 14	34.56	43.40	38.17	33.98	31.75	17.80
CT 15	0.00	6.41	0.67	2.53	6.58	0.00
CT 16	45.70	36.91	38.95	42.02	46.06	28.12
CT 17	0.82	0.00	0.82	0.00	1.23	0.00
CT 18	0.00	0.00	0.00	0.00	0.00	0.00

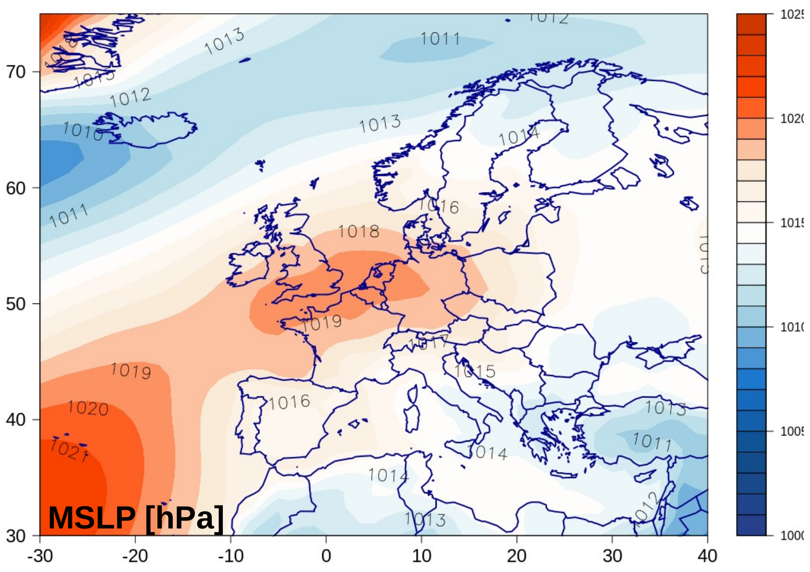
October-March

	Nord-West	Ost	Nord-Ost	Nord-Stau	Süd	West
CT 1	0.00	1.42	1.42	0.00	0.24	0.00
CT 2	0.00	0.00	0.40	0.00	0.00	0.00
CT 3	0.00	0.00	0.00	0.00	0.00	0.00
CT 4	0.00	0.00	0.00	0.00	0.00	0.00
CT 5	0.00	0.00	0.55	0.00	0.00	0.00
CT 6	10.11	15.31	17.58	14.18	1.51	12.95
CT 7	0.00	0.12	0.48	0.00	0.00	0.00
CT 8	0.00	3.24	0.17	2.73	7.50	1.02
CT 9	0.00	0.00	0.00	0.35	1.40	0.35
CT 10	37.90	40.06	38.14	33.81	25.64	23.24
CT 11	19.81	13.24	19.59	12.25	5.67	13.65
CT 12	0.00	0.75	1.49	0.00	0.00	0.00
CT 13	3.03	3.84	8.69	0.20	0.00	3.84
CT 14	33.42	34.28	32.43	33.09	30.24	29.32
CT 15	0.00	0.00	0.00	0.00	0.00	0.00
CT 16	0.00	0.00	0.00	0.00	0.00	0.00
CT 17	47.03	38.92	42.75	36.29	31.03	39.44
CT 18	0.00	3.85	4.40	0.00	0.00	1.65

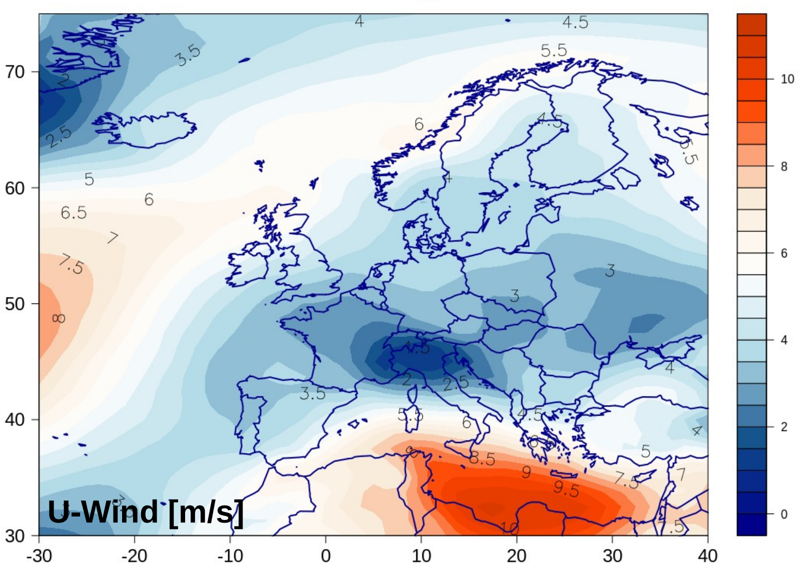
Definition of drought-relevant circulation types: All circulation types that are associated with a precipitation mean below the 20th percentile (1961-2017) on at least 20% of all CT days in at least one region.

