Atmospheric circulation types and extreme areal precipitation in southern central Europe – impacts of present and future climate change

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Zentralanstalt für Meteorologie und Geodynamik

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KONTAKT UND INFO

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WETRAX

Weather patterns, cyclone tracks and related precipitation extremes

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Data bases:

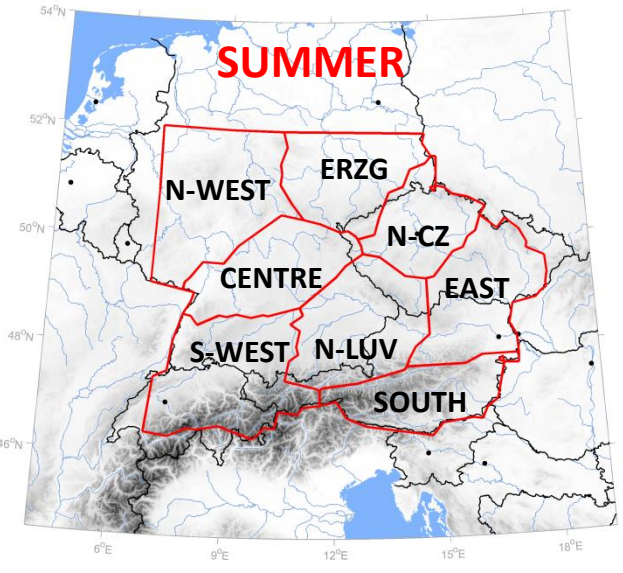
- daily gridded rainfall data 1951-2006
  (ZAMG, DWD, 6 km horizontal resolution)

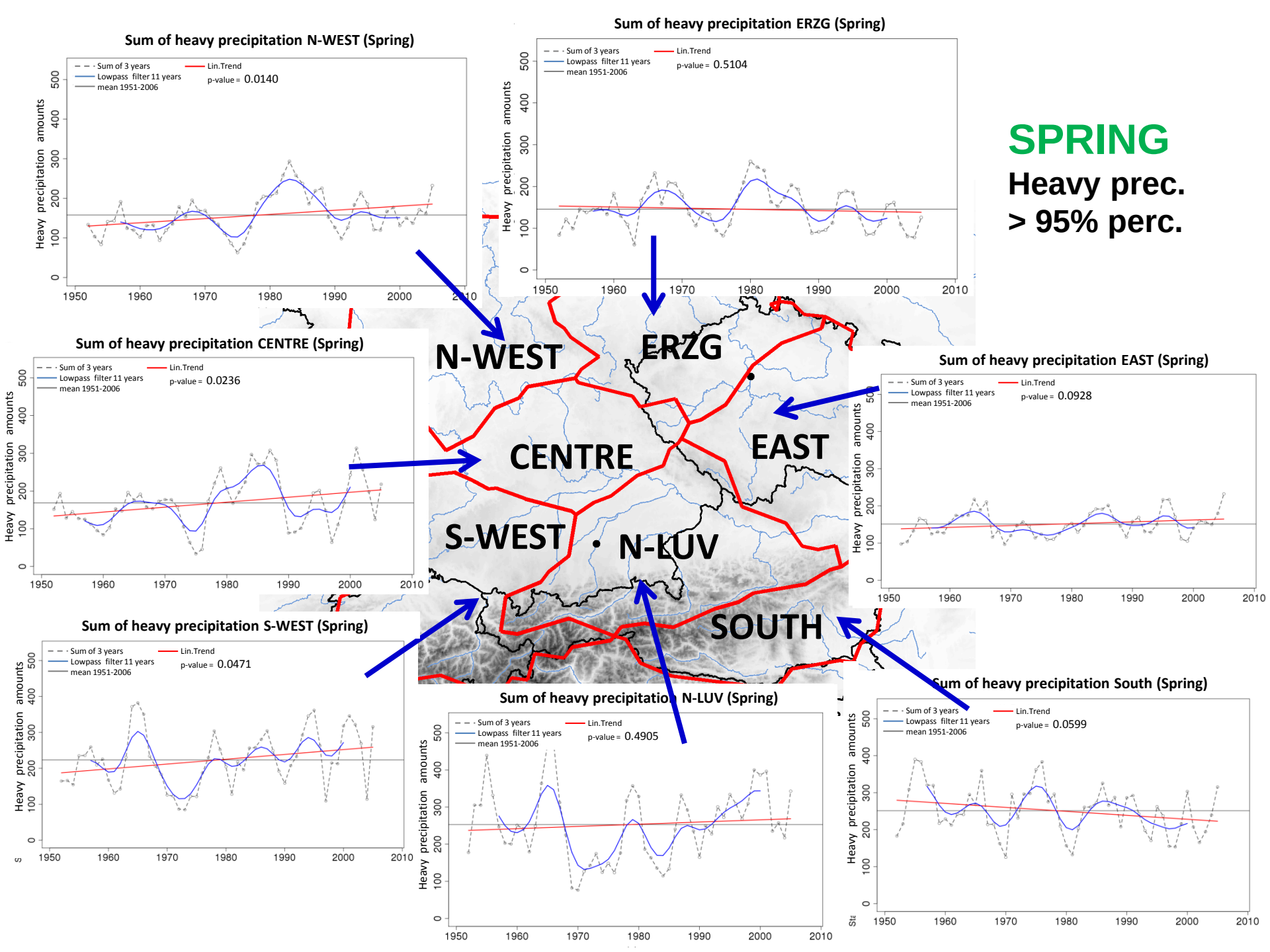
- NCEP1 re-analysis data of atmospheric variables
  (e.g. SLP, geop. heights, omega, specific and relative humidity)

Projections of global climate models (esp. ECHAM6-ESM, ECEarth) for two periods and two scenarios:

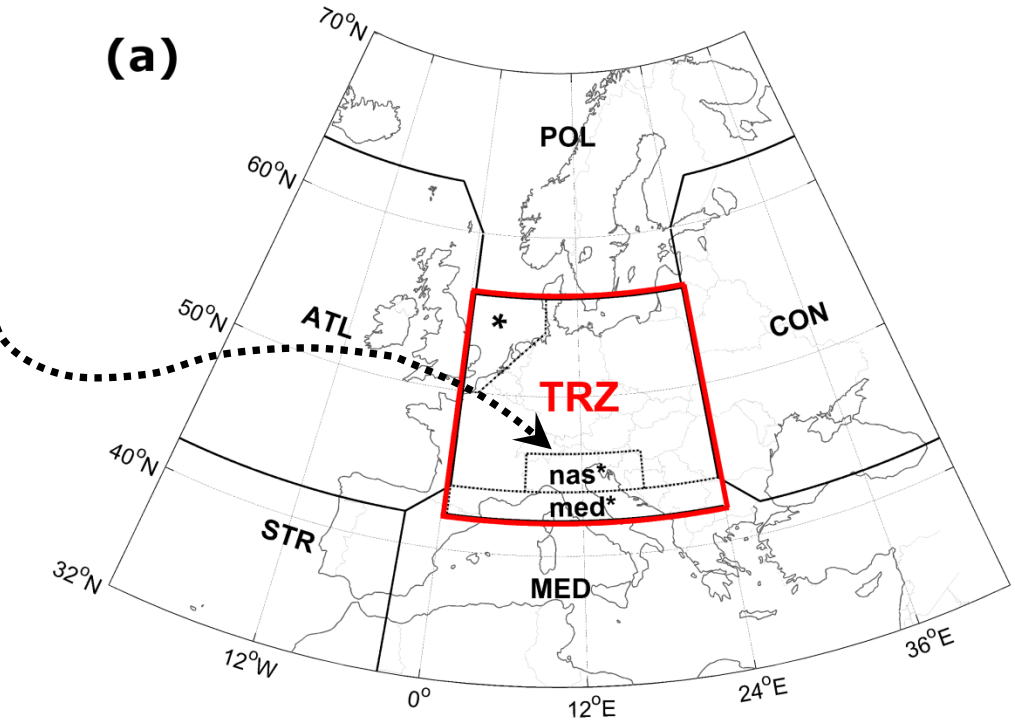
- 2021-2050 and 2071-2100
- RCP 4.5 and RCP 8.5

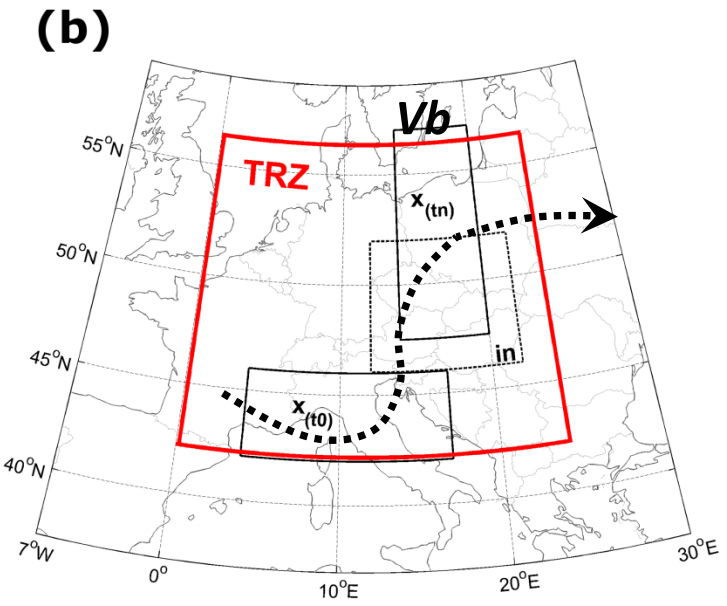
Regions of similar precipitation variability




Sum of heavy precipitation N-WEST (Spring)
Sum of 3 years
Lowpass filter 11 years
mean 1951-2006
Lin.Trend
p-value = 0.0140
Heavy precipitation amounts
Sum of heavy precipitation ERZG (Spring)
p-value = 0.5104
SPRING
Heavy prec.
> 95% perc.
N-WEST
ERZG
CENTRE
EAST
S-WEST
N-LUV
SOUTH
Sum of heavy precipitation CENTRE (Spring)
p-value = 0.0236
Sum of heavy precipitation EAST (Spring)
p-value = 0.0928
Sum of heavy precipitation S-WEST (Spring)
p-value = 0.0471
Sum of heavy precipitation N-LUV (Spring)
p-value = 0.4905
Sum of heavy precipitation South (Spring)
p-value = 0.0599

1st approach: Automatic classification of cyclone tracks





Hofstätter, M., Chimani, B., Lexer, A., and G. Blöschl: A stream-based classification of European cyclone tracks. (MWR, 2015)

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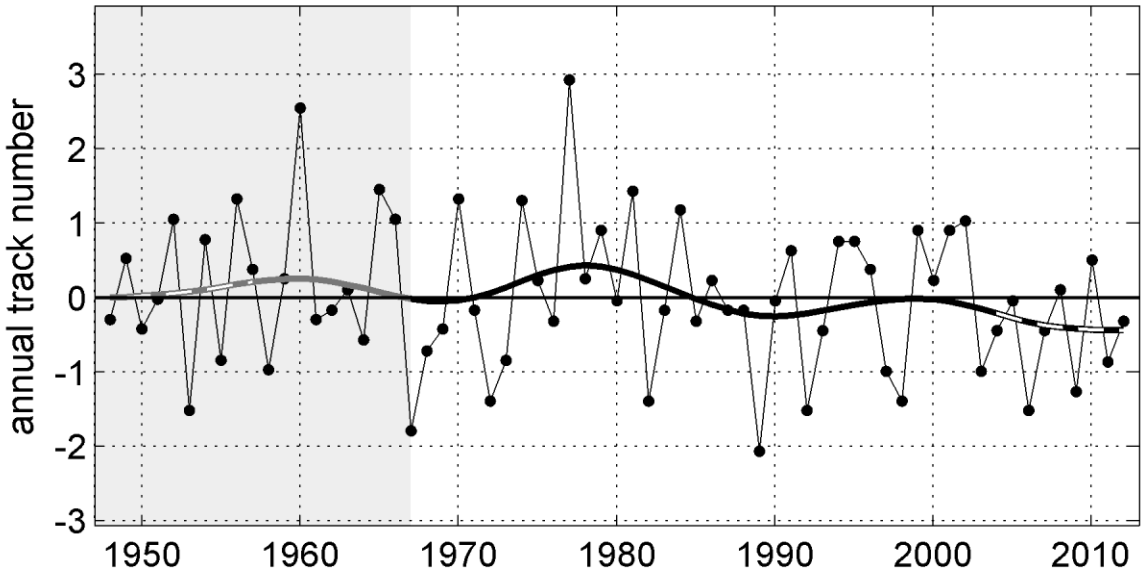
Vb-track

recent changes

NCEP1

(composite SLP, 700)

Entire year, all events (strong, weak)



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Vb-track

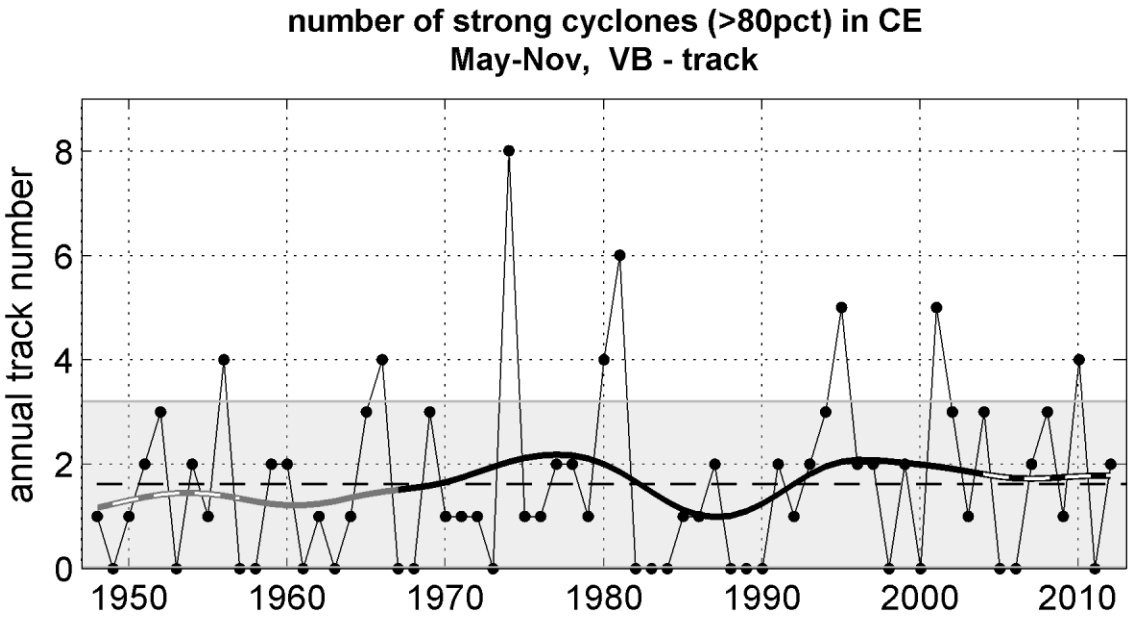
recent changes

NCEP1

(composite SLP, 700)

May-Nov;

only strong cyclones



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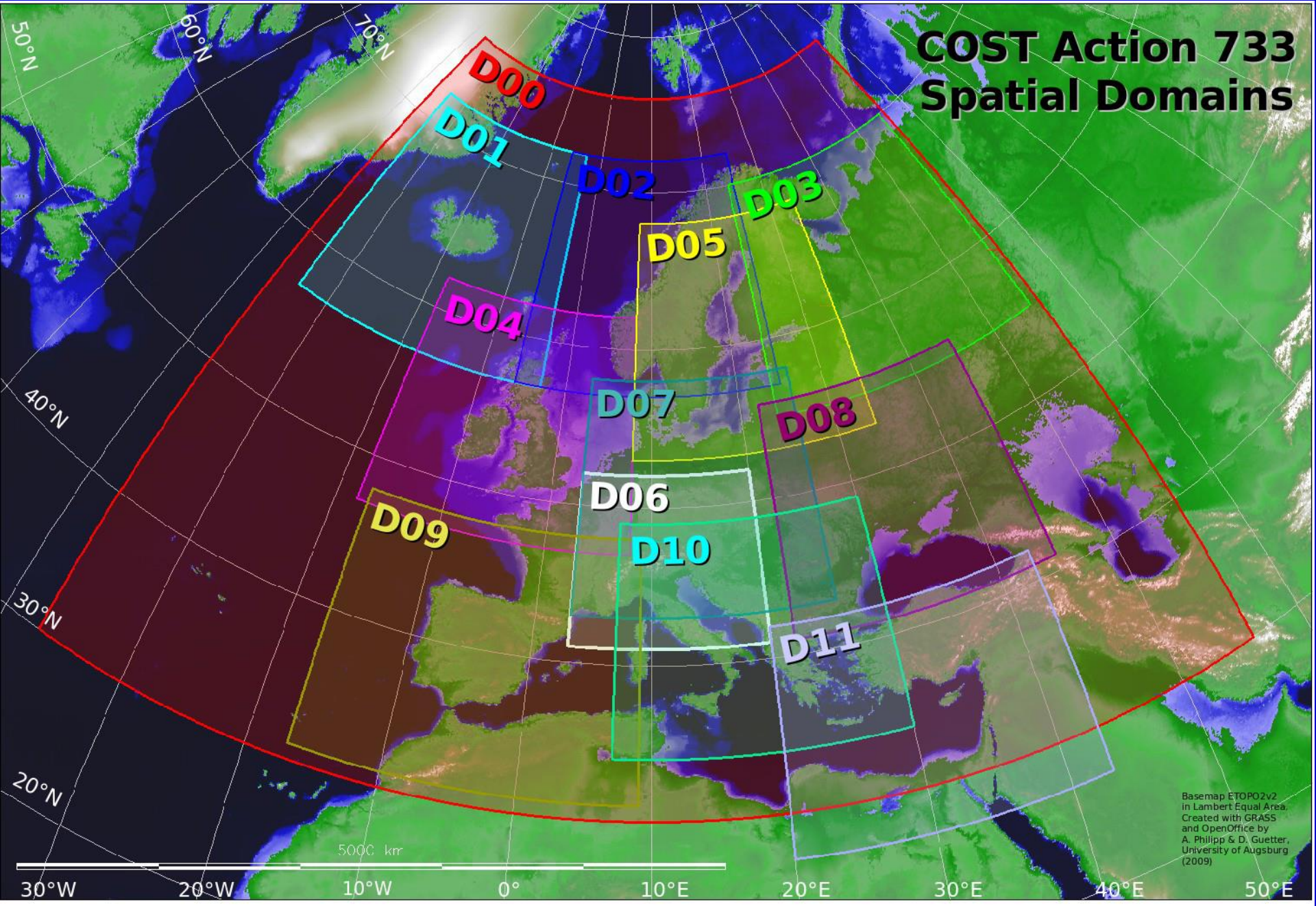
Second approach:

- **Classification of large-scale atmospheric circulation types**

- **Derivation of seasonal heavy precipitation frequencies and heavy precipitation amounts for the rainfall regions dependent on the occurrence frequencies of circulation types**

- **future assessments based on modified occurrence frequencies of circulation types in global climate model projections**



Domain 06 (Alps): 41N-52N, 3E-20E

finally applied circulation type classification: SANDRA (Simulated ANnealing and Diversified RAndomization)

- with differently weighted variable fields
  (SLP, Omega and rel. humidity 700 hPa level)

- conditioned mode (inclusion of regional rainfall time series)

- separately for seasons and rainfall regions

- uniform number of classes: 18

Percentage share of days with heavy precipitation within the 7 rainfall regions for the circulation types (CT1 to CT 18) in Spring

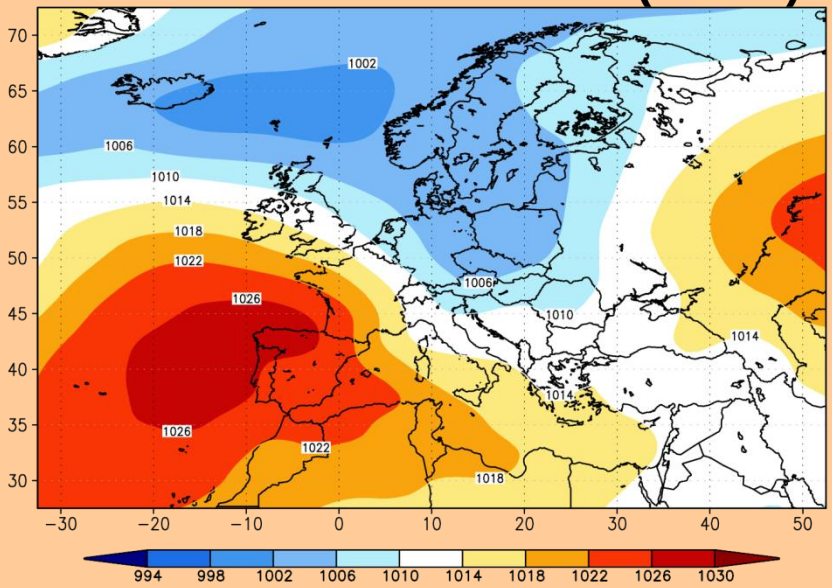
	N-West	Erzg	S-West	East	N-Luv	Centre	South
CT1	0	5,04	0	3,49	5,81	0,78	0
CT2	17,44	18,6	9,3	10,47	13,95	**24,42**	1,55
CT3	1,16	1,94	1,94	9,69	4,26	1,55	**55,04**
CT4	0	0	0	0	0	0	0
CT5	0	0	0,39	0	0,39	0,39	0
CT6	2,33	5,43	19,77	3,1	10,47	11,24	0,39
CT7	4,26	3,49	5,81	3,49	6,2	6,2	1,94
CT8	0	0	0	0	0	0	0
CT9	1,16	0,39	6,59	0	0	0,78	0
CT10	**45,74**	**20,54**	7,75	1,94	0,39	19,77	0
CT11	1,55	4,26	4,65	9,69	10,47	3,49	**20,54**
CT12	0	0	0	0	0	0	0
CT13	7,36	7,36	**34,11**	4,26	9,69	**20,16**	5,04
CT14	1,16	6,59	8,91	**20,54**	**31,78**	5,81	12,79
CT15	0	2,71	0,39	1,16	0,39	0	0
CT16	0,78	17,44	0,39	**29,84**	6,2	2,33	1,55
CT17	16,67	5,43	0	0,39	0	3,1	0
CT18	0,39	0,78	0	1,94	0	0	1,16

Percentage of days of Spring circulation types (CT1 to CT18) connected with heavy precipitation in the 7 rainfall regions

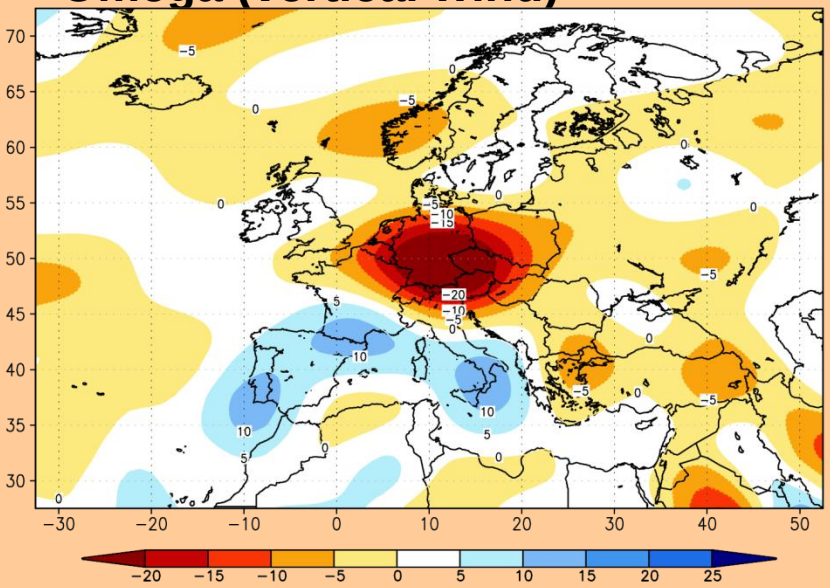
	N-West	Erzg	S-West	East	N-Luv	Centre	South
CT1	0	3,92	0	2,71	4,52	0,6	0
CT2	60,81	64,86	32,43	36,49	48,65	85,14	5,41
CT3	1,6	2,67	2,67	13,37	5,88	2,14	75,94
CT4	0	0	0	0	0	0	0
CT5	0	0	0,2	0	0,2	0,2	0
CT6	2,47	5,76	20,99	3,29	11,11	11,93	0,41
CT7	64,71	52,94	88,24	52,94	94,12	94,12	29,41
CT8	0	0	0	0	0	0	0
CT9	1,02	0,34	5,76	0	0	0,68	0
CT10	78,67	35,33	13,33	3,33	0,67	34	0
CT11	7,41	20,37	22,22	46,3	50	16,67	98,15
CT12	0	0	0	0	0	0	0
CT13	21,35	21,35	98,88	12,36	28,09	58,43	14,61
CT14	3,57	20,24	27,38	63,1	97,62	17,86	39,29
CT15	0	1,22	0,17	0,52	0,17	0	0
CT16	2,08	46,88	1,04	80,21	16,67	6,25	4,17
CT17	11,88	3,87	0	0,28	0	2,21	0
CT18	0,26	0,52	0	1,3	0	0	0,78

Centroid CT 7, Spring 1951-2006

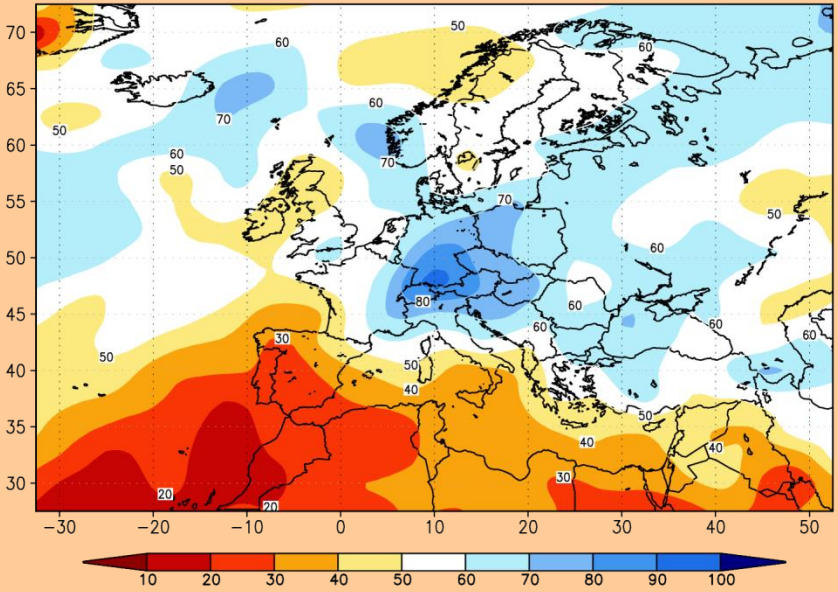
Mean Sea Level Pressure (MSLP)



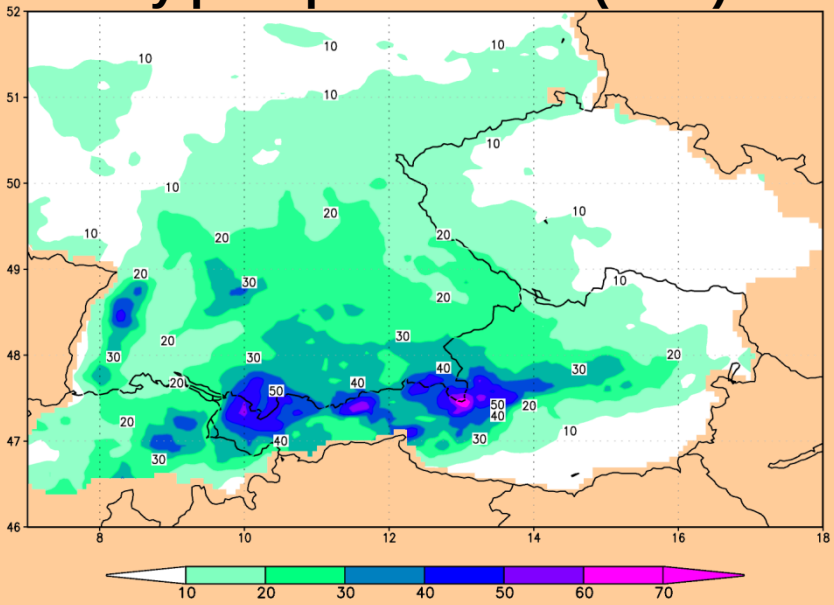
Omega (vertical wind)



Relative humidity (Rhum)

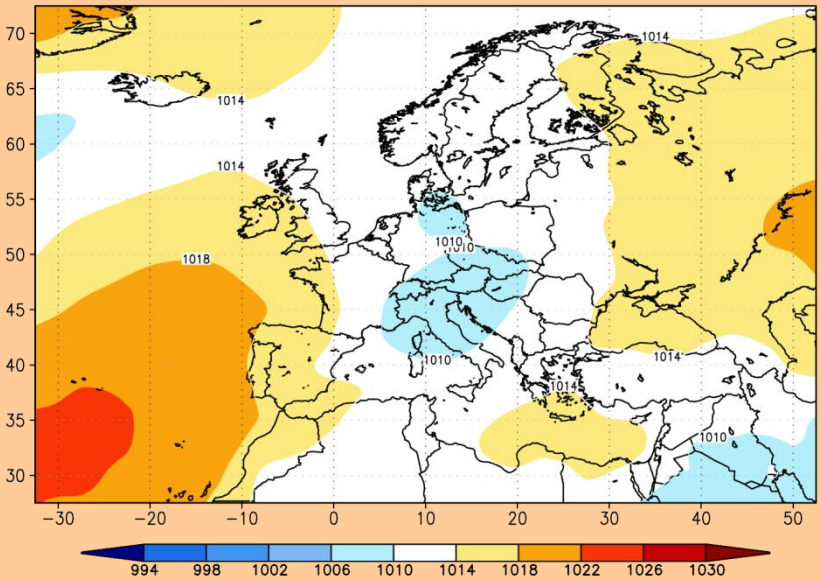


Daily precipitation rate (Prec)