Drought relevant circulation type 12 April-September

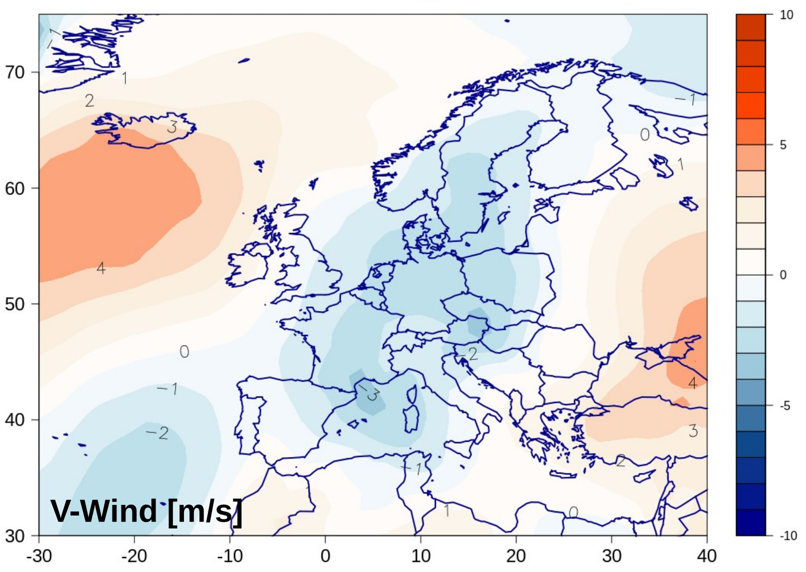
Type 12 – Mean Sea Level Pressure



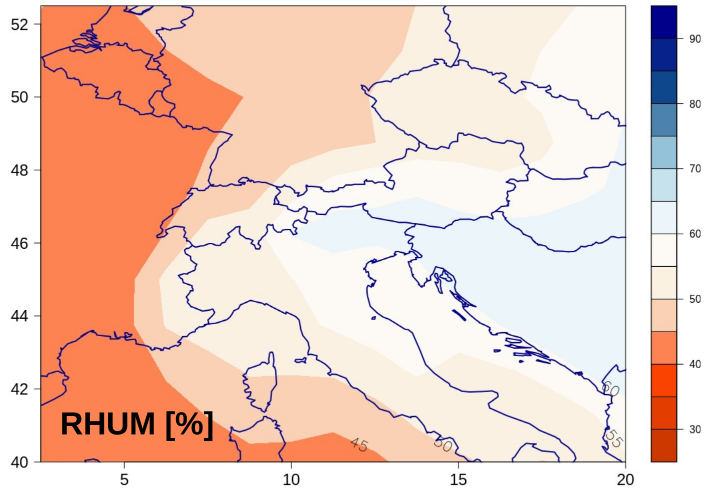
Type 12 – U-Component of Wind



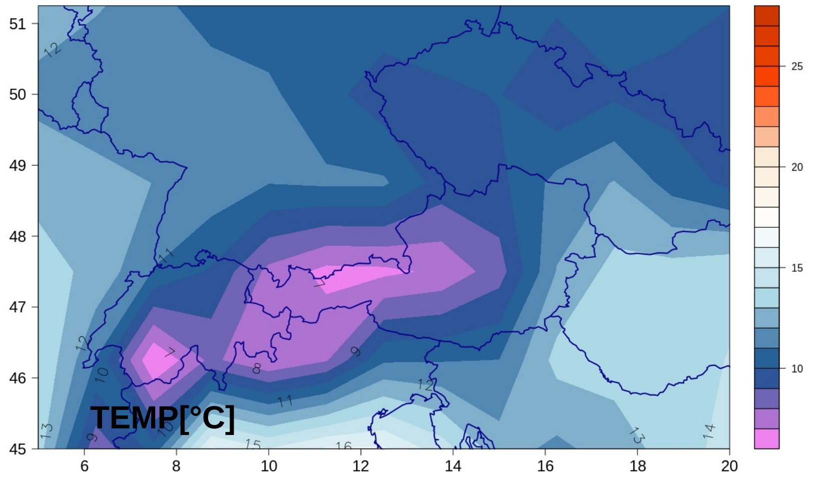
Type 12 – V-Component of Wind



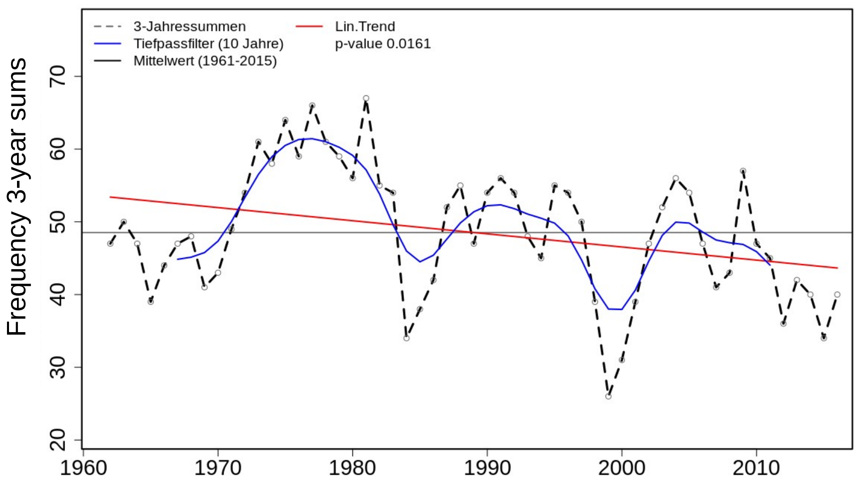
Type 12 – Relative Humidity



Type 12 – Temperature



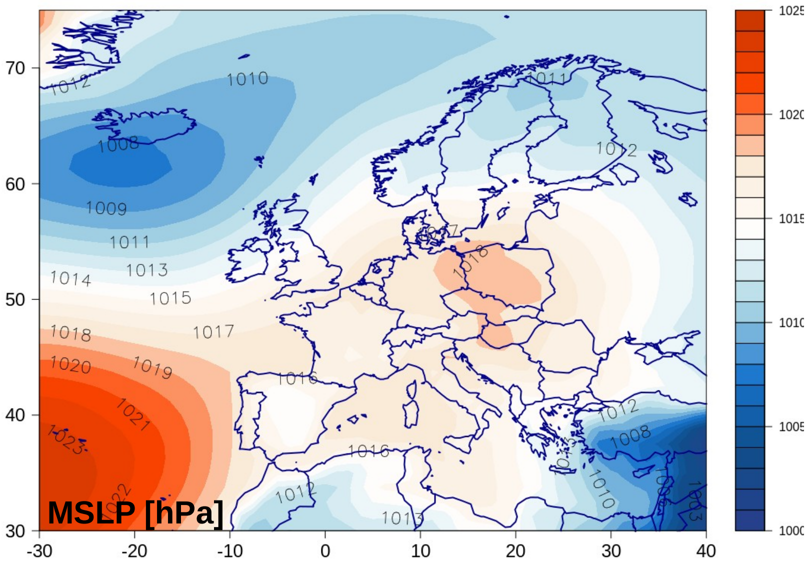
Type 12 – Frequency



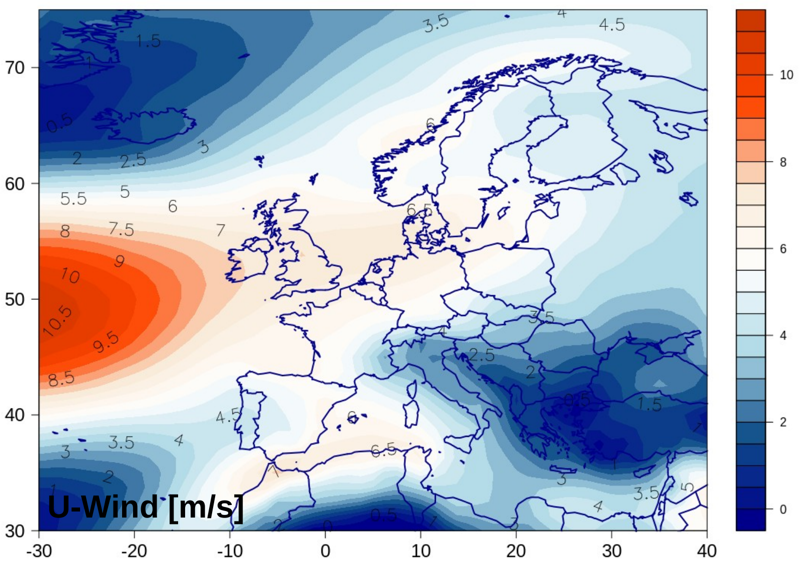
Drought relevant CT 12 mean fields from all single days 1961-2015: mean sea level pressure [hPa] (MSLP), U-and V-Wind component [m/s] at 700 hPa, relative humidity [%] (RHUM) at 700 hPa and Temperature [°C] (TEMP) at 2m. Trend analysis (confidence level 95%), moving 3-year occurrence frequencies, smoothed time series (Gaussian low-pass filter over 10 years) and linear trend

Drought relevant circulation type 14 April-September

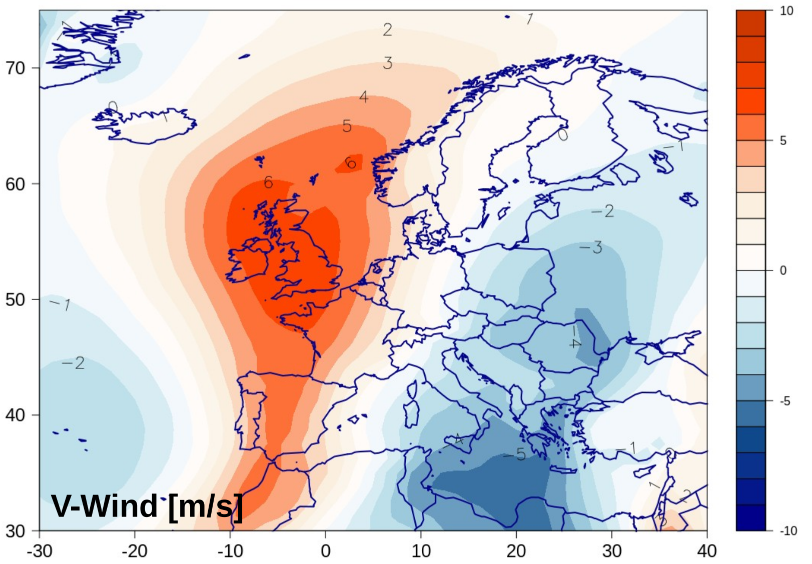
Type 14 – Mean Sea Level Pressure



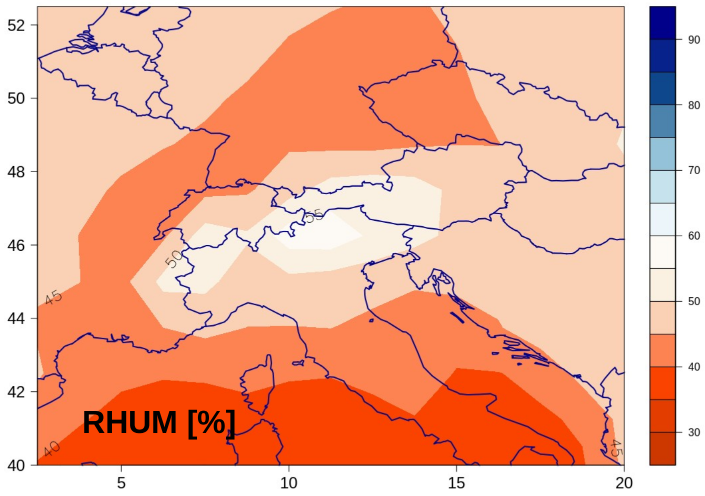
Type 14 – U-Component of Wind



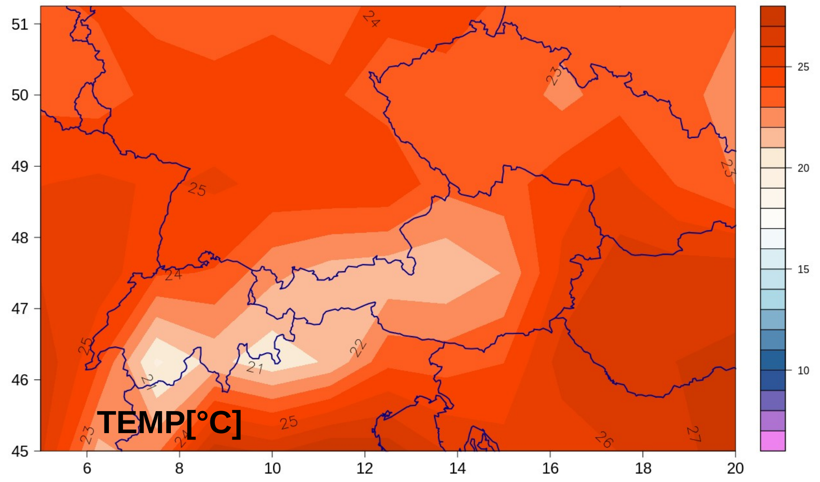
Type 14 – V-Component of Wind



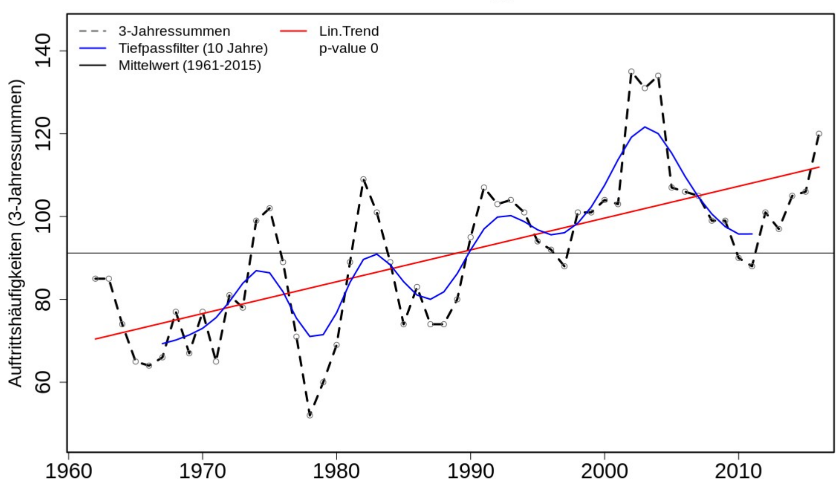
Type 14 – Relative Humidity



Type 14 – Temperature



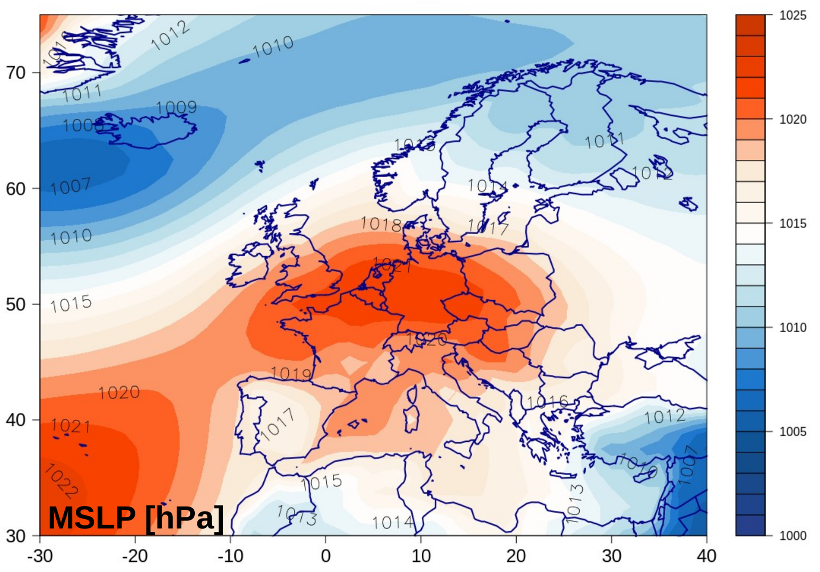
Type 14 – Frequency



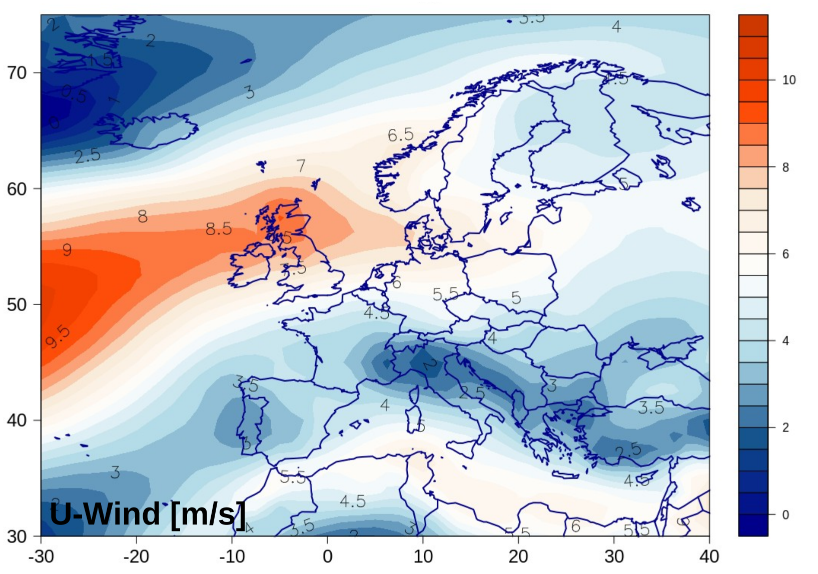
Drought relevant CT 16 mean fields from all single days 1961-2015: mean sea level pressure [hPa] (MSLP), U-and V-Wind component [m/s] at 700 hPa, relative humidity [%] (RHUM) at 700 hPa and Temperature [°C] (TEMP) at 2m. Trend analysis (confidence level 95%), moving 3-year occurrence frequencies, smoothed time series (Gaussian low-pass filter over 10 years) and linear trend

Drought relevant circulation type 16 April-September

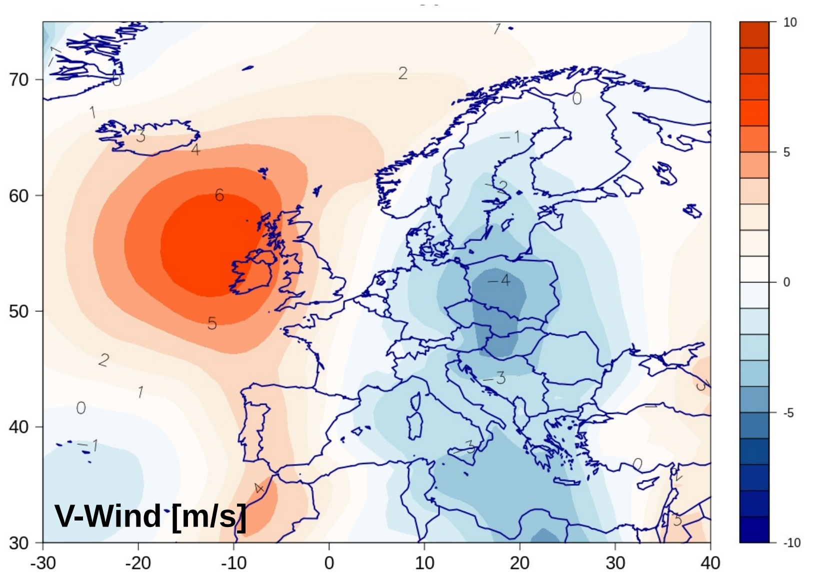
Type 16 – Mean Sea Level Pressure



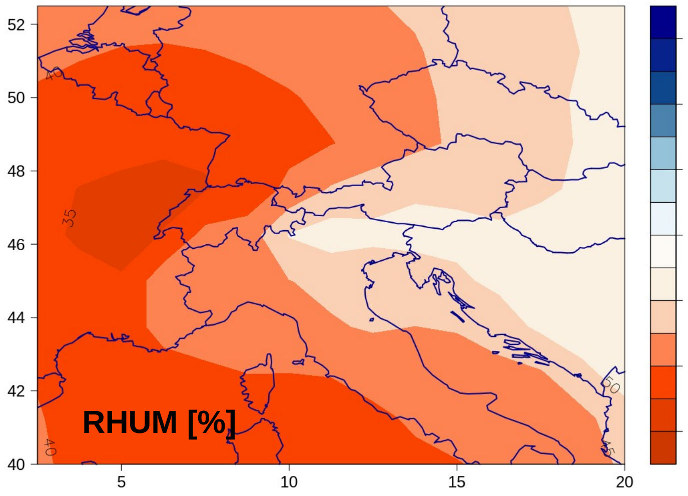
Type 16 – U-Component of Wind



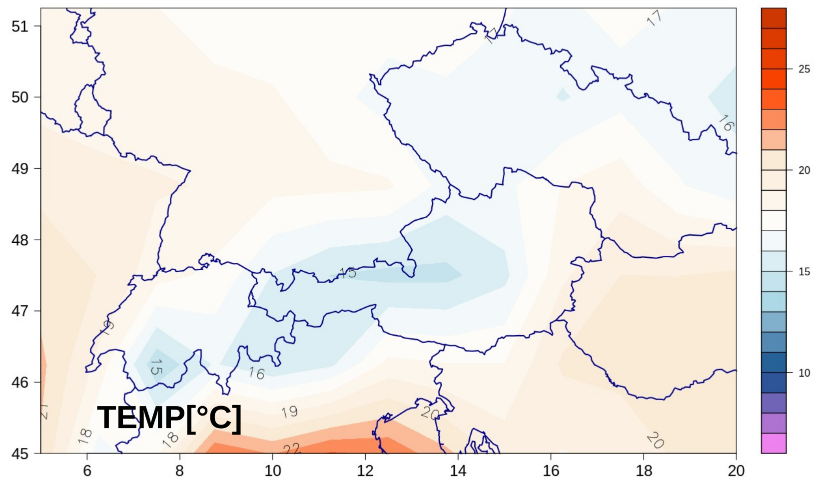
Type 16 – V-Component of Wind



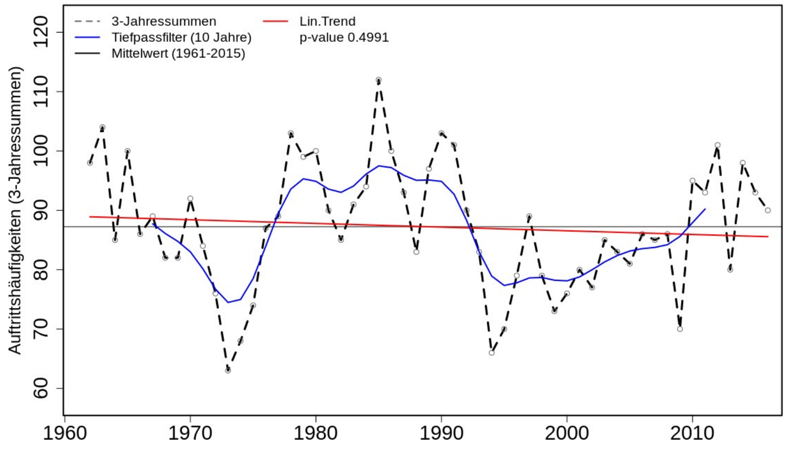
Type 16 – Relative Humidity



Type 16 – Temperature



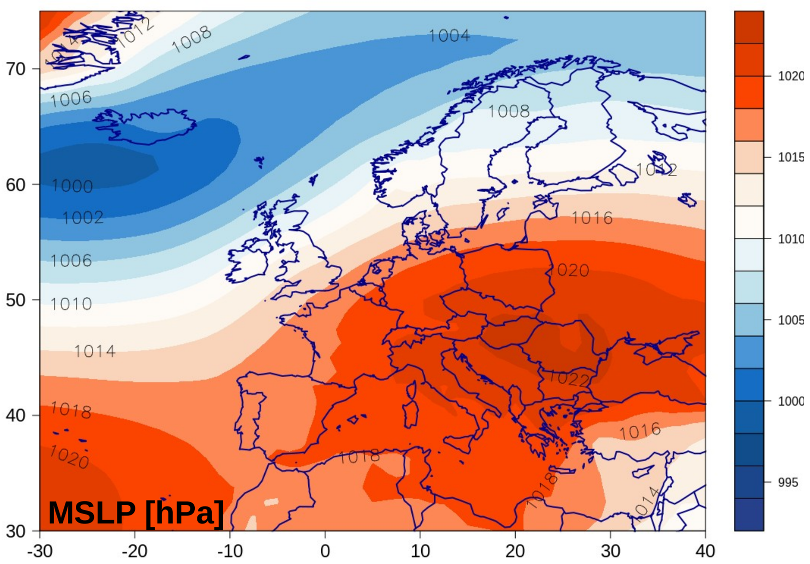
Type 16 – Frequency



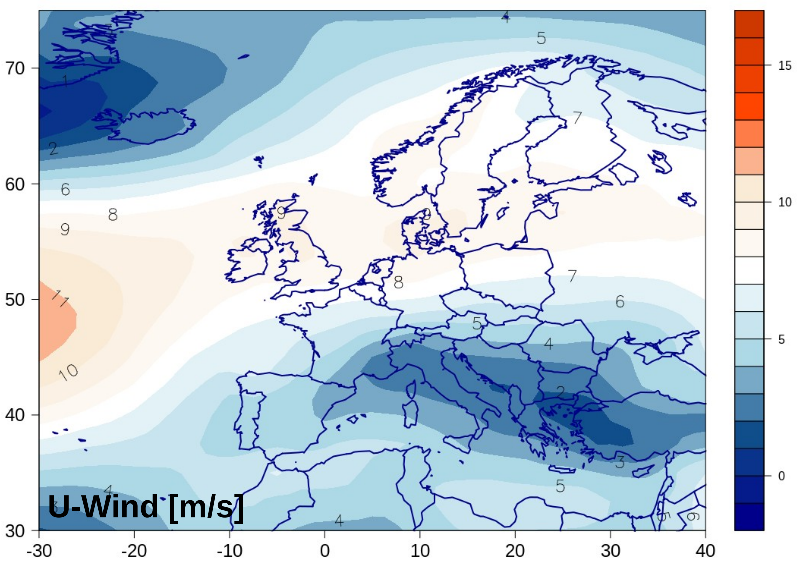
Drought relevant CT 16 mean fields from all single days 1961-2015: mean sea level pressure [hPa] (MSLP), U-and V-Wind component [m/s] at 700 hPa, relative humidity [%] (RHUM) at 700 hPa and Temperature [°C] (TEMP) at 2m. Trend analysis (confidence level 95%), moving 3-year occurrence frequencies, smoothed time series (Gaussian low-pass filter over 10 years) and linear trend