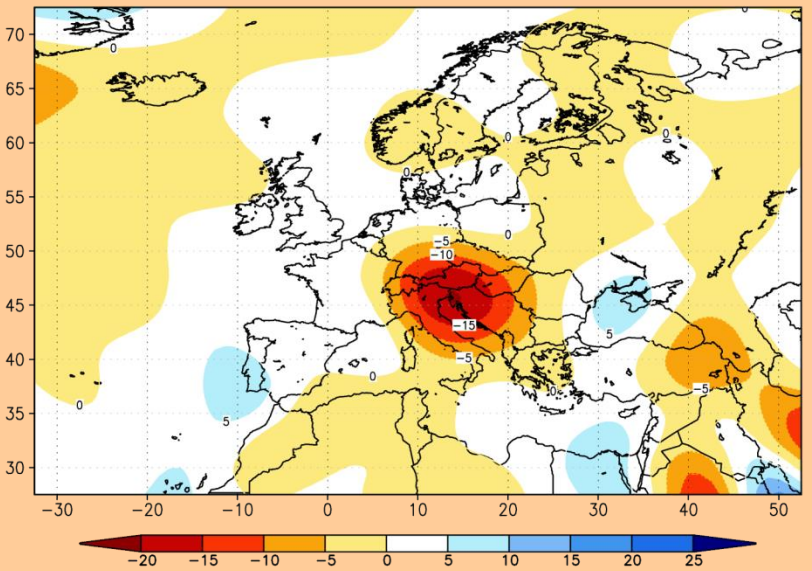


Centroid CT 3, Spring 1951-2006

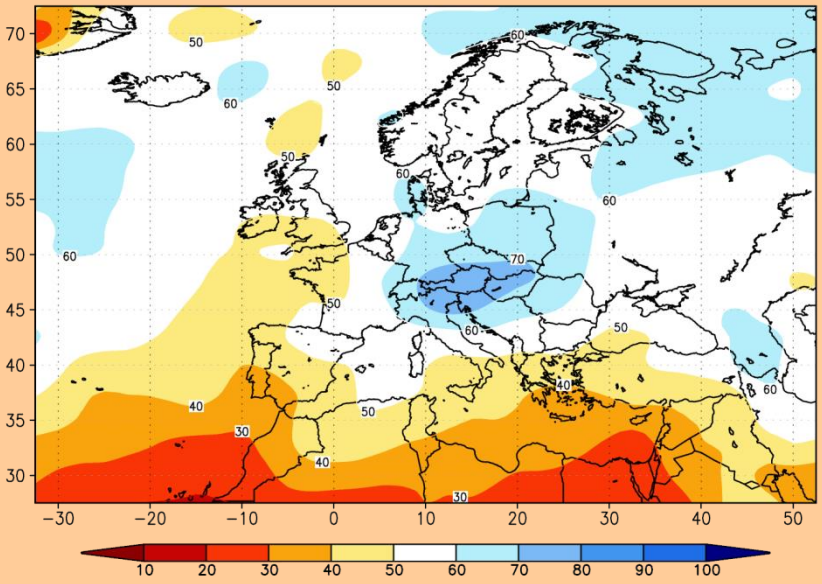
MSLP



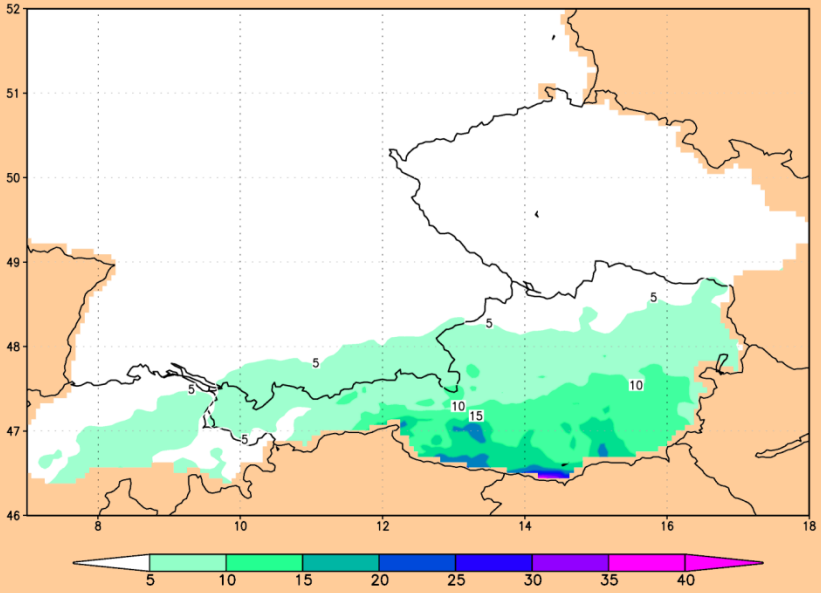
Omega



Rhum

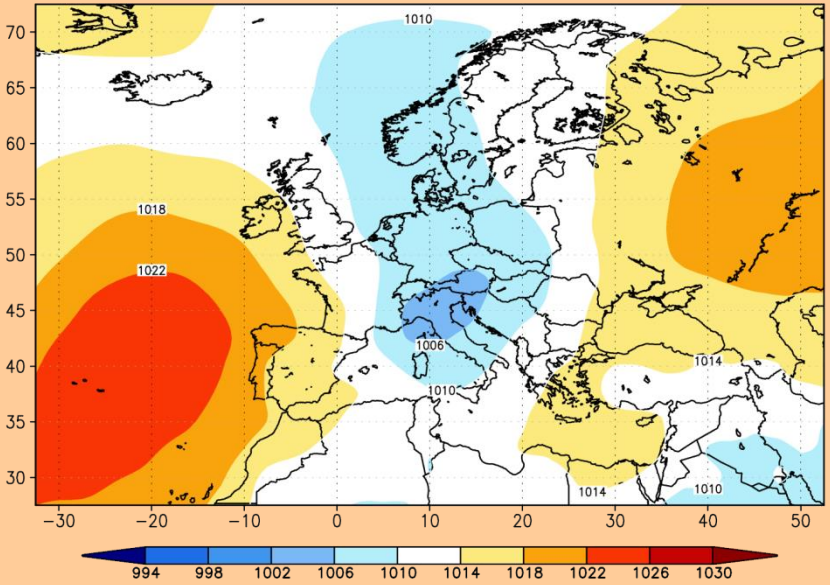


Prec

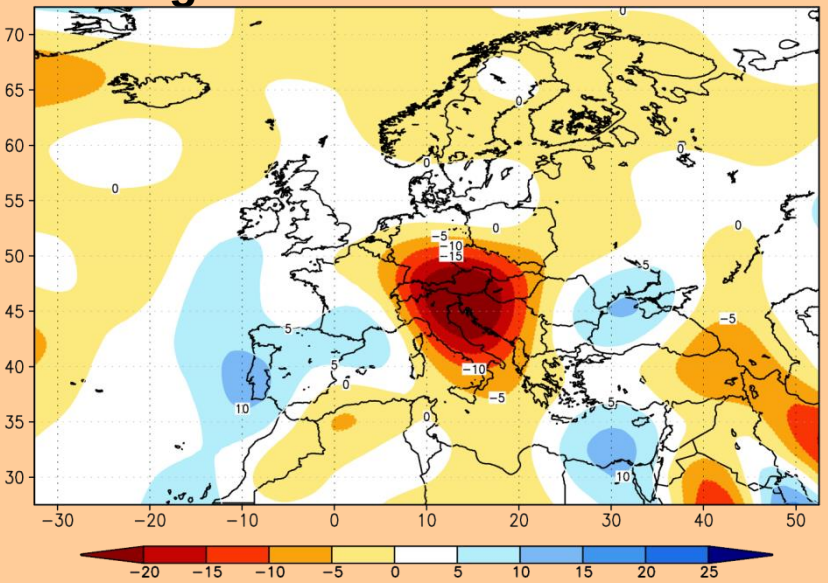


Centroid CT 11, Spring 1951-2006

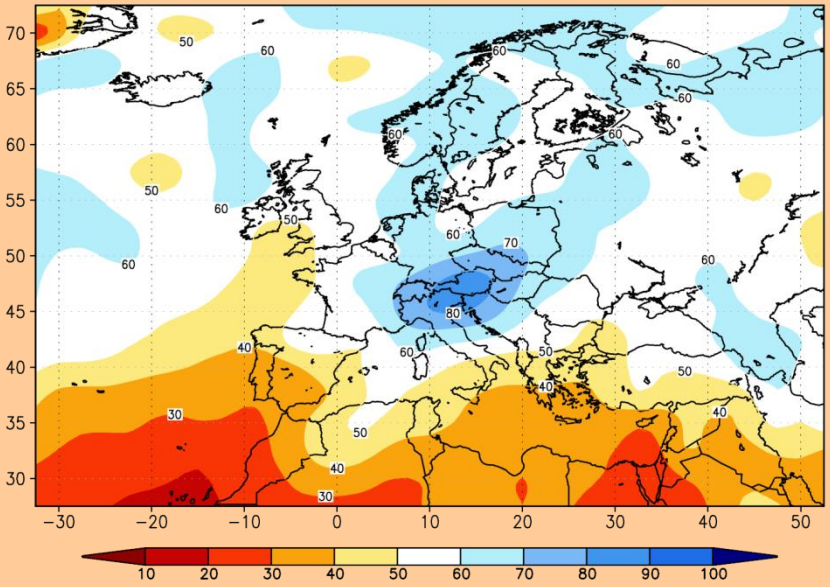
MSLP



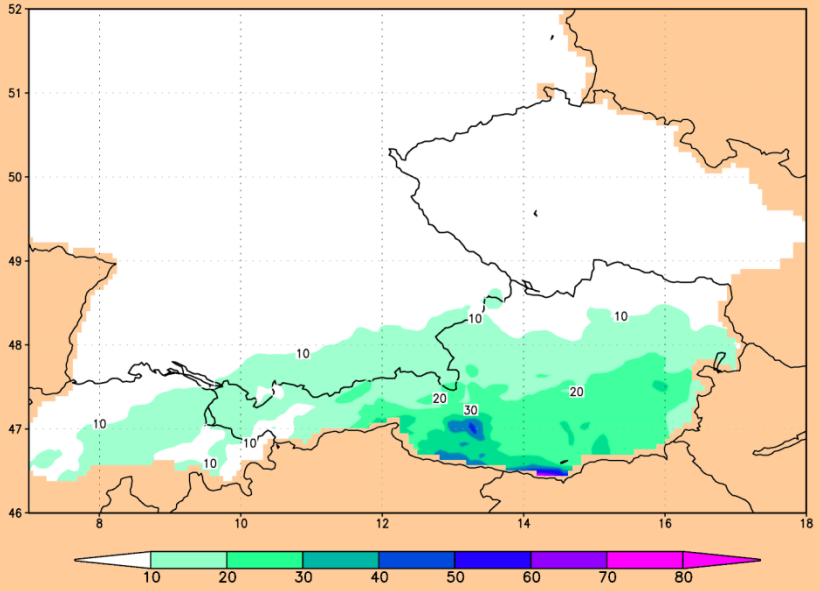
Omega



Rhum

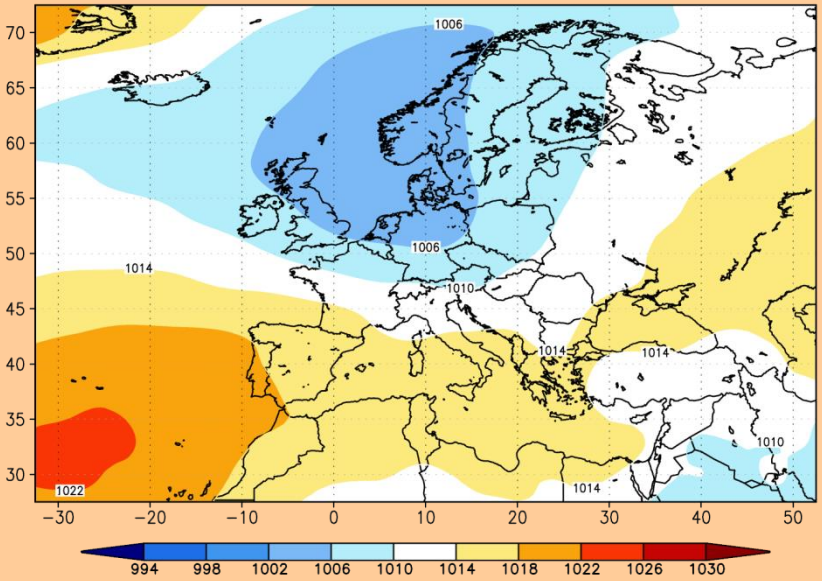


Prec

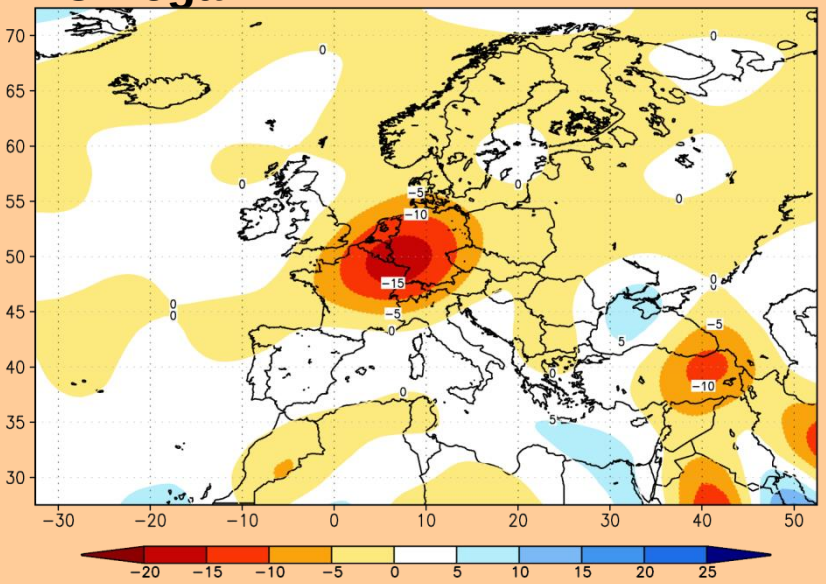


Centroid CT 10, Spring 1951-2006

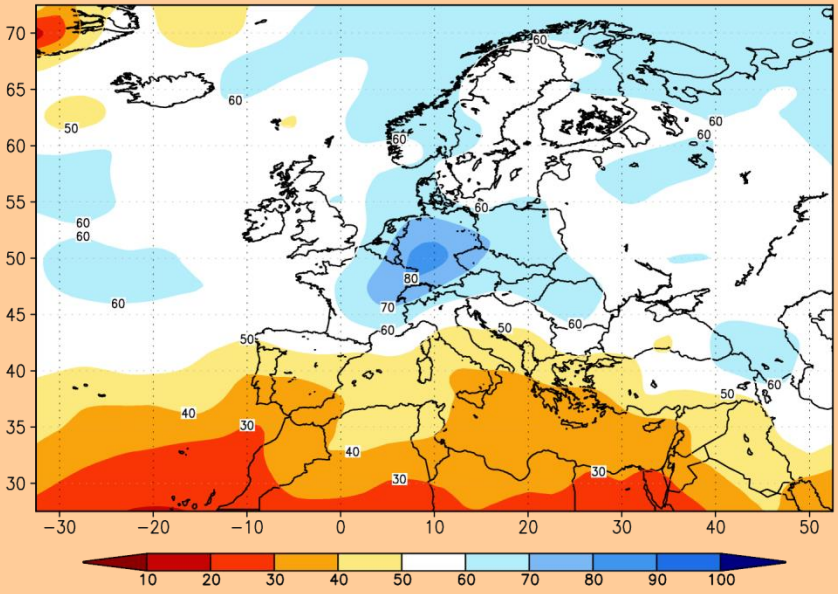
MSLP



Omega



Rhum



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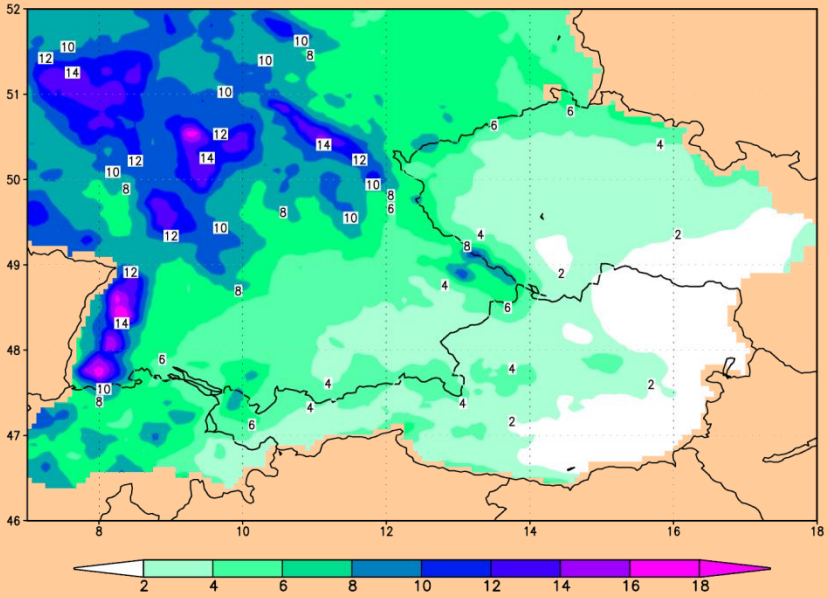
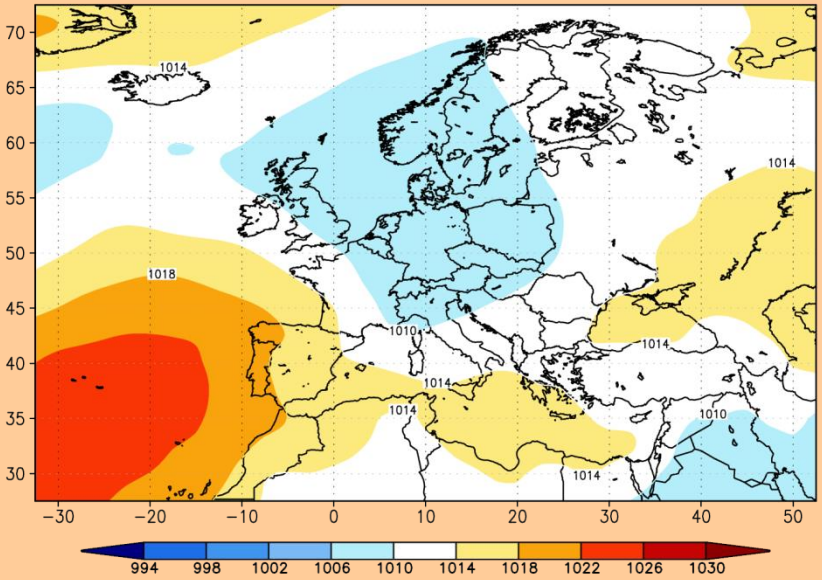
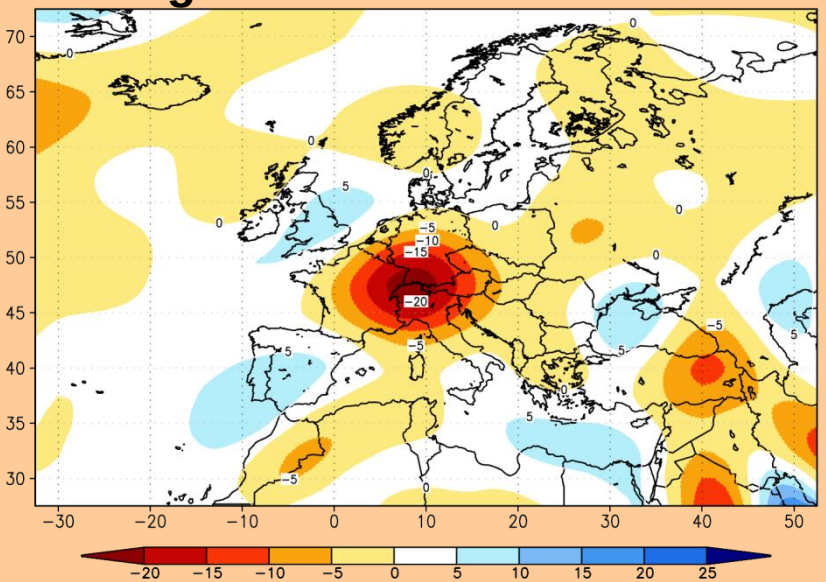


Centroid CT 13, Spring 1951-2006

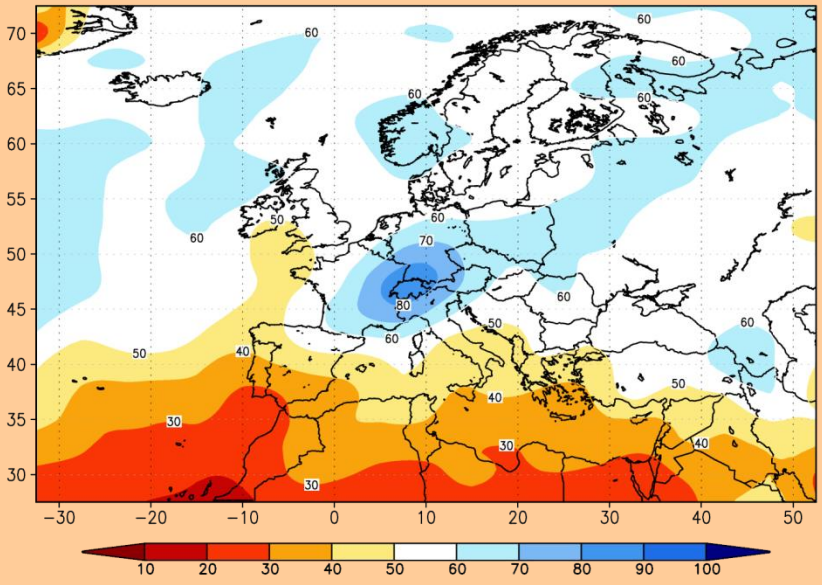
MSLP



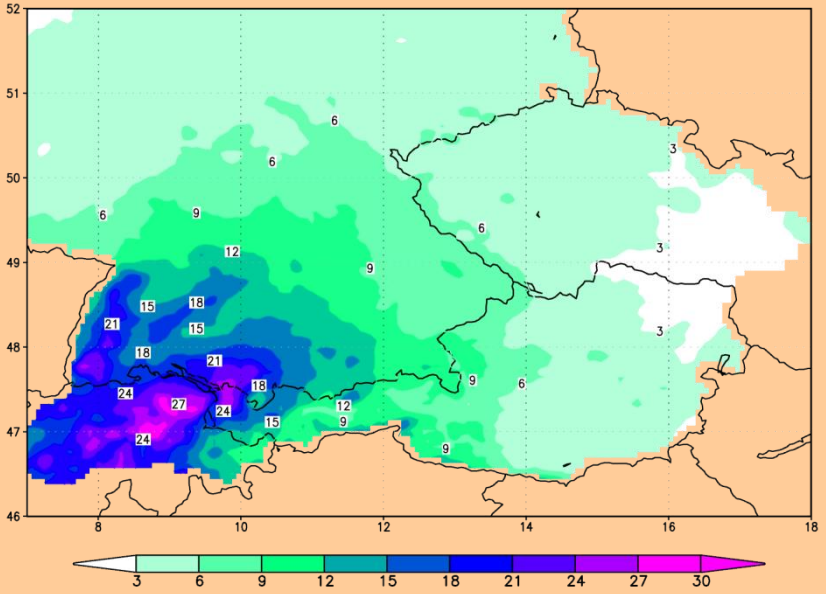
Omega



Rhum

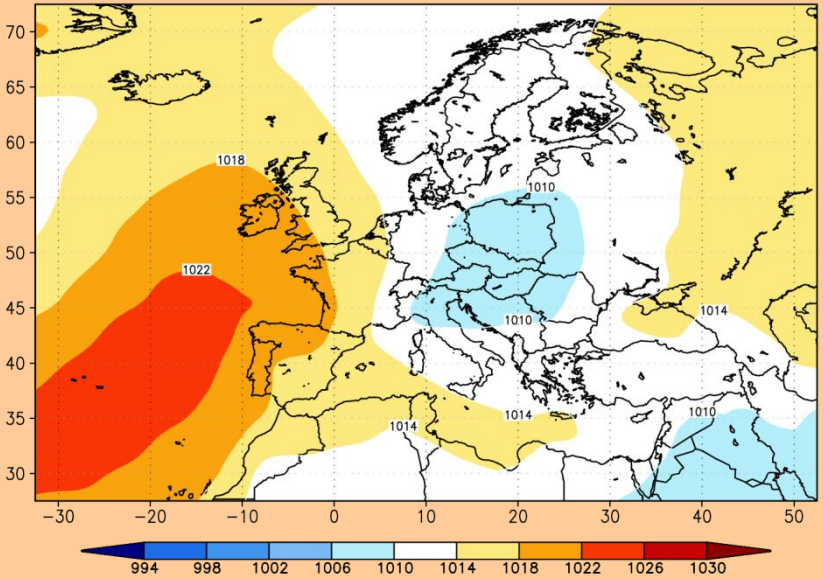


Prec



Centroid CT 14, Spring 1951-2006

MSLP



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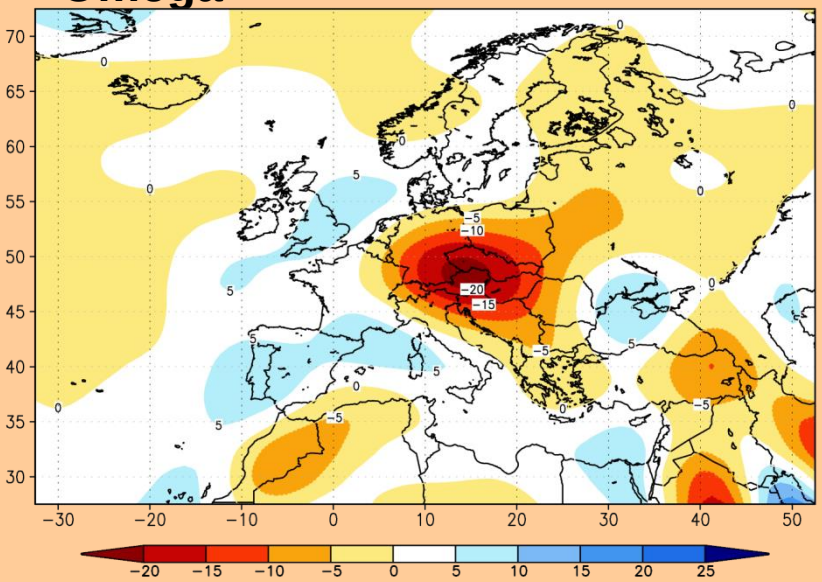
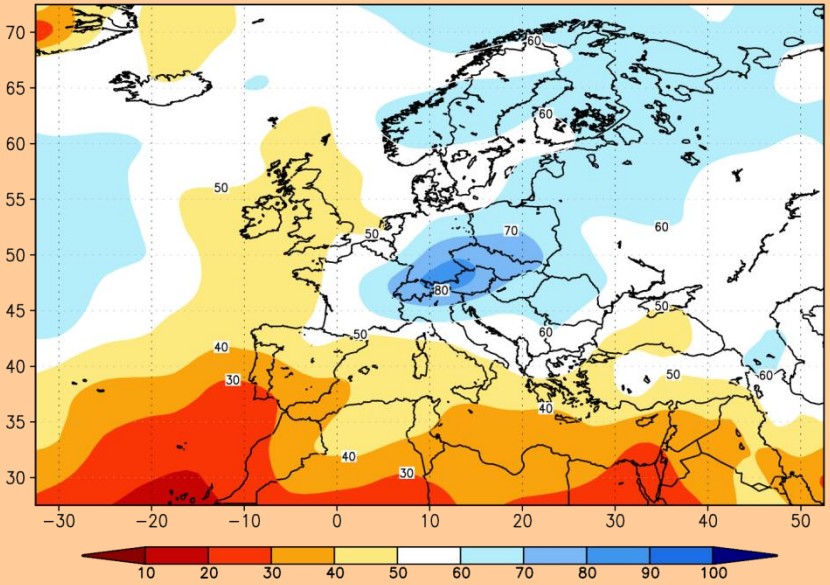


Rhum



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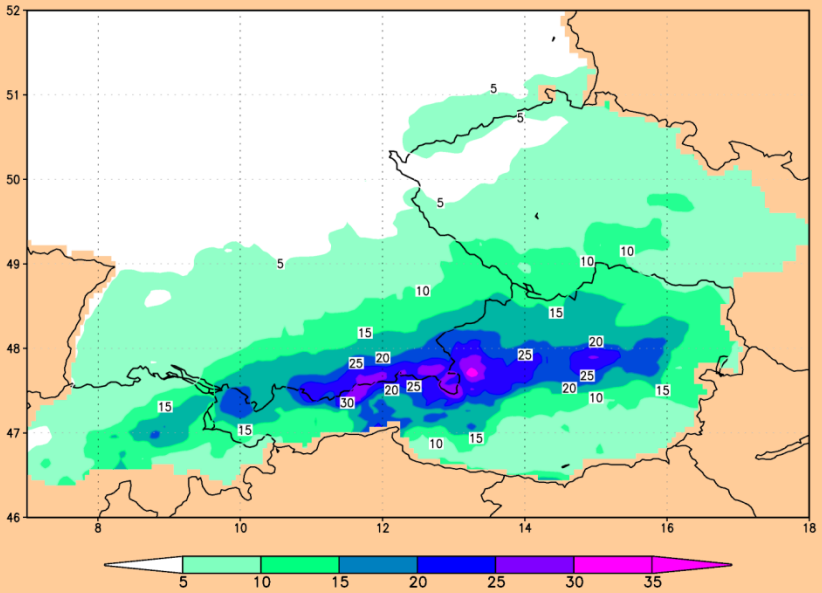
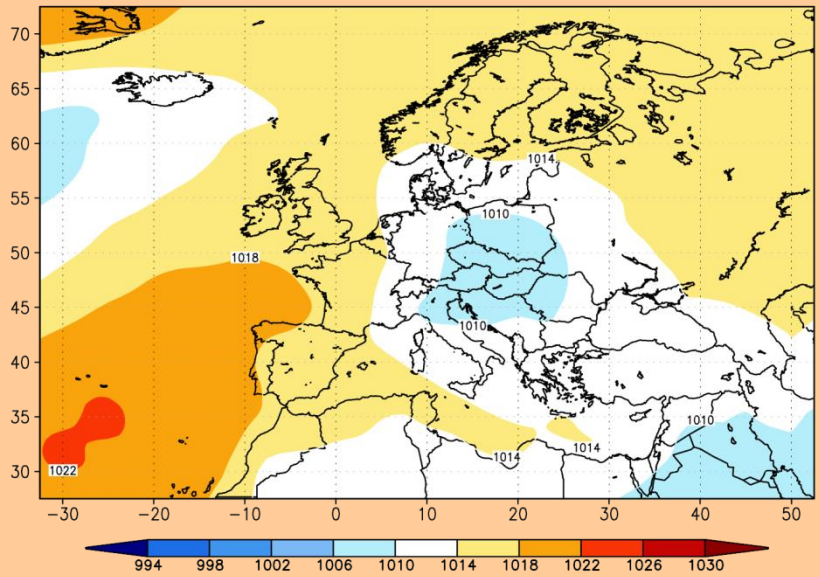
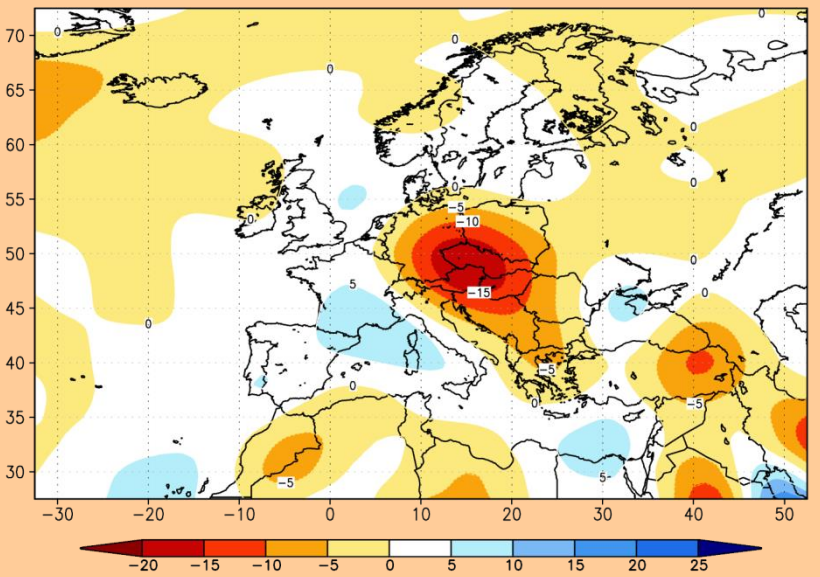


Centroid CT 16, Spring 1951-2006

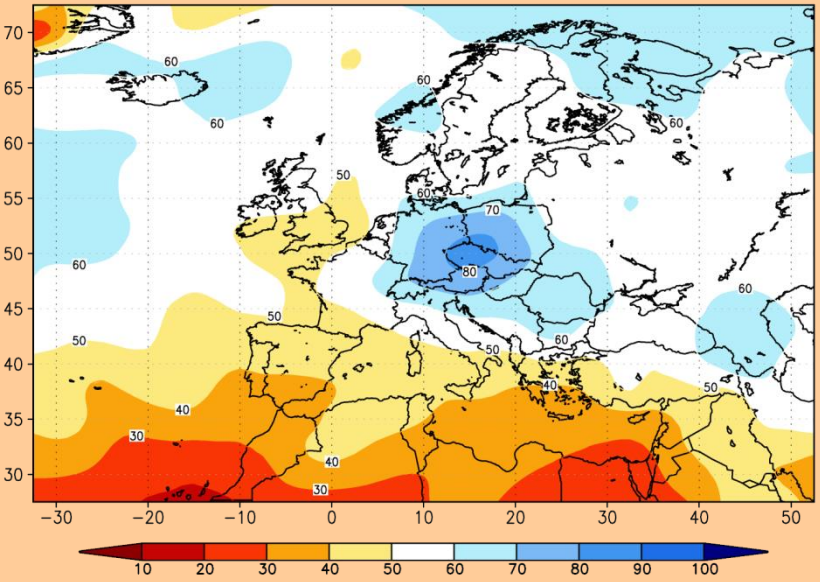
MSLP



Omega



Rhum



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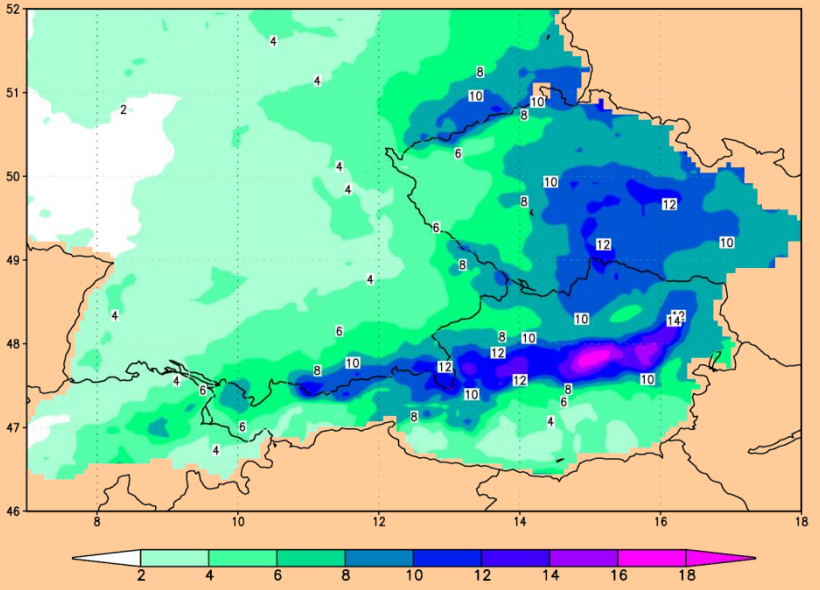
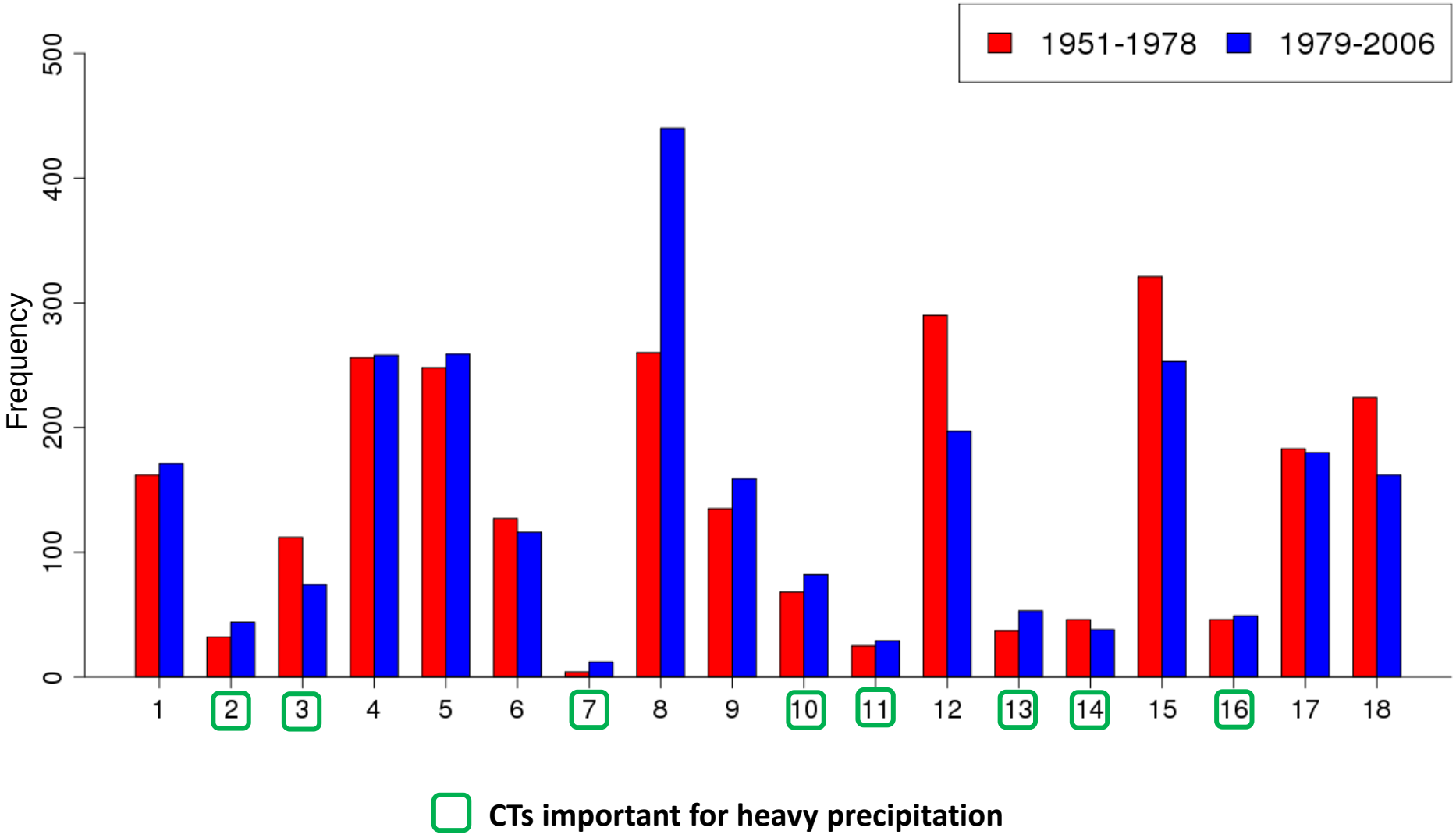
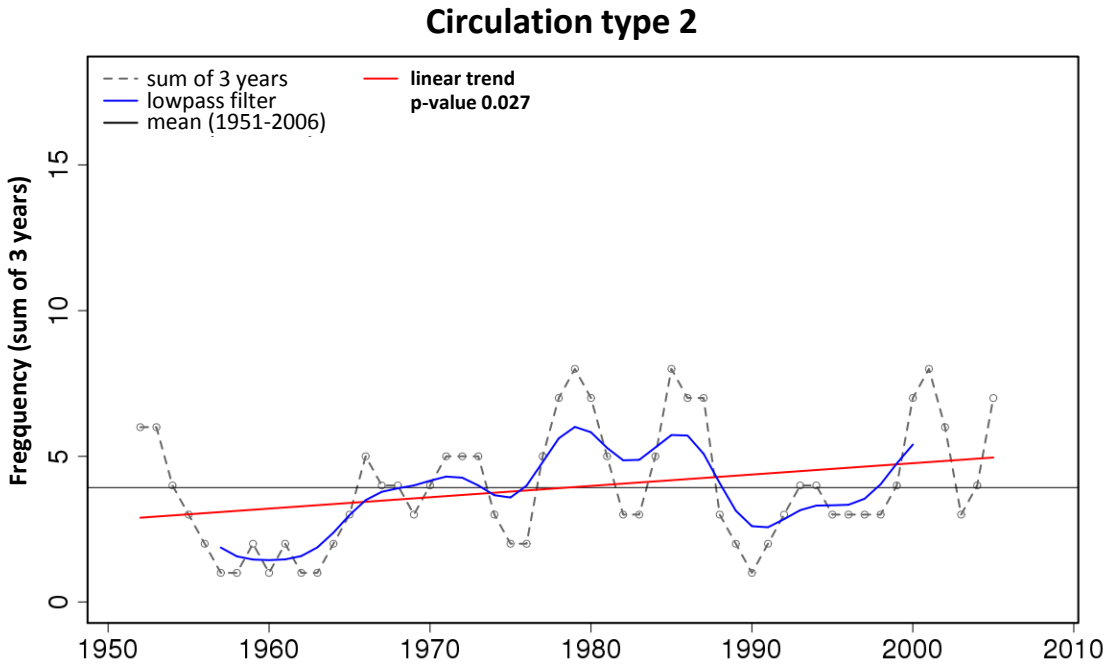