Drought relevant circulation type 10 October-March

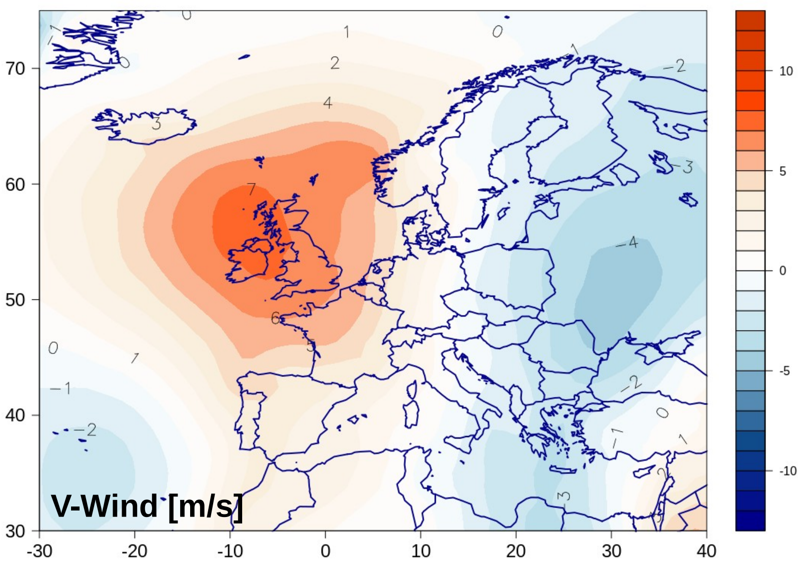
Type 10 – Mean Sea Level Pressure



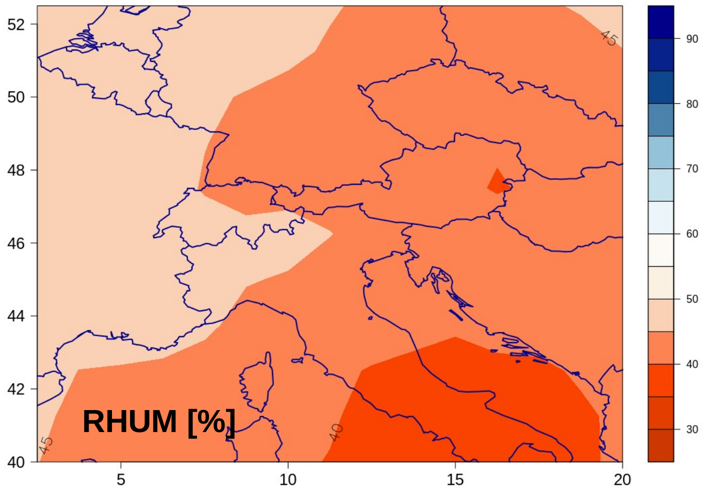
Type 10 – U-Component of Wind



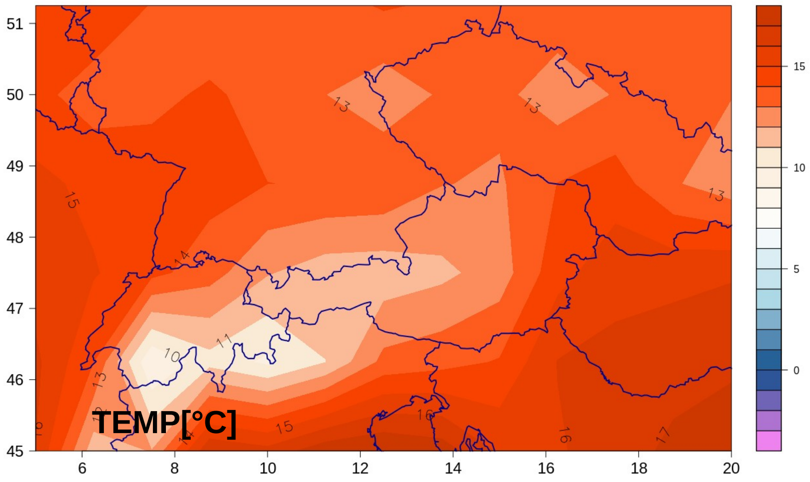
Type 10 – V-Component of Wind



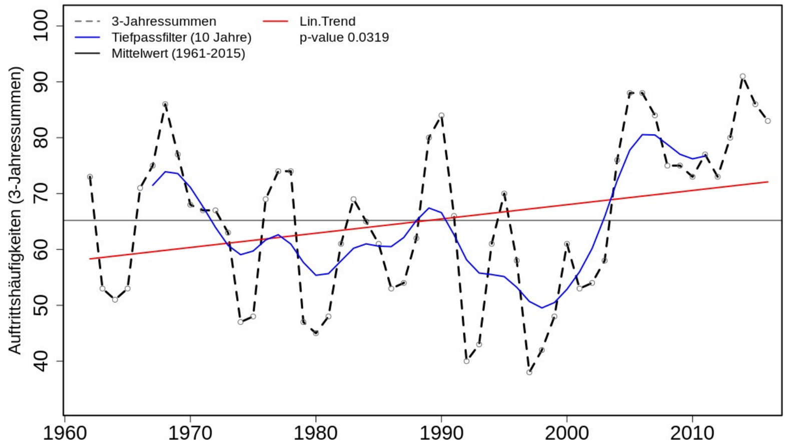
Type 10 – Relative Humidity



Type 10 – Temperature



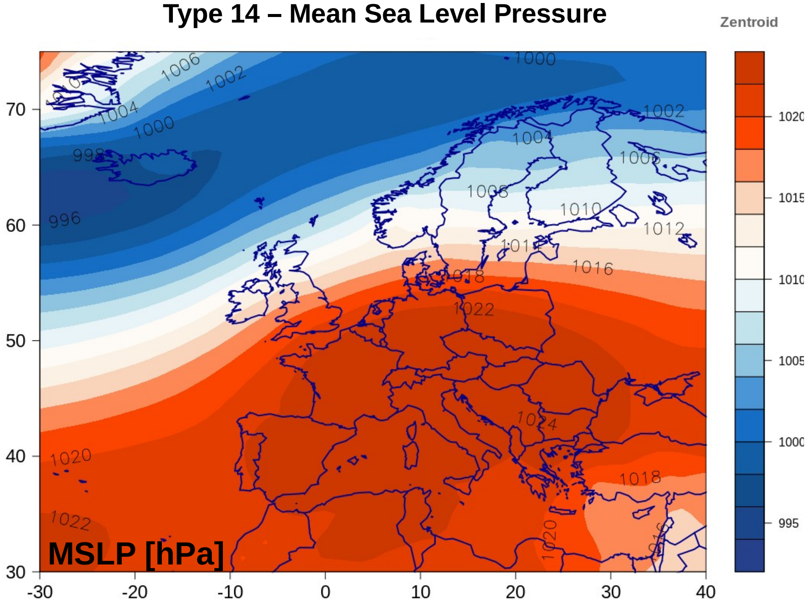
Type 10 – Frequency



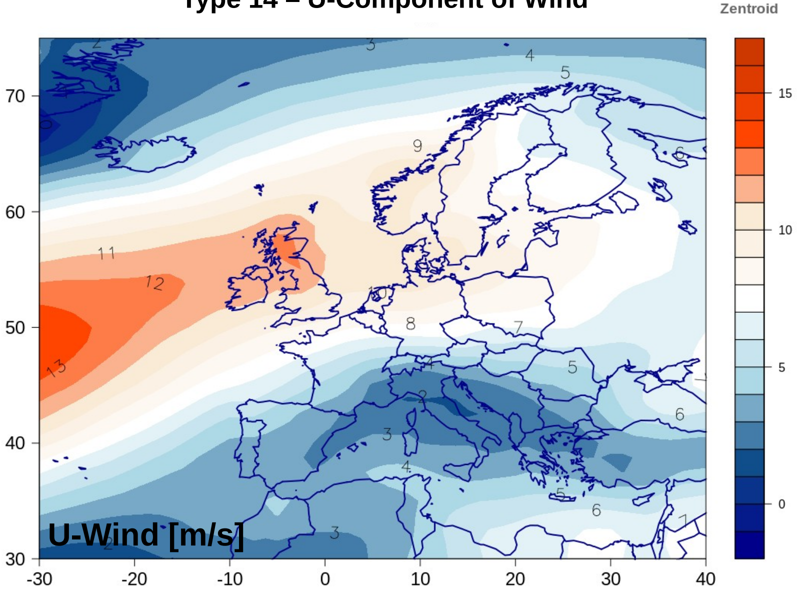
Drought relevant CT 10 mean fields from all single days 1961-2015: mean sea level pressure [hPa] (MSLP), U-and V-Wind component [m/s] at 700 hPa, relative humidity [%] (RHUM) at 700 hPa and Temperature [°C] (TEMP) at 2m. Trend analysis (confidence level 95%), moving 3-year occurrence frequencies, smoothed time series (Gaussian low-pass filter over 10 years) and linear trend