Frequencies of circulation types Spring (MAM)

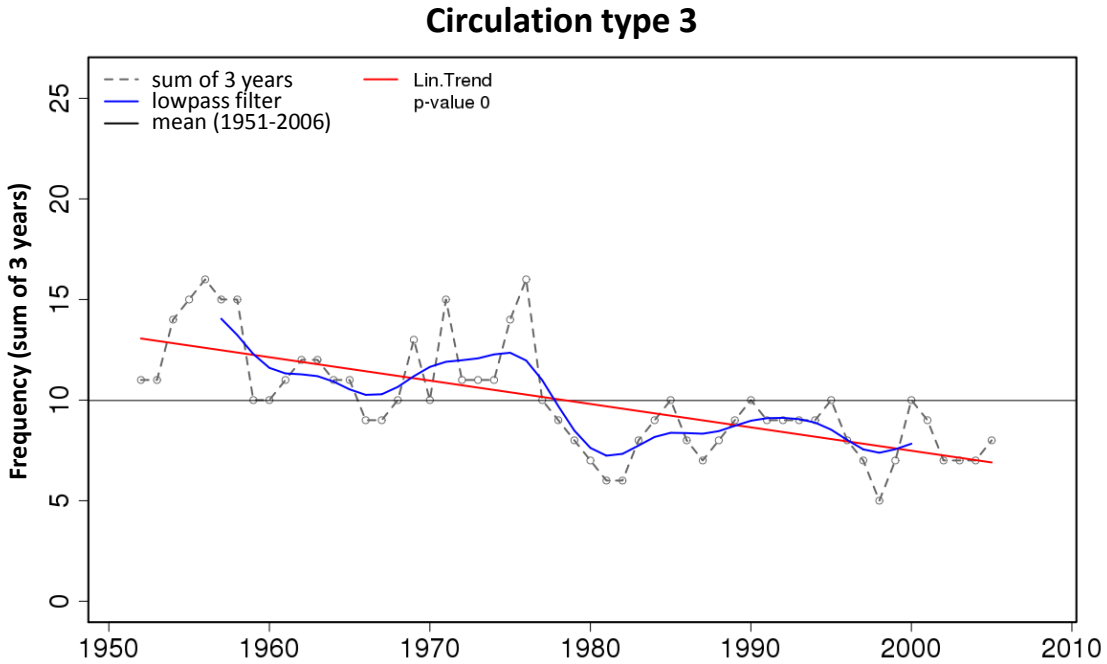


CTs important for heavy precipitation



Spring

Subpolar low (N and W)



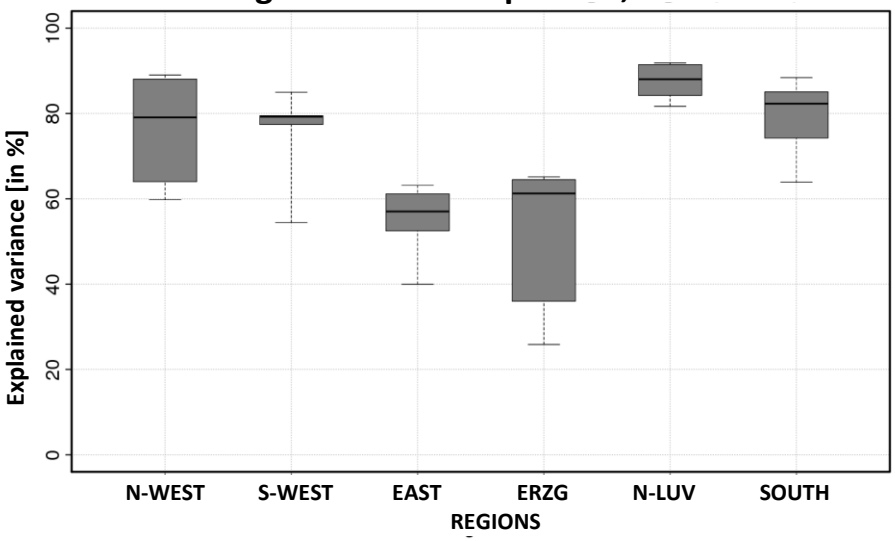
Cut-off low (S)

Multiple linear regression models for seasonal heavy precipitation

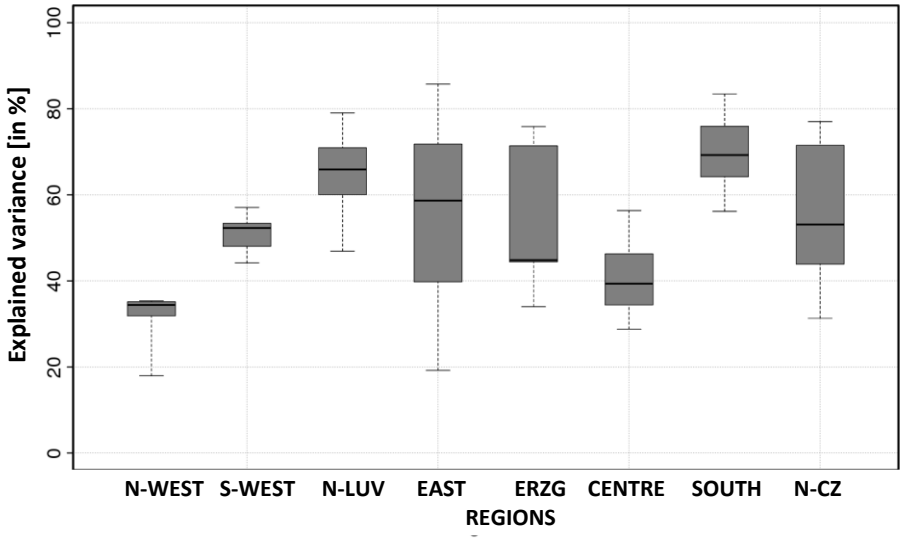
Predictors: monthly frequencies of circulation types

In each case **5 Models** with 5 different calibriation and validation periods

Explained variance of heavy precipitation amounts during the validation periods, Winter

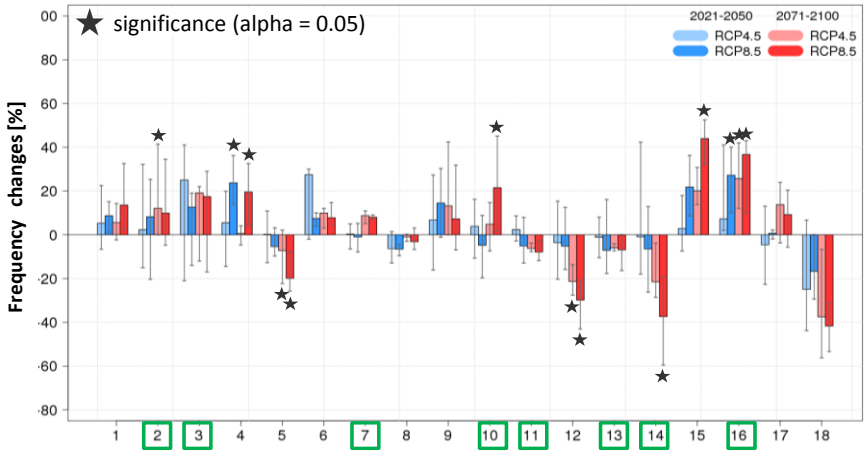


Explained variance of heavy precipitation amounts during the validation periods, Summer

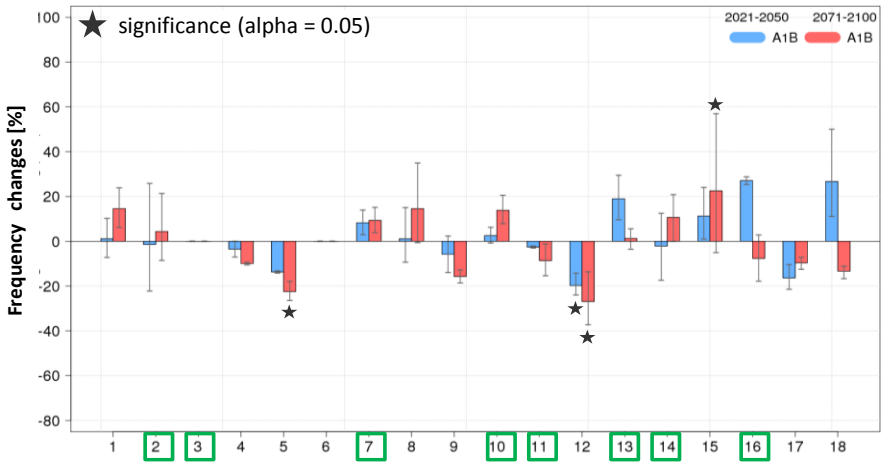


- Regional and seasonal differences (highest performance in winter)
- Indications for non-stationarities of predictor-predictand-relationships esp. in summer

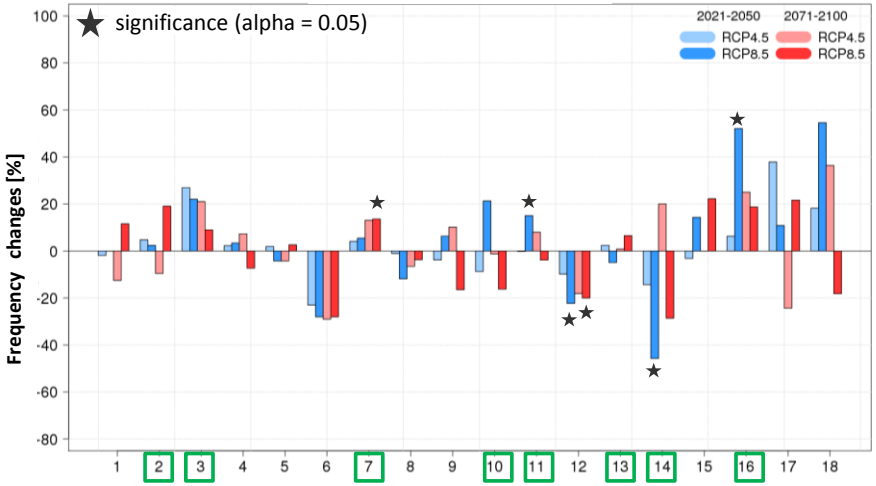
1a: ECHAM6, Spring



1b: ECHAM5, Spring



1c: EC-Earth, Spring



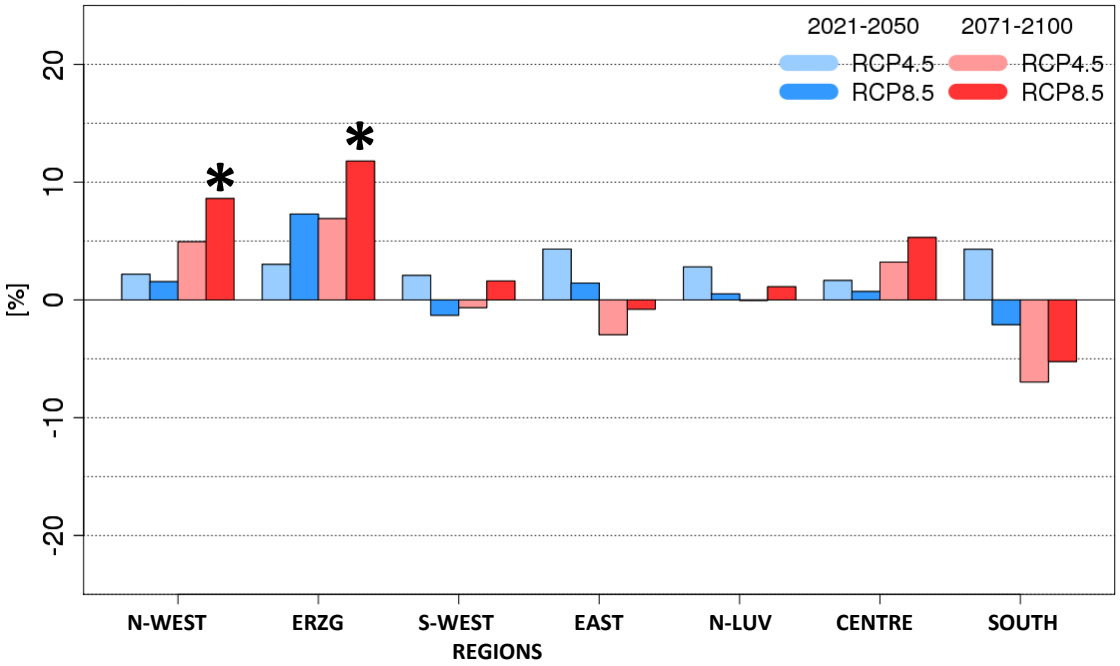
Frequency changes (%) of circulation types in **Spring** between projection periods (2021-2050 and 2071-2100) and the reference period (1971-2000).