Drought relevant circulation type 14 October-March

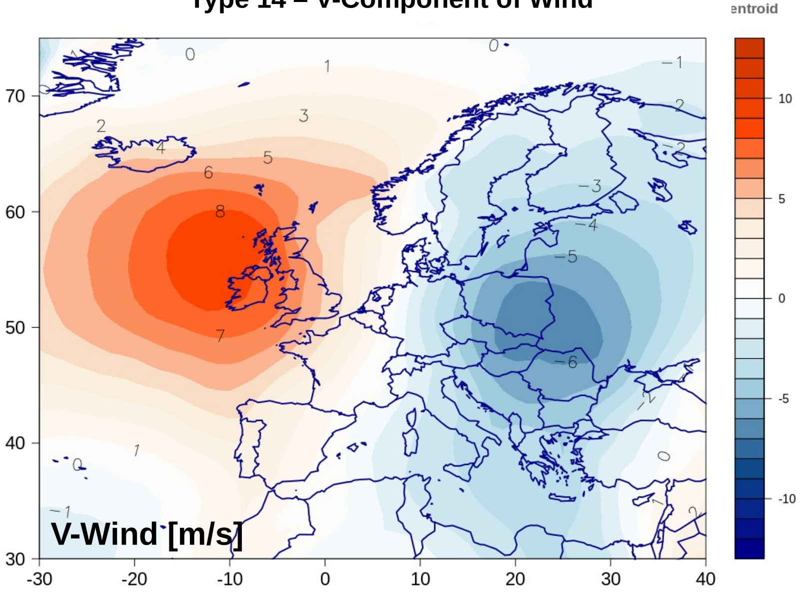
Type 14 – Mean Sea Level Pressure



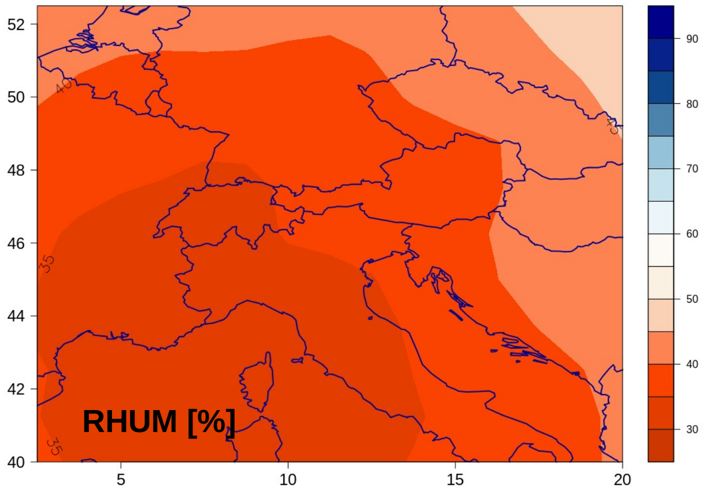
Type 14 – U-Component of Wind



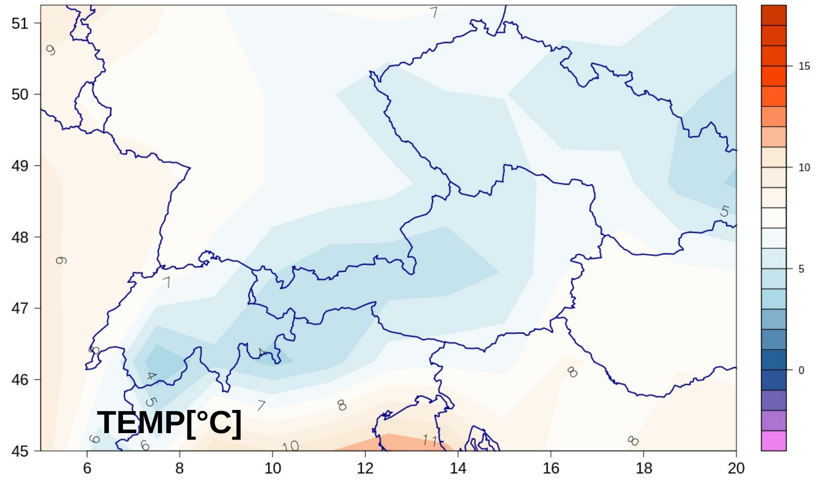
Type 14 – V-Component of Wind



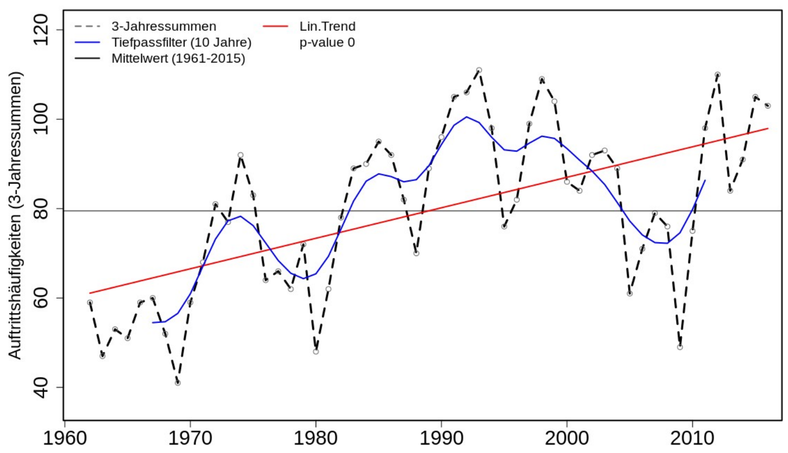
Type 14 – Relative Humidity



Type 14 – Temperature



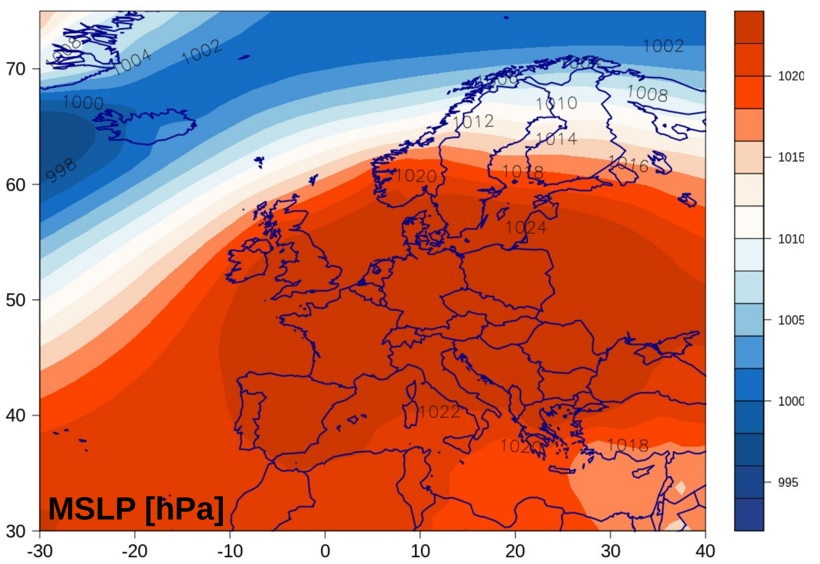
Type 14 – Frequency



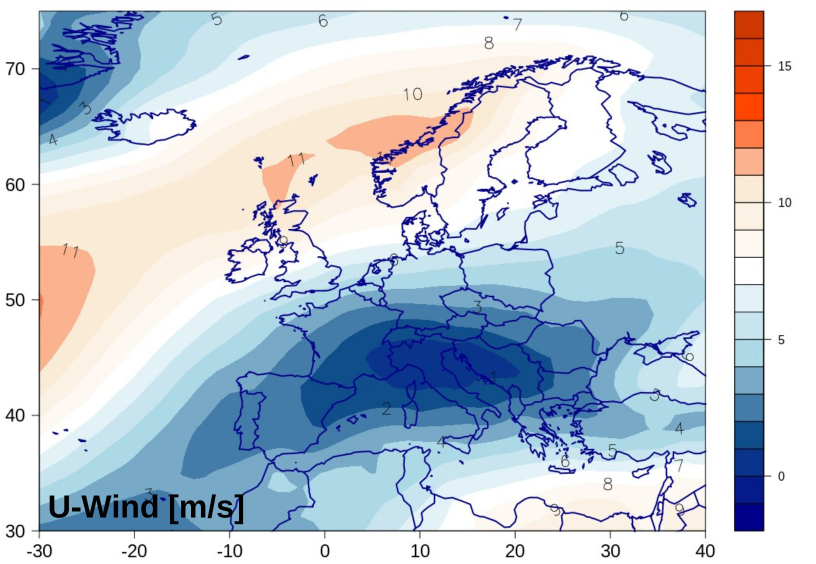
Drought relevant CT 14 mean fields from all single days 1961-2015: mean sea level pressure [hPa] (MSLP), U-and V-Wind component [m/s] at 700 hPa, relative humidity [%] (RHUM) at 700 hPa and Temperature [°C] (TEMP) at 2m. Trend analysis (confidence level 95%), moving 3-year occurrence frequencies, smoothed time series (Gaussian low-pass filter over 10 years) and linear trend