For multiple realisations, the ensemble mean and the range are shown

☐ **CTs important for heavy precipitation**

Heavy precipitation frequencies Spring, % changes wrt 1971-2000,

based on ECHAM6-Predictors

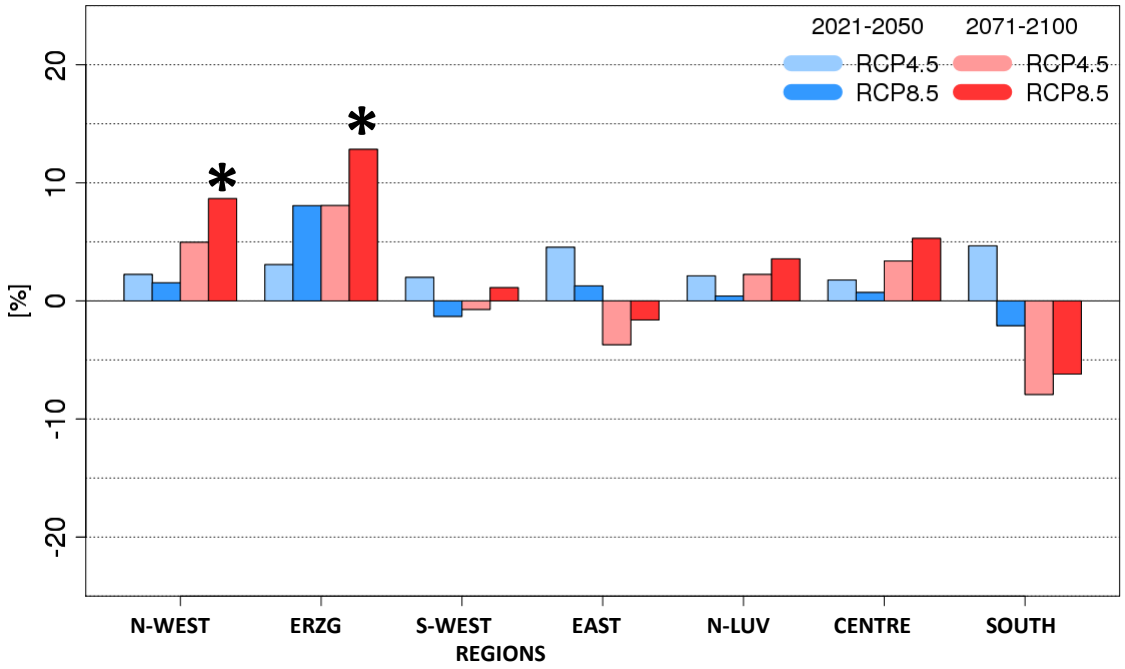


* 95% significance

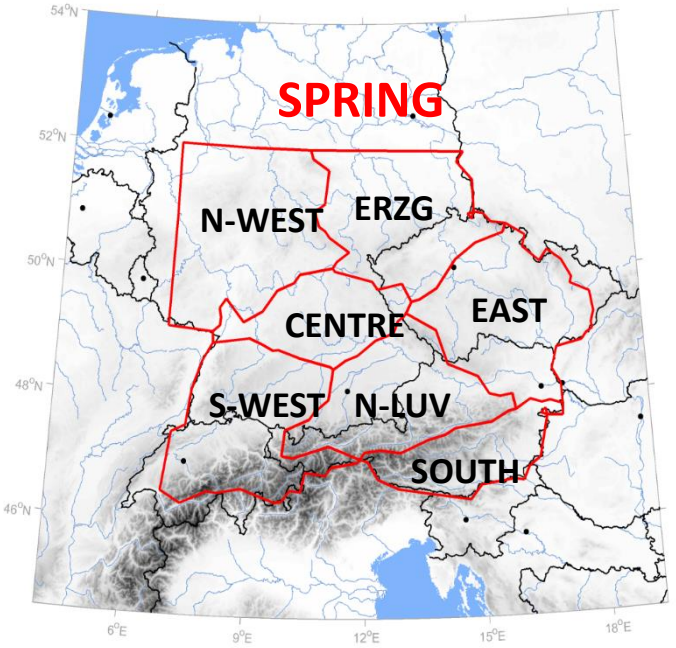
- increase in northern regions (up to +12%)
- decrease „South“ (up to -7%)

Heavy precipitation amounts Spring, % changes wrt 1971-2000,

based on ECHAM6-Predictors



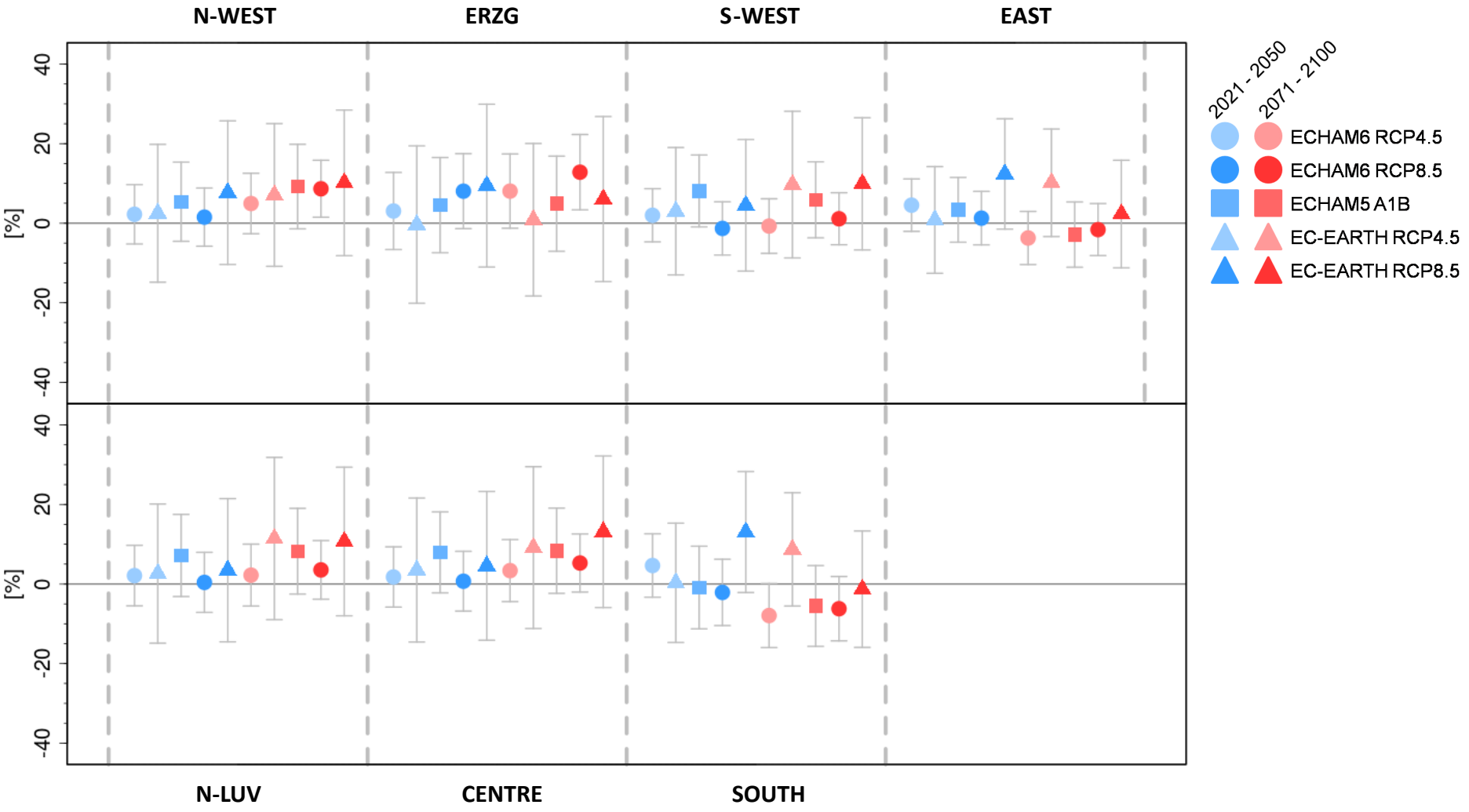
* 95% significance



- increase in northern regions (up to +13%)
- decrease „South“ (up to -8%)

Changes (%) of heavy precipitation amounts

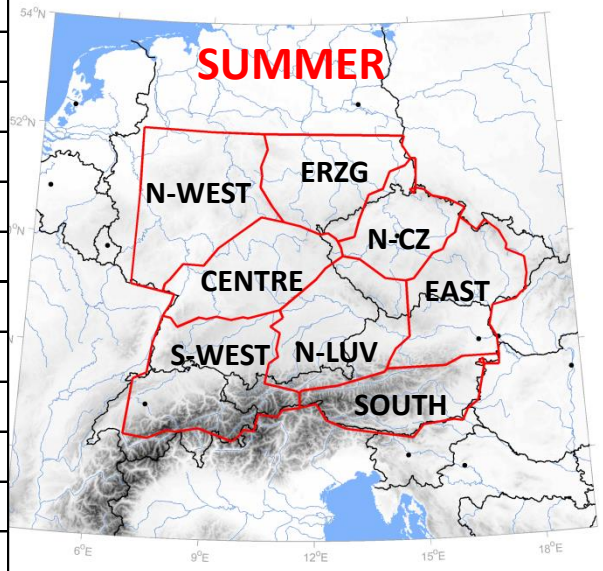
Predictors from different GCMs, **Spring**



Changes for ensemble means with respect to 1971-2000
including 95% confidence intervals

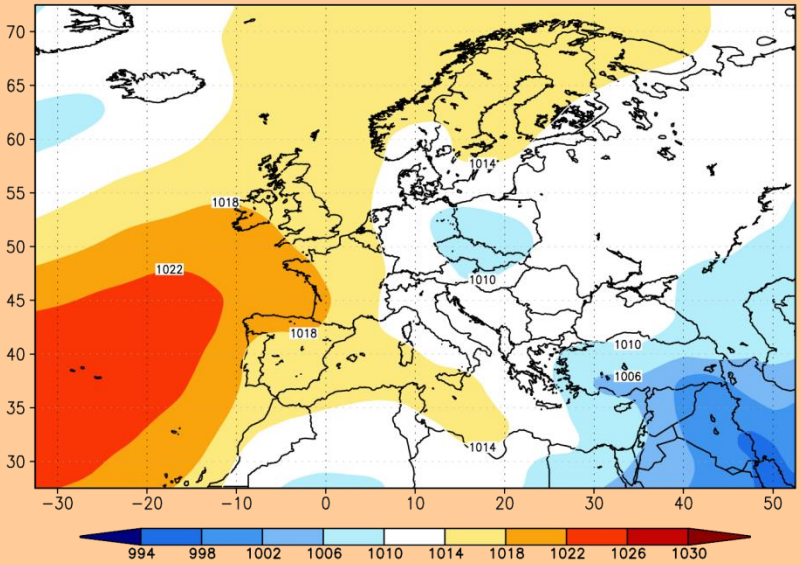
Percentage of days of Summer circulation types (CT1 to CT18) connected with heavy precipitation in the 8 rainfall regions

	N-West	S-West	N-Luv	East	Erzg	Centre	South	N-Cz
CT1	34,6	7,4	25,9	12,4	91,4	53,1	0	63
CT2	53,5	30,8	4,1	0,6	20,9	49,4	0,6	7
CT3	0,5	0,5	1	7,7	0,5	0,5	47,2	0
CT4	0,2	0	0	0,2	0,2	0	0	0
CT5	7,1	67,9	96,4	75	46,4	21,4	71,4	75
CT6	0	4,4	52,2	78,9	13,3	7,8	4,4	52,2
CT7	0	0	0	0	0	0	0	0
CT8	2,3	29,9	30,4	13,6	3,3	7,9	5,6	15
CT9	6,3	26,1	36	51,4	6,3	1,8	99,1	12,6
CT10	0,8	0	0,3	5,3	3,9	0,3	0	1,9
CT11	14,3	0	0	0,3	6,3	2,5	0,3	1,1
CT12	0	0	0	0,3	0	0	0	0
CT13	0	0	0	0	0	0	0	0
CT14	0	0	0,7	1	1,2	0,5	0	2,6
CT15	25,8	93,9	62,1	10,6	34,9	68,2	15,2	40,9
CT16	3,8	5,8	0	0	2	3,5	0	0,6
CT17	9,3	0	1,2	5,7	10,5	8,1	2,4	8,7
CT18	1,6	0	0	0,3	0	0,3	0	0,3

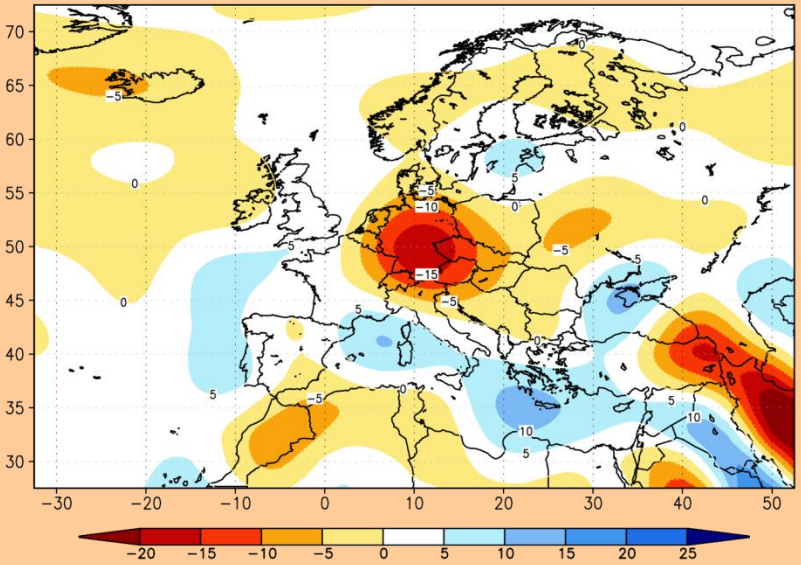


Centroids CT 1, Summer 1951-2006

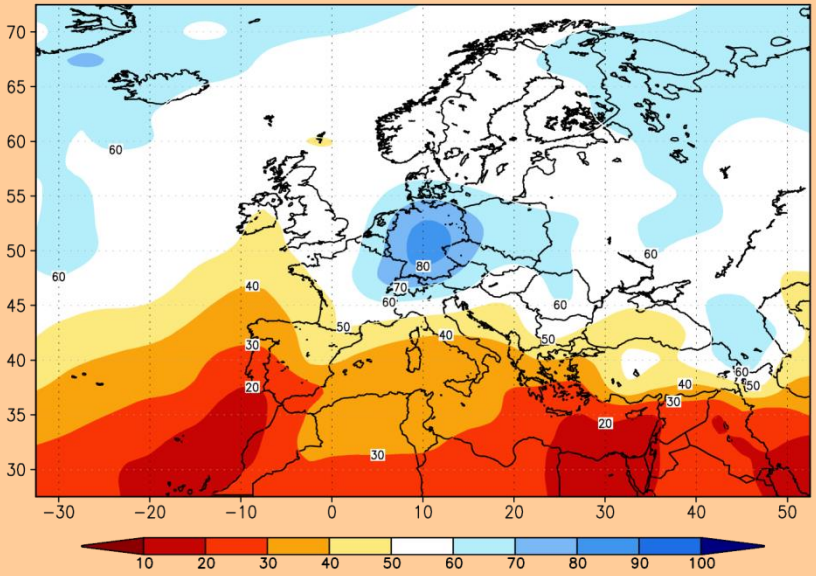
MSLP



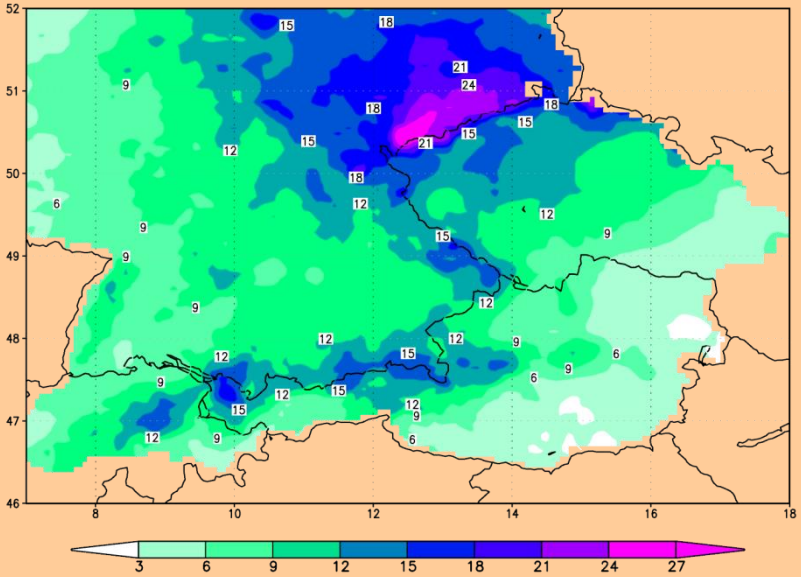
Omega



Rhum

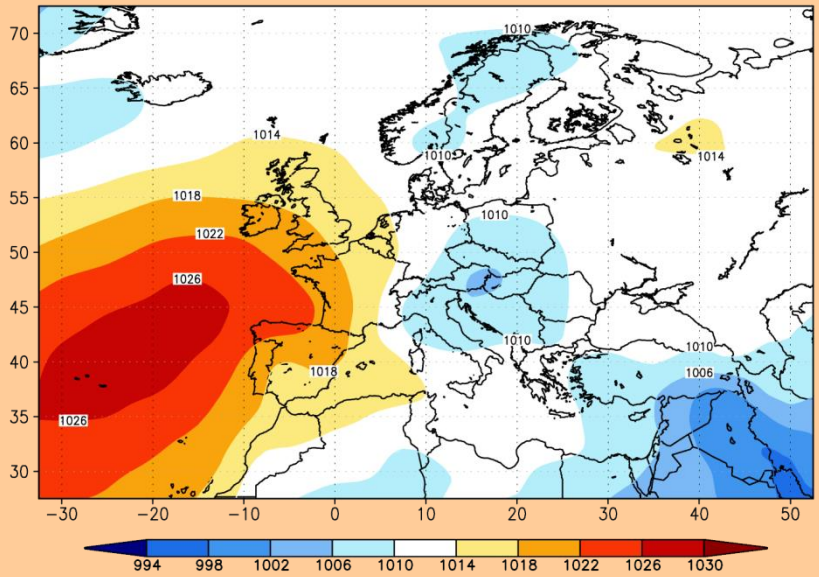


Prec

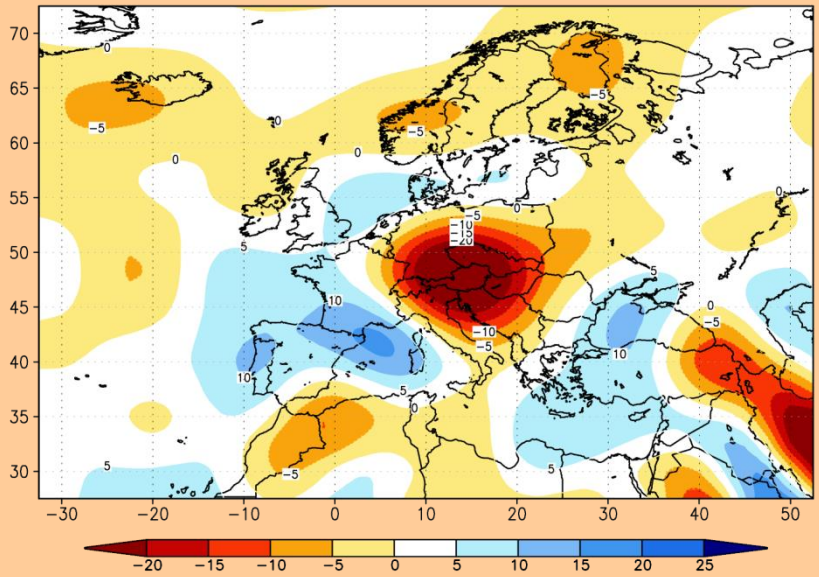


Centroids CT 5, Summer 1951-2006

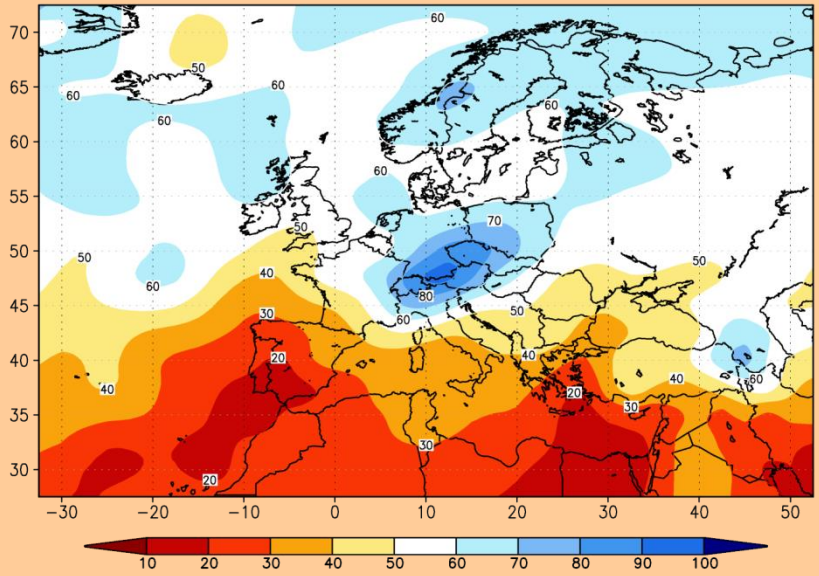
MSLP



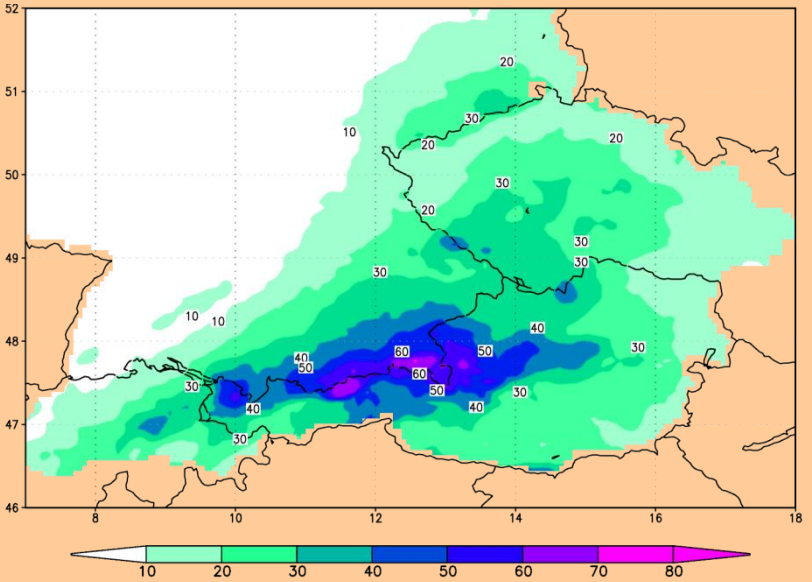
Omega



Rhum

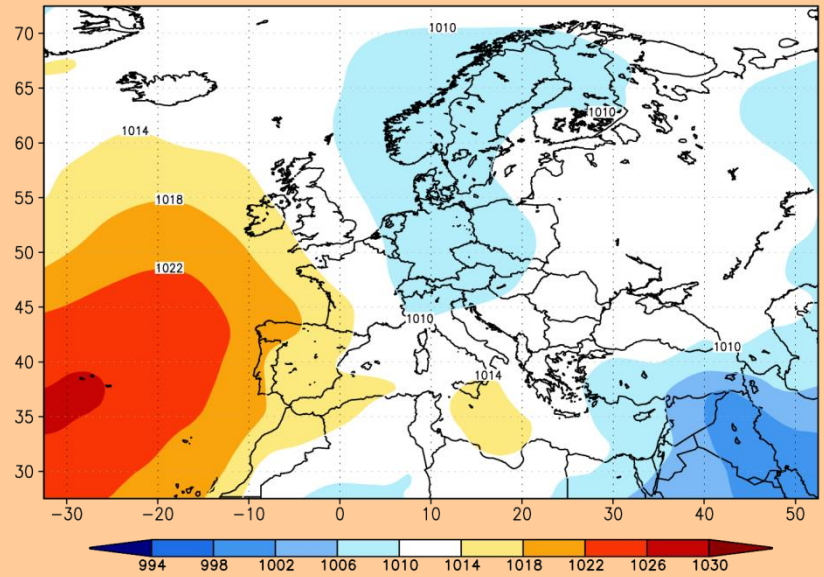


Prec

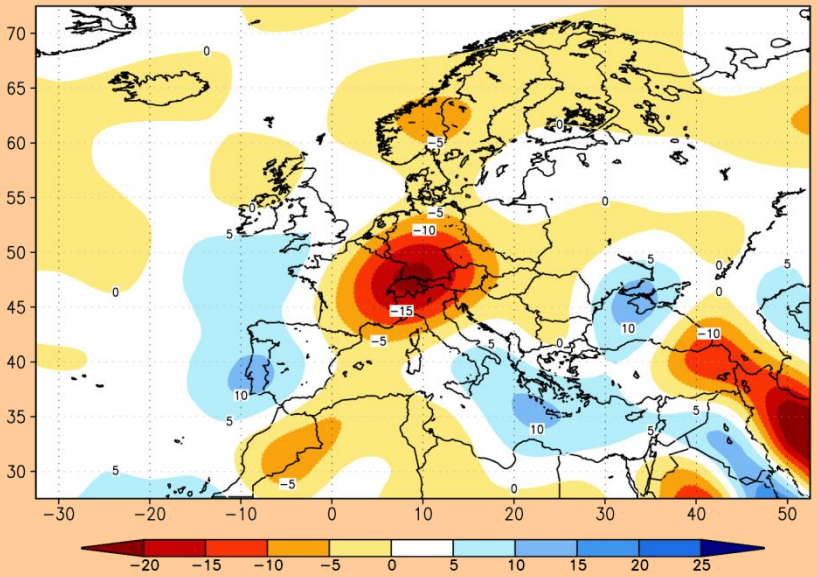


Centroids CT 15, Summer 1951-2006

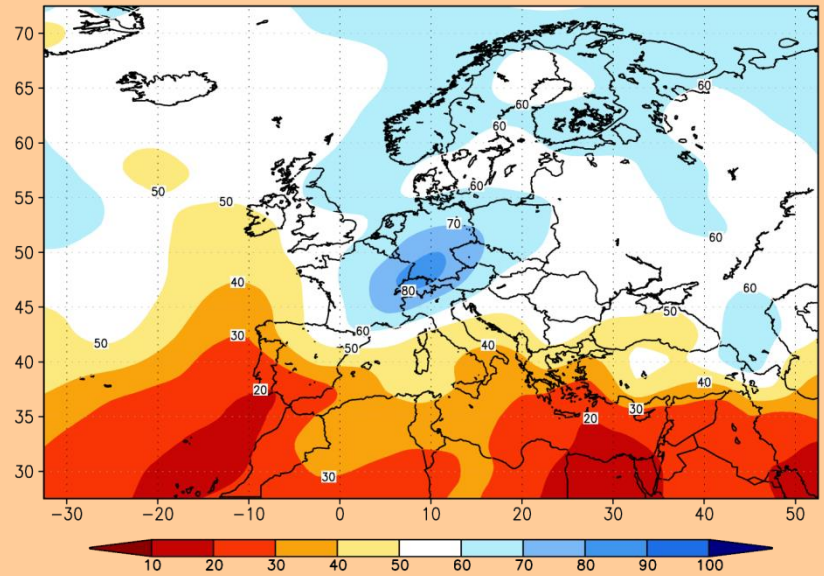
MSLP



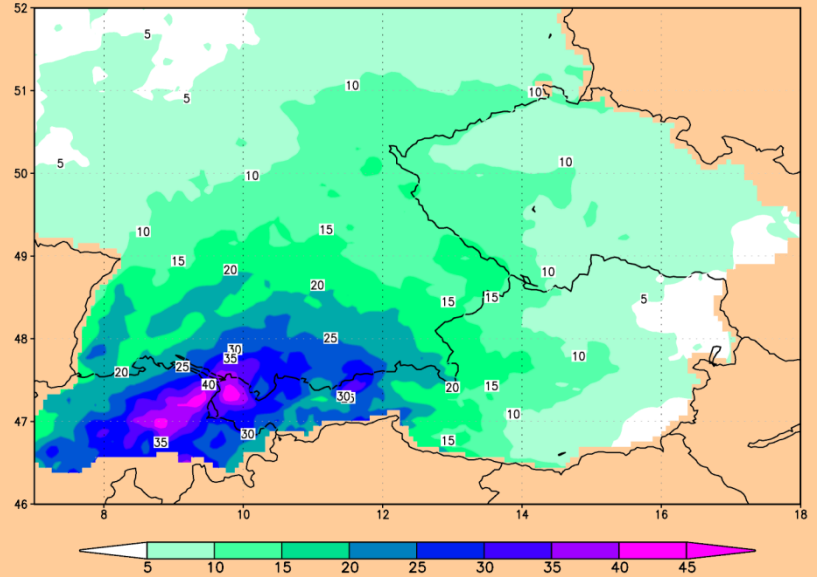
Omega



Rhum

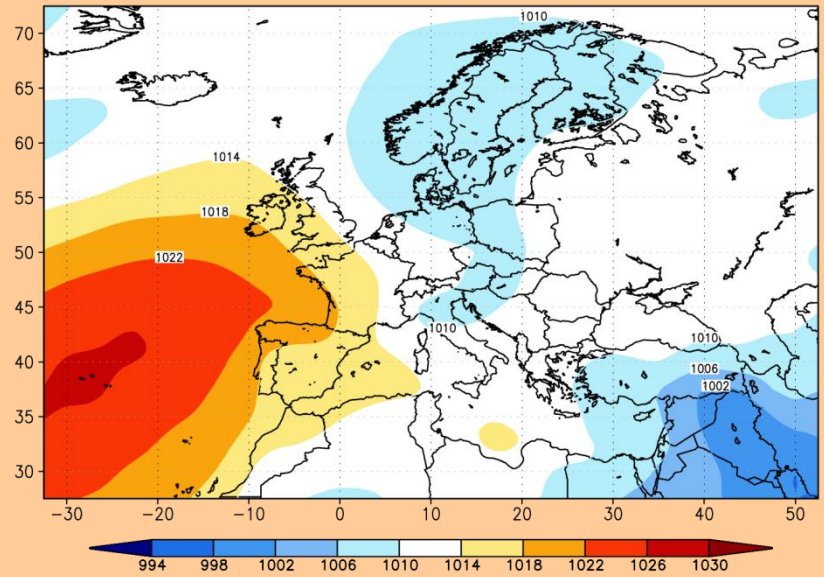


Prec

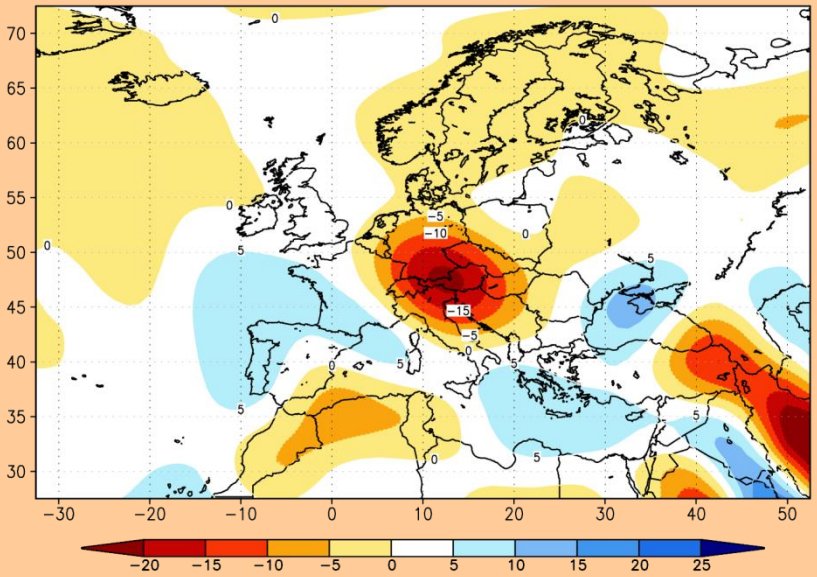


Centroids CT 9, Summer 1951-2006

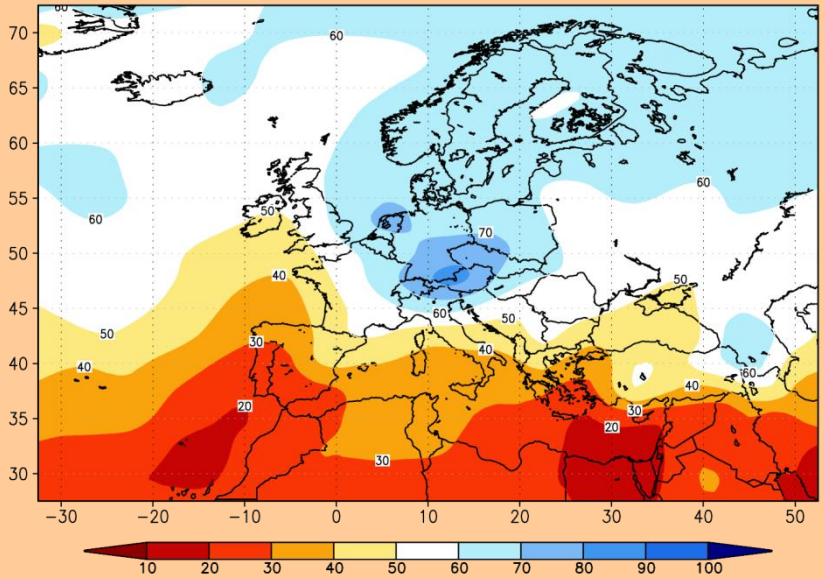
MSLP



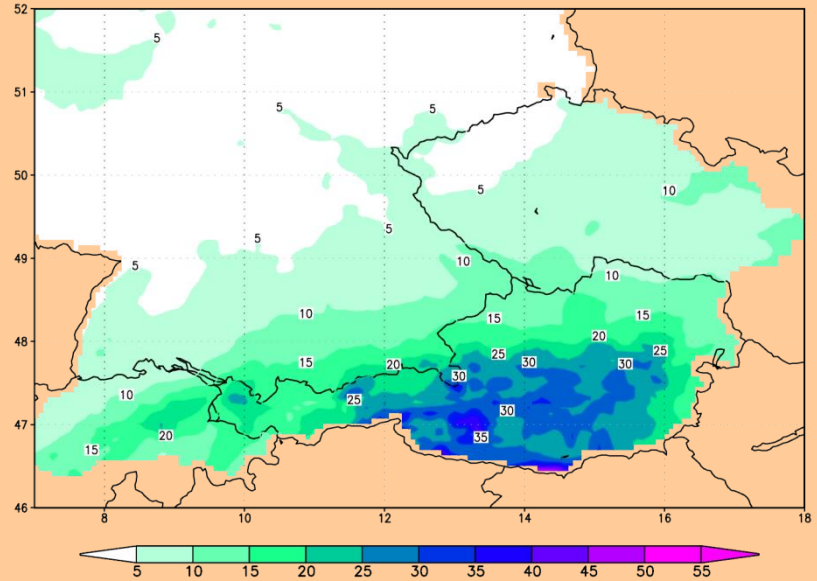
Omega



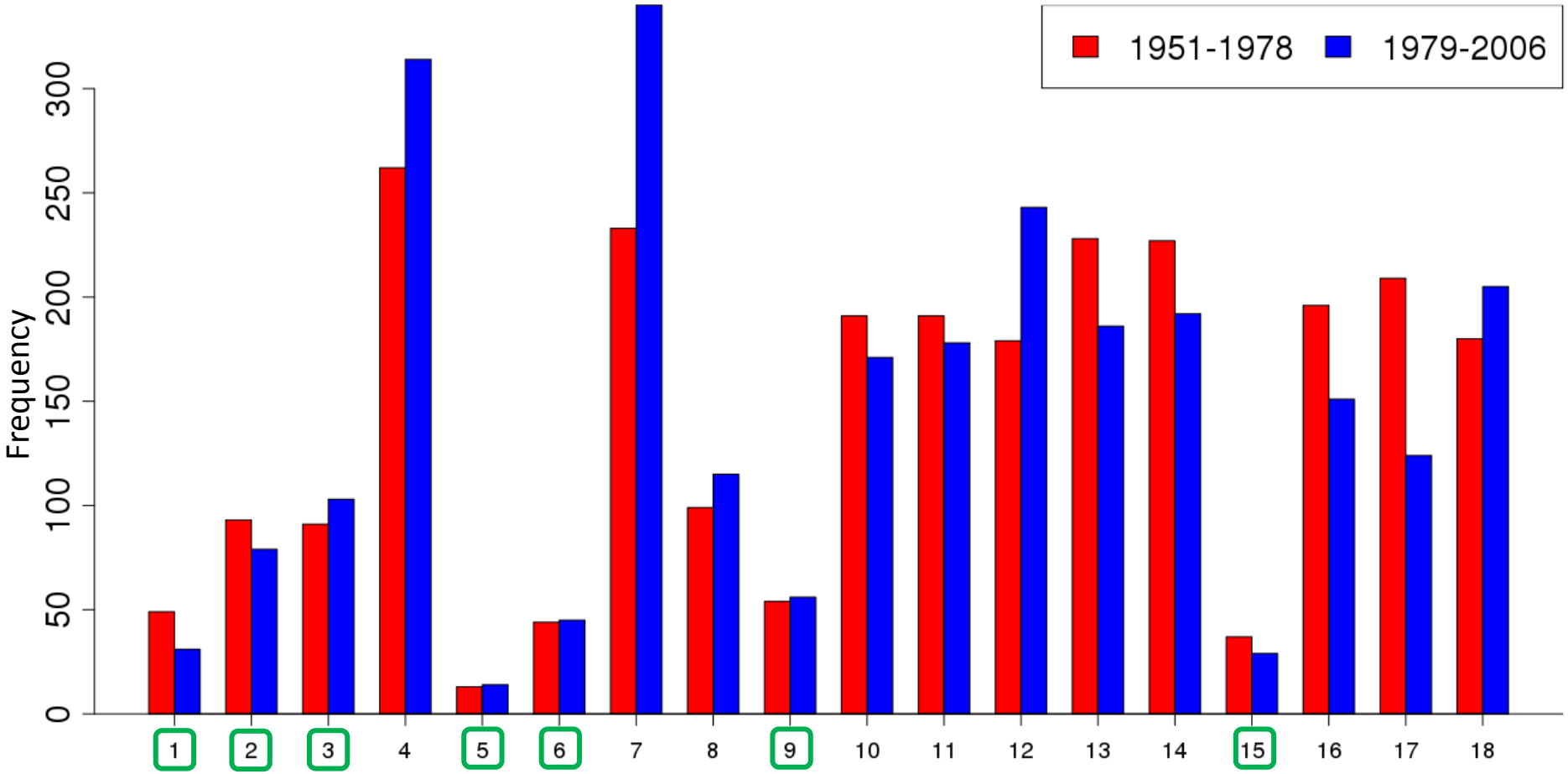
Rhum



Prec

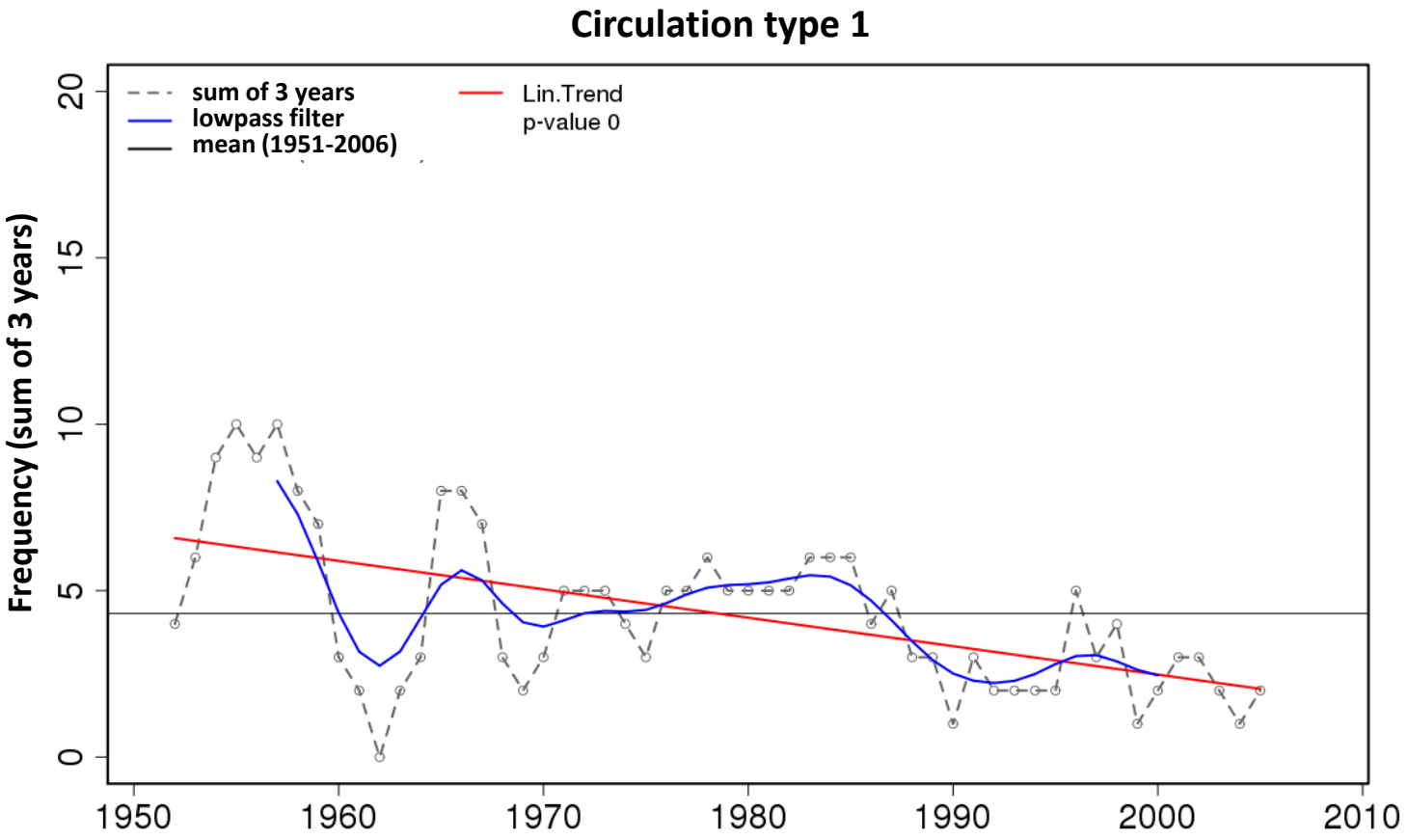