Drought relevant circulation type 17 October-March

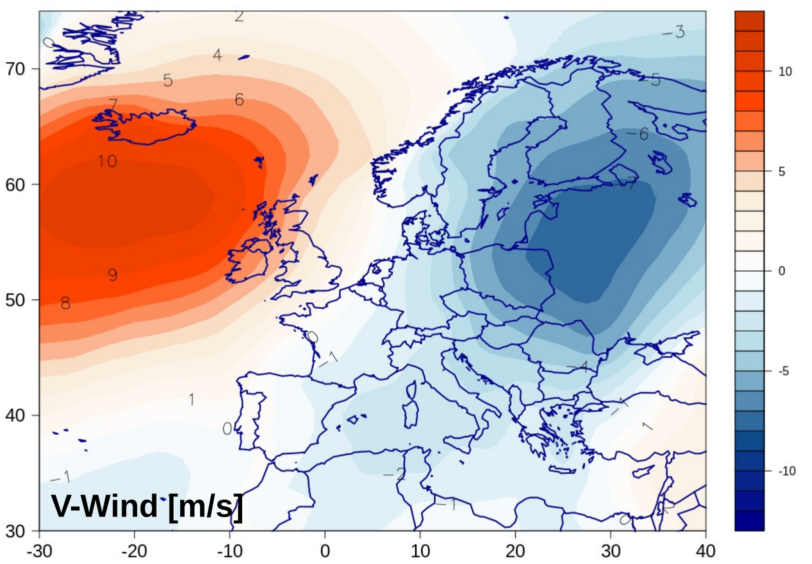
Type 17 – Mean Sea Level Pressure



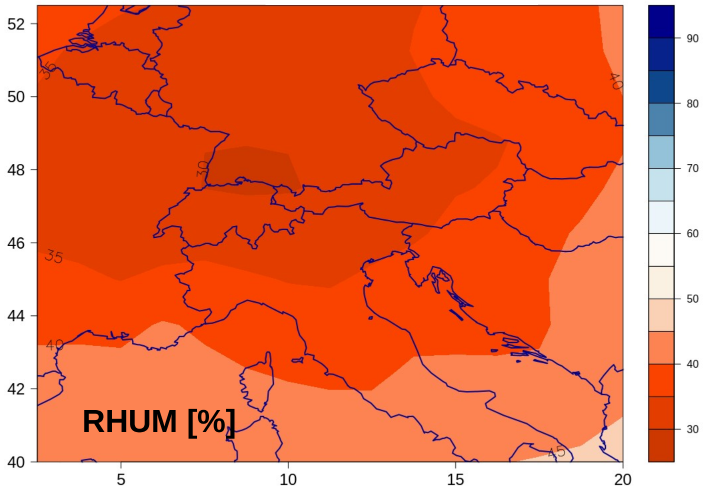
Type 17 – U-Component of Wind



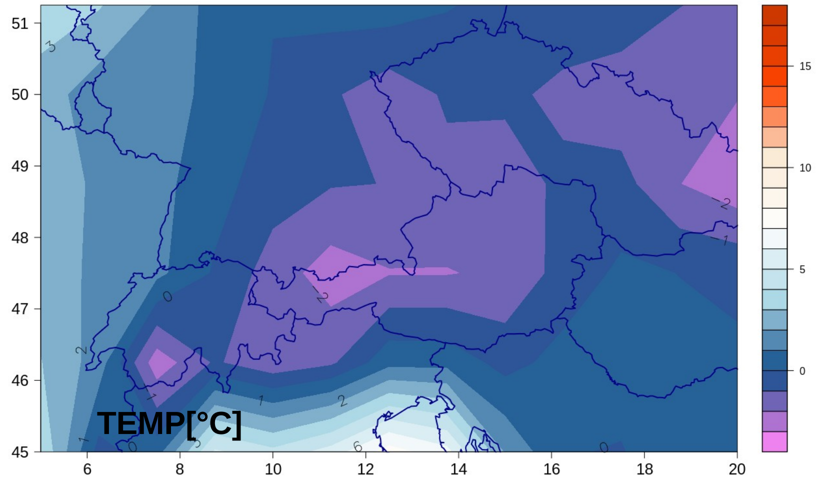
Type 17 – V-Component of Wind



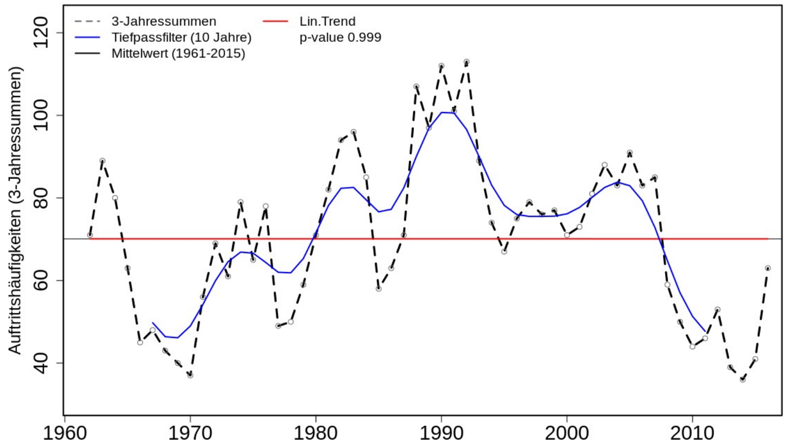
Type 17 – Relative Humidity



Type 17 – Temperature



Type 17 – Frequency

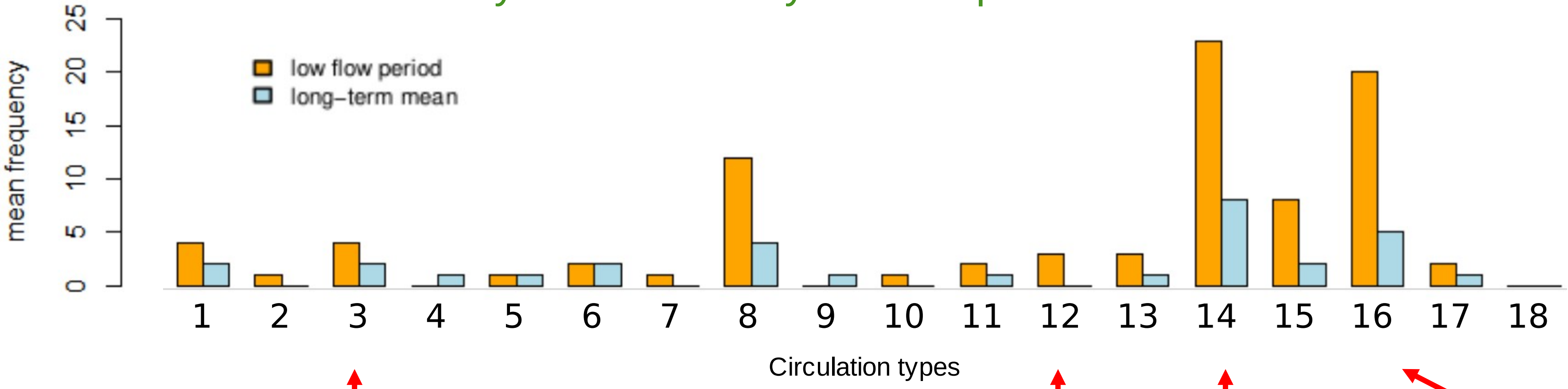


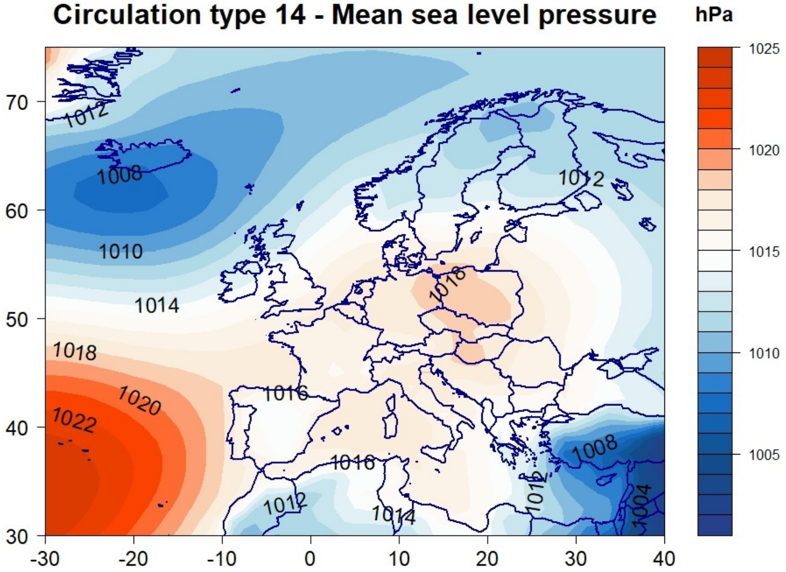
Drought relevant CT 17 mean fields from all single days 1961-2015: mean sea level pressure [hPa] (MSLP), U-and V-Wind component [m/s] at 700 hPa, relative humidity [%] (RHUM) at 700 hPa and Temperature [°C] (TEMP) at 2m. Trend analysis (confidence level 95%), moving 3-year occurrence frequencies, smoothed time series (Gaussian low-pass filter over 10 years) and linear trend

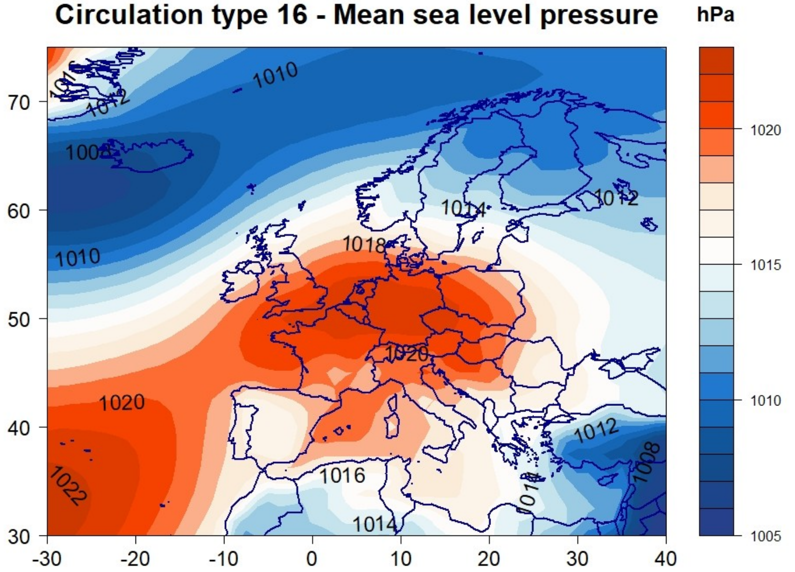
4 Implications for low flow

87 consecutive days - mean discharge below the 5th percentile 7.1 [m^3/s] of the long-term mean.

Isar river Germany Bavaria 6. July – 30. September 1962

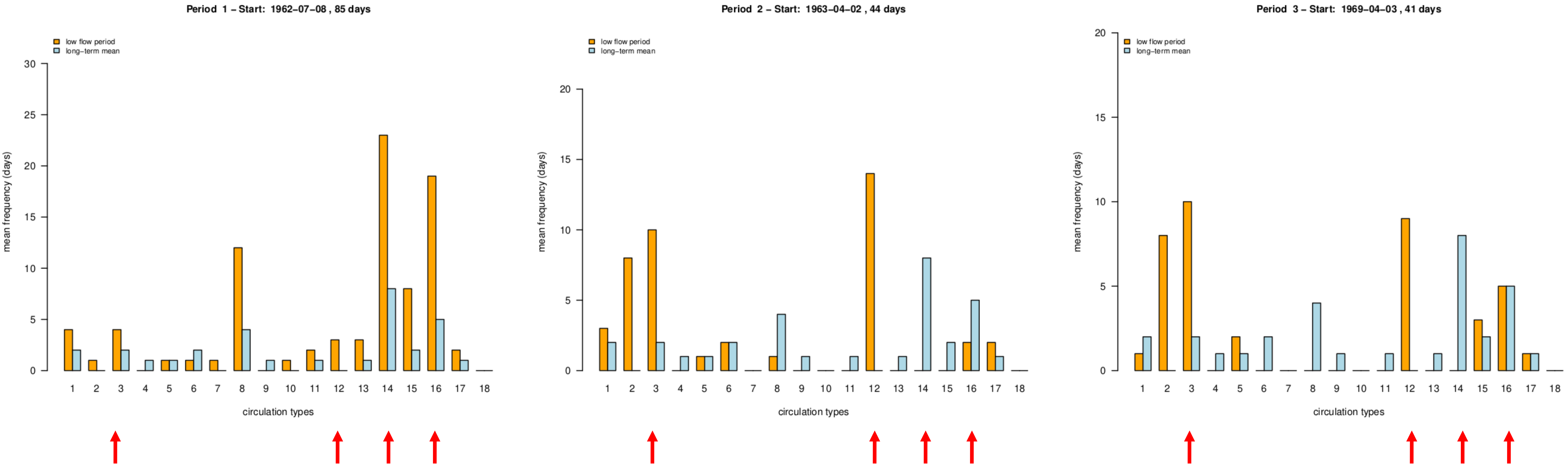






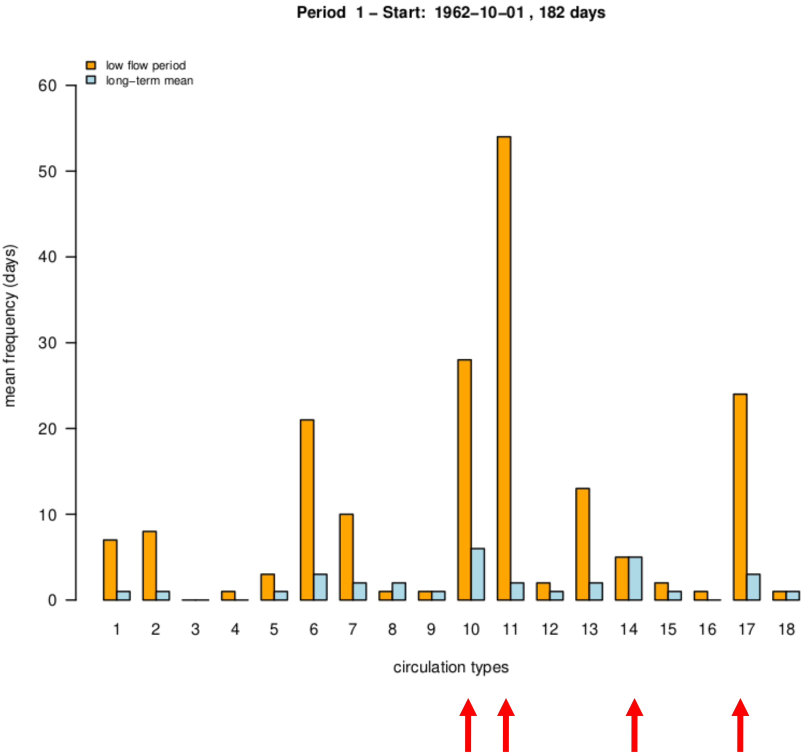
4 Implications for low flow

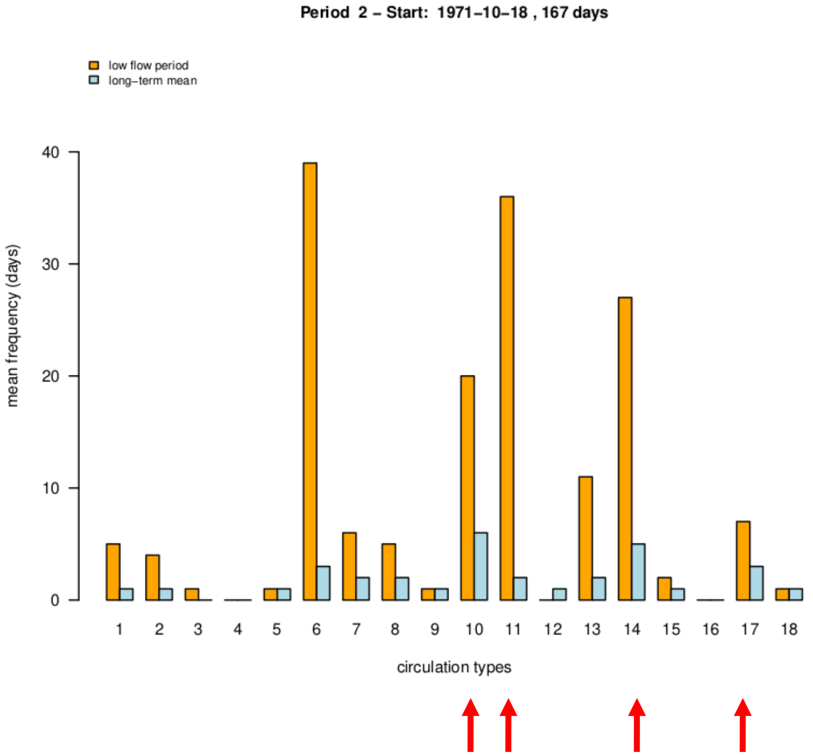
Circulation type frequencies during summer low-flow periods

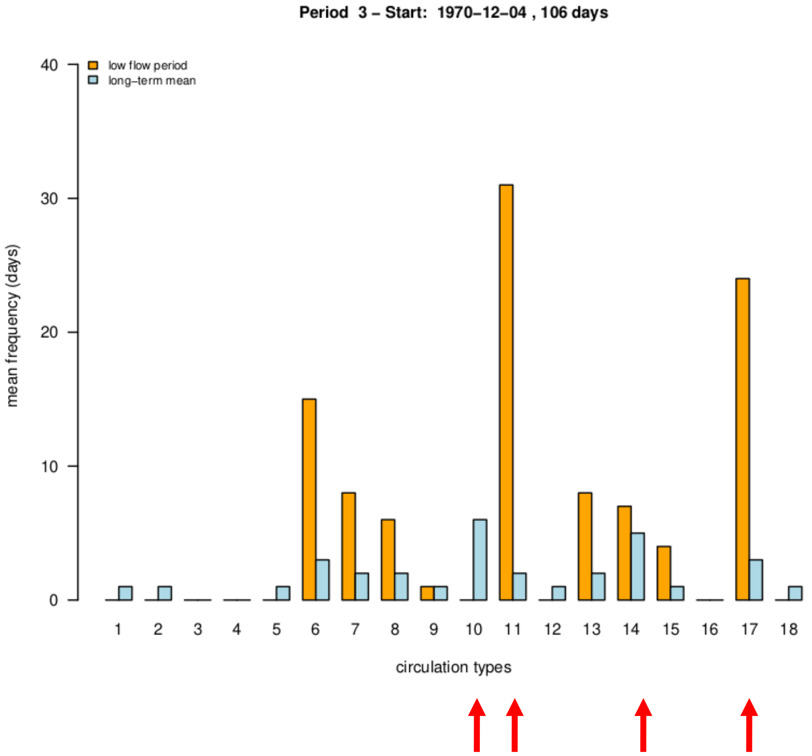


4 Implications for low flow

Circulation type frequencies during winter low-flow periods







5 Future Changes

Frequency changes

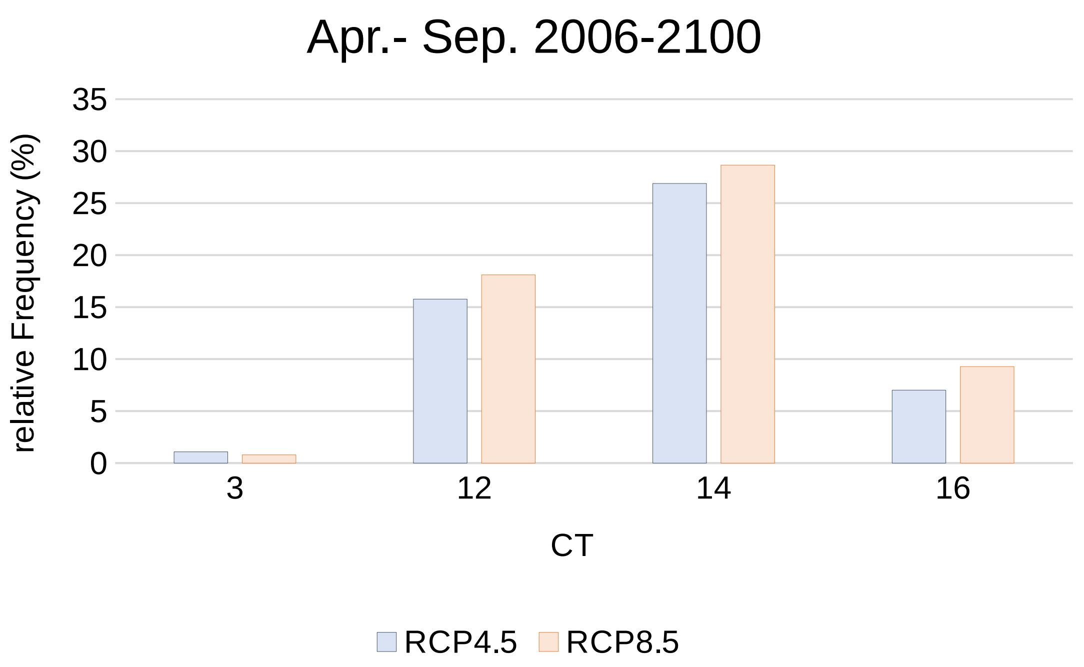
of drought-relevant circulation types in the regional climate models (RCP8.5) between the control period (1971-2000) and the projection periods (2031-2060 and 2071-2100)

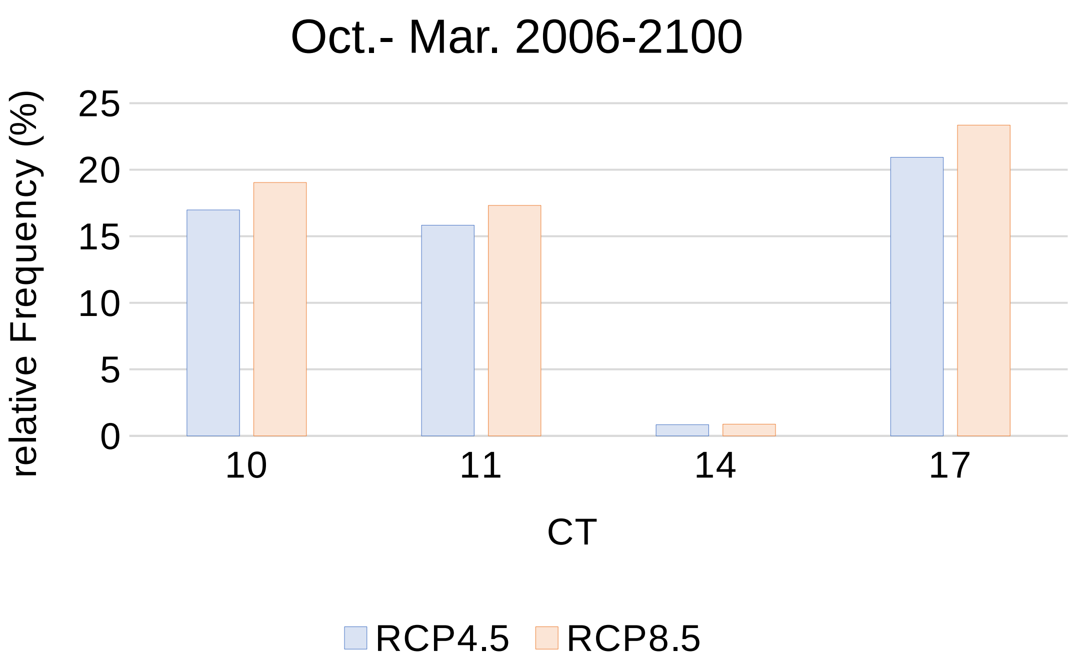
1. Projection Period 2031-2060	**April-September**				**October-March**			
CT	3	12	14	16	10	11	14	17
ICHEC-EARTH-CCLM	0,35	0,10	0,73	0,74	0,23	0,53	0,98	0,74
ICHEC-EARTH-ACMO22r1	0,90	0,34	0,60	0,74	0,97	0,94	0,56	0,62
ICHEC-EARTH-RCA4	0,54	0,29	0,37	0,97	0,59	0,85	0,68	0,79
ICHEC-EARTH-RACMOr12	0,00	1,00	0,57	0,01	0,71	0,00	0,00	0,01
MPI-CCLM	0,57	0,09	0,87	0,28	0,39	0,59	0,16	0,23
MPI-RCA	0,25	0,29	0,33	0,43	0,73	0,73	0,73	0,28
2. Projection Period 2071-2100								
ICHEC-EARTH-CCLM	0,09	0,01	0,00	0,31	0,00	0,00	0,45	0,90
ICHEC-EARTH-ACMO22r1	0,76	0,00	0,00	0,01	0,00	0,00	0,16	0,17
ICHEC-EARTH-RCA4	0,76	0,01	0,00	0,03	0,00	0,00	0,14	0,29
ICHEC-EARTH-RACMOr12	0,68	0,00	0,00	0,00	0,00	0,01	0,84	0,00
MPI-CCLM	0,71	0,00	0,00	0,33	0,00	0,00	0,94	0,22
MPI-RCA	0,71	0,00	0,00	0,10	0,00	0,00	0,01	0,16

p-values for α = 0.05, Wilcoxon-Mann-Whitney rank sum test; red = sign. increase, blue = sign. decrease

5 Future Changes

Frequency differences – RCP4.5 und RCP8.5





Relative frequencies of occurrence of drought-relevant circulation types (%) for RCP4.5 and RCP8.5 in the regional climate model MPI-RCAv1.

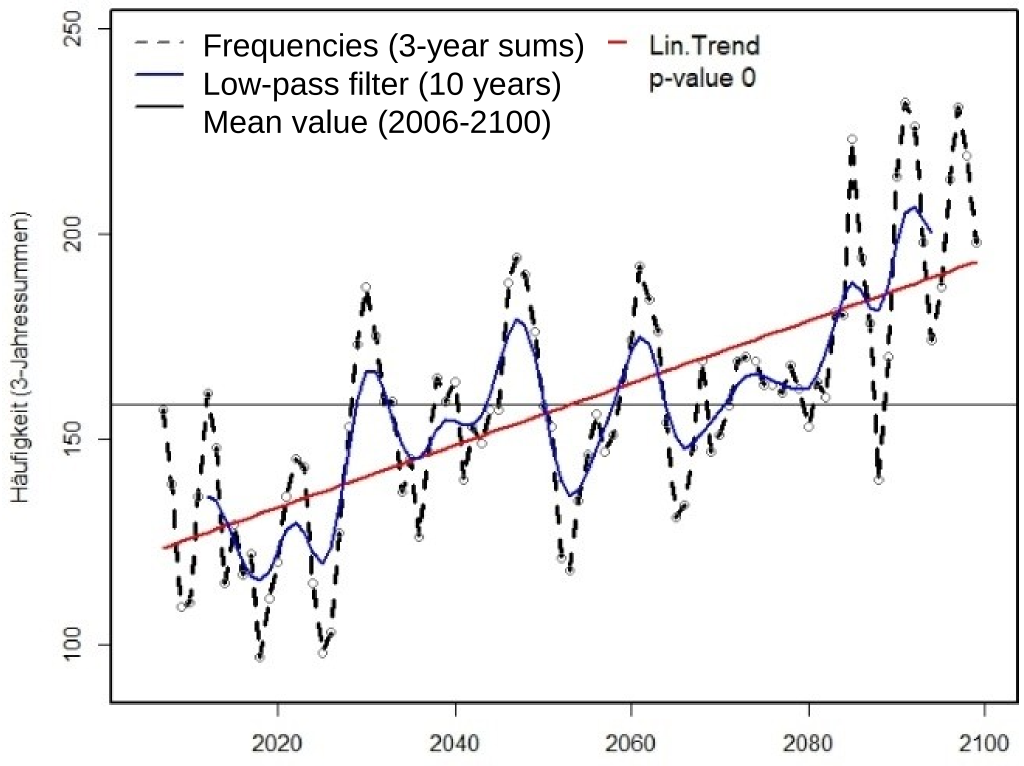
Drought-relevant circulation types occur more frequently in a stronger greenhouse climate.

5 Future Changes

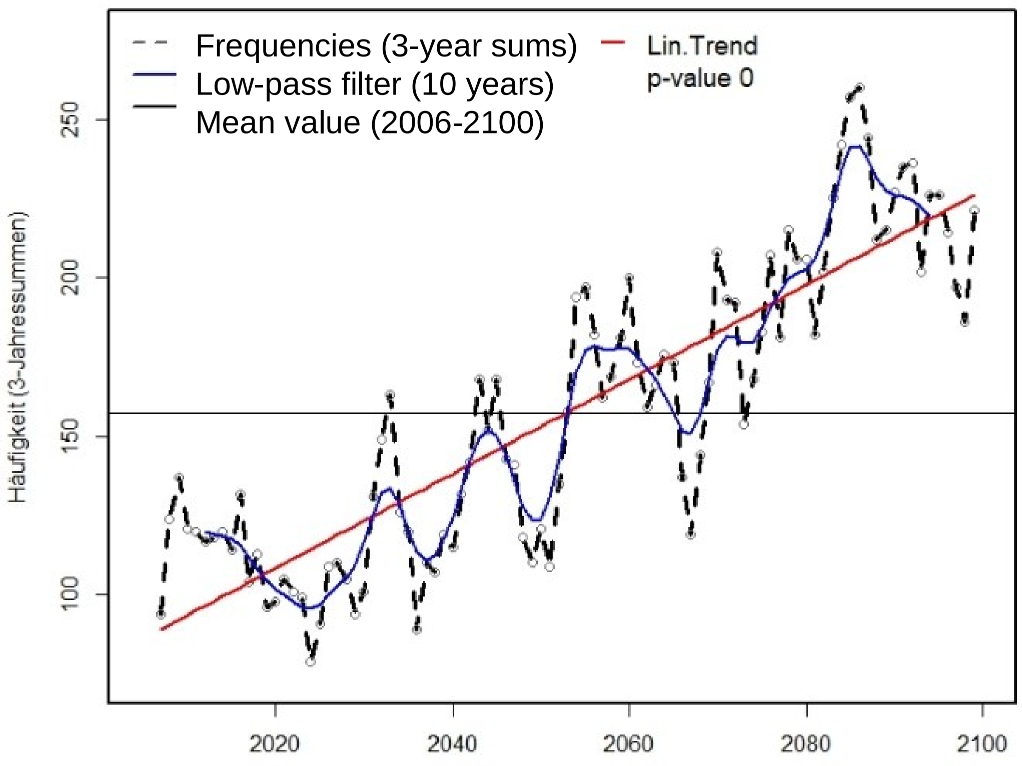
Decadal variations and long-term trends in **projected frequencies** of drough-relevant circulation types – RCP4.5 und RCP8.5

CT 14 – April – September (regional climate model MPI-RCA4)

RCP4.5



RCP8.5



5 Future Changes

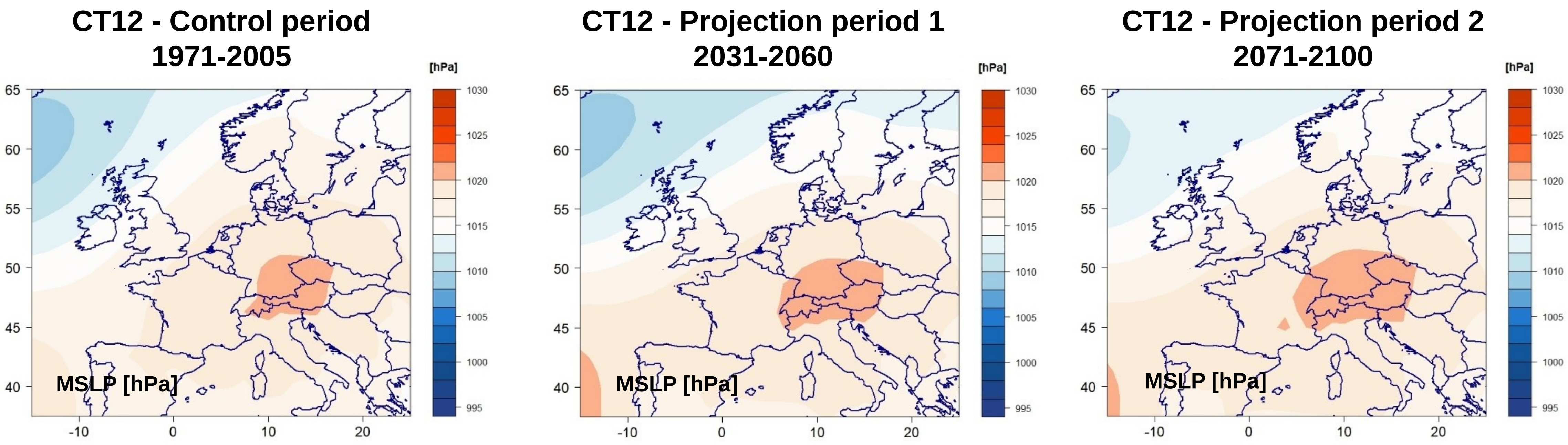
Persistence changes

Changes (%) in maximum persistence of drought-relevant circulation types in the regional climate models between the control period (1971-2000) and the projection periods (2031-2060 and 2071-2100)

Regional climate model	EC-EARTH_r1_ RACMO22Ev1	EC-EARTH_r12_ CCLM4-8-17	EC-EARTH_r12_ RACMO22Ev1	EC-EARTH_r12_ RCA4v.1	MPI-M-MPI-ESM_r1_ CCLM4-8-17	MPI-M-MPI-ESM_r1_ RCAv.1
CT	**April-September 2031-2060**					
3	50,00	-7,69	-15,38	9,09	-7,69	9,09
12	-15,38	17,24	17,20	12,64	-1,27	3,49
14	13,68	-5,56	19,32	-4,84	25,00	19,39
16	-37,70	19,05	-2,00	-3,51	-6,82	-2,08
	April-September 2071-2100					
3	41,67	-7,69	-7,69	9,09	-7,69	9,09
12	-23,08	10,34	1,08	0,00	-18,99	-16,28
14	63,16	53,70	60,23	54,84	70,00	70,41
16	-32,79	11,90	-8,00	-17,54	-15,91	-16,67

5 Future Changes

Type-internal changes



Type-internal change of the drought-relevant circulation type 12, April-September in the regional climate model MPI_RCA. Surface pressure and temperature composites for the control period (1971-2000) and the projection periods (2031-2060, 2071-2100).

5 Future Changes

Type-internal changes

Circulation type-specific trend analysis of surface air pressure (hPa) and temperature (°C) for the regional climate model MPI-RCA, RCP8.5. 2006-2100, Minimum (min), maximum (max), mean (mean), and difference (diff) between minimum and maximum values of variables

	Mean sea level pressure				Temperature			
CT	min	mean	max	diff	min	mean	max	diff
April-September								
3	0,00	0,01	0,50	0,00	0,47	0,43	0,33	0,38
12	0,53	0,32	0,01	0,02	0,00	0,00	0,32	0,00
14	0,01	0,00	0,00	0,27	0,00	0,00	0,00	0,00
16	0,01	0,00	0,00	0,80	0,00	0,08	0,85	0,00
October-March								
10	0,02	0,60	0,00	0,00	0,00	0,02	0,52	0,00
11	0,27	0,02	0,00	0,00	0,00	0,00	0,00	0,00
14	0,93	0,09	0,19	0,67	0,01	0,25	0,06	0,15
17	0,00	0,03	0,32	0,00	0,00	0,00	0,00	0,00

p-values for α = 0.05, Mann-Kendall trend test; red = sign. increase, blue = sign. decrease

6 Summary and Conclusion

- **drought-relevant circulation types** have been identified via advanced circulation type classification for the period 1961-2017

- projection of circulation types on RCM-output:
  - **frequency changes** until 2100 (showing increasing and decreasing trends for specific types)
  - changes appear more **distinct after 2071**
  - higher frequencies of drought relevant types **under RCP8.5**
  - varying **changes in persistence** of types
  - **within-type changes** include intensified anticyclonic conditions, increasing temperatures, reduced humidity

- drought relevant **types are related to periods of low flow** in the Isar river:
  - in summer mainly types with elongated Azores high pressure ridge
  - in winter mainly anticyclonic types centred over southern and central Europe
  - overall increasing frequencies of low flow relevant types until 2100 in summer