Frequencies of circulation types Summer (JJA)



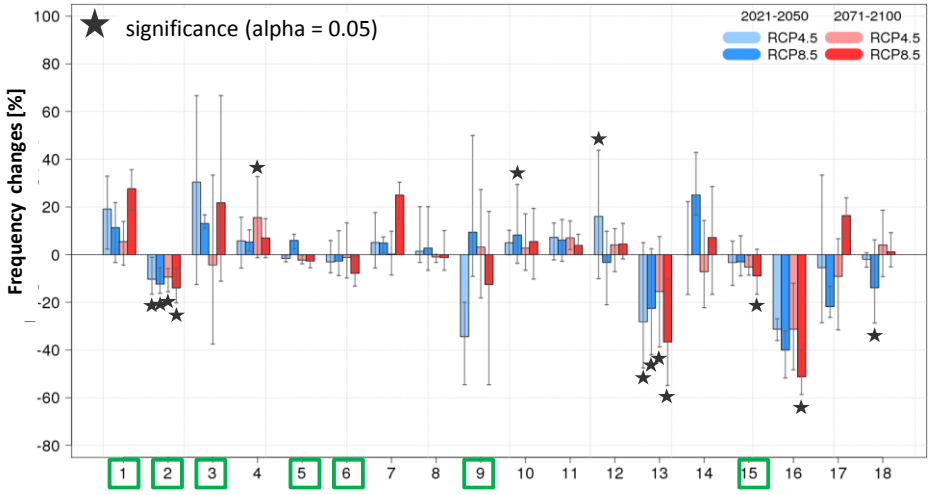
CTs important for heavy precipitation

Summer

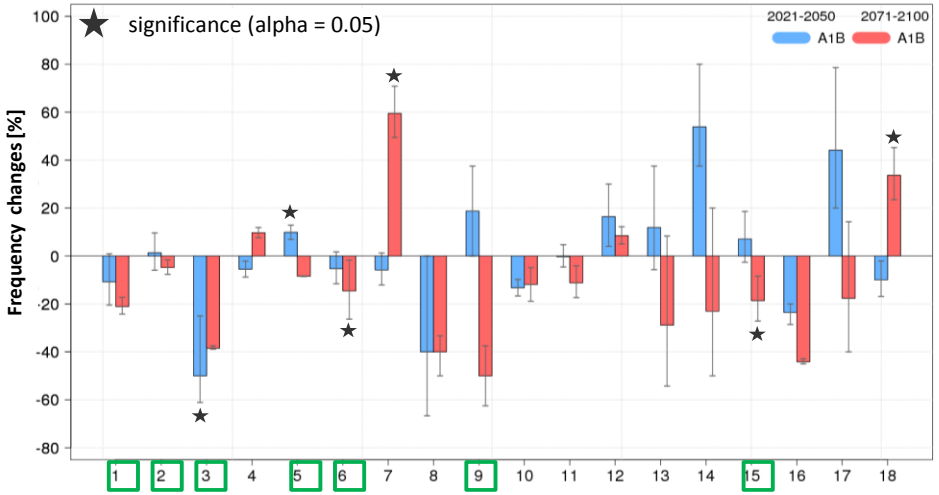


Cut-off low (NE)

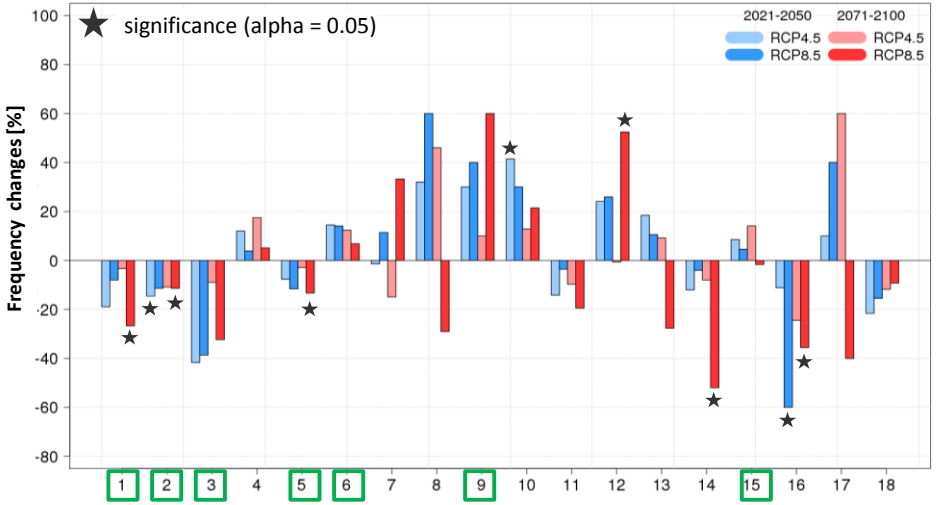
2a: ECHAM6, Summer



2b: ECHAM5, Summer



2c: EC-Earth, Summer



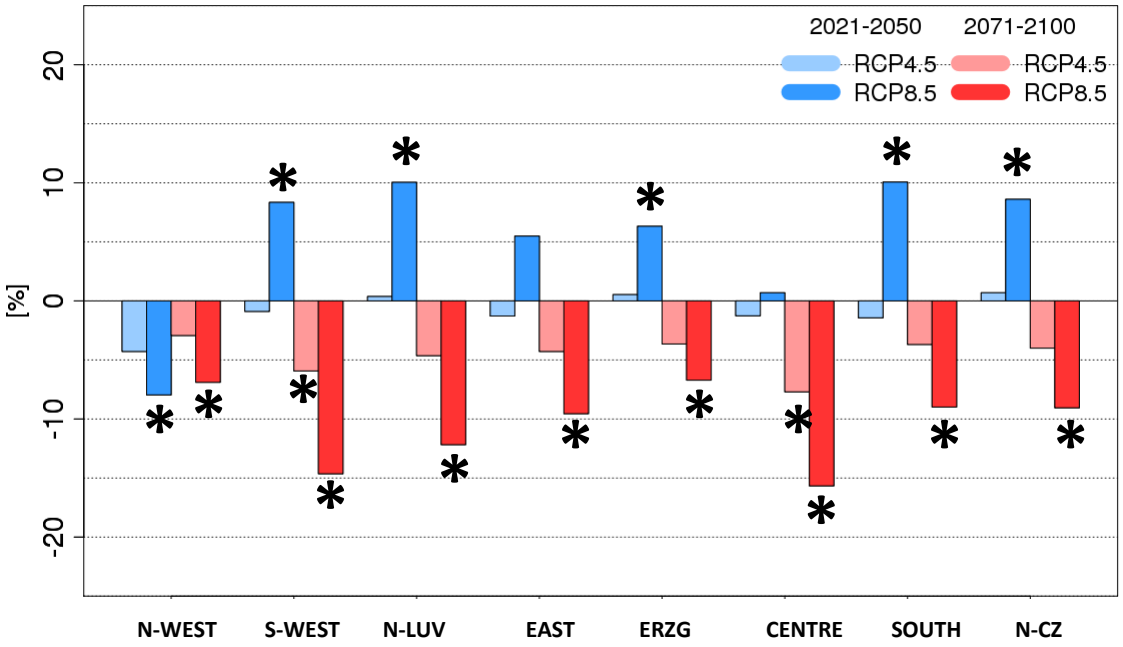
Frequency changes (%) of circulation types in **Summer** between projection periods (2021-2050 and 2071-2100) and the reference period (1971-2000).

For multiple realisations, the ensemble mean and the range are shown

CTs important for heavy precipitation

Heavy precipitation frequencies Summer, % changes wrt 1971-2000,

based on ECHAM6-Predictors

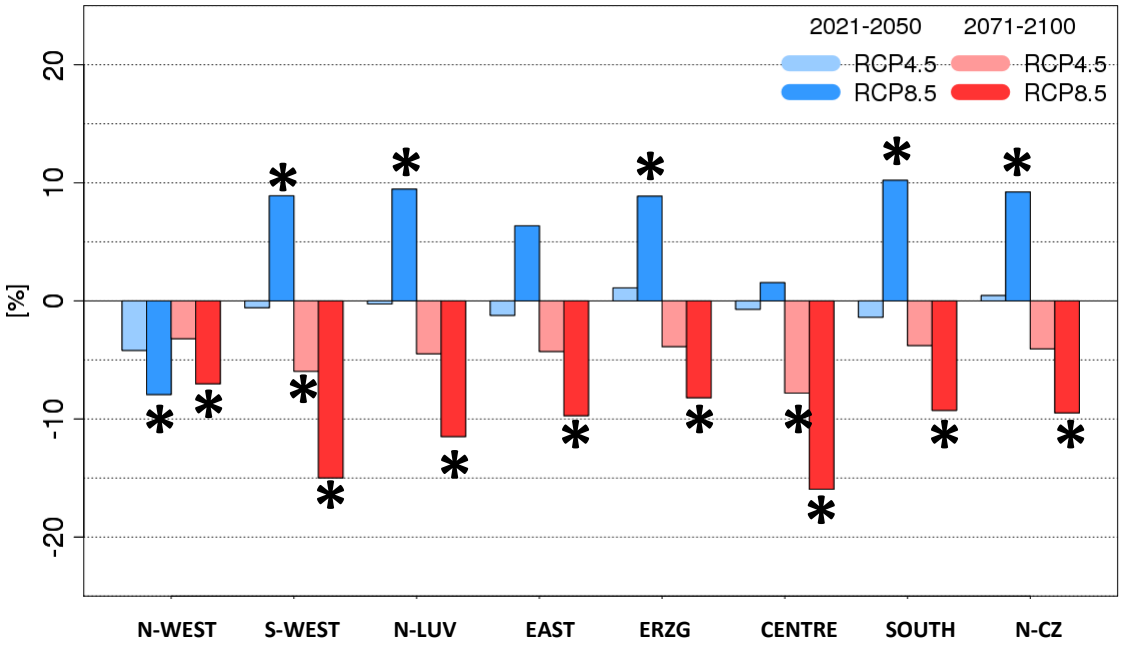


* 95% significance

- 2021-2050 mainly increases for RCP8.5 (up to +10%)
- decreases 2071-2100 (up to -16%) esp. for RCP8.5

Heavy precipitation amounts Summer, % changes wrt 1971-2000,

based on ECHAM6-Predictors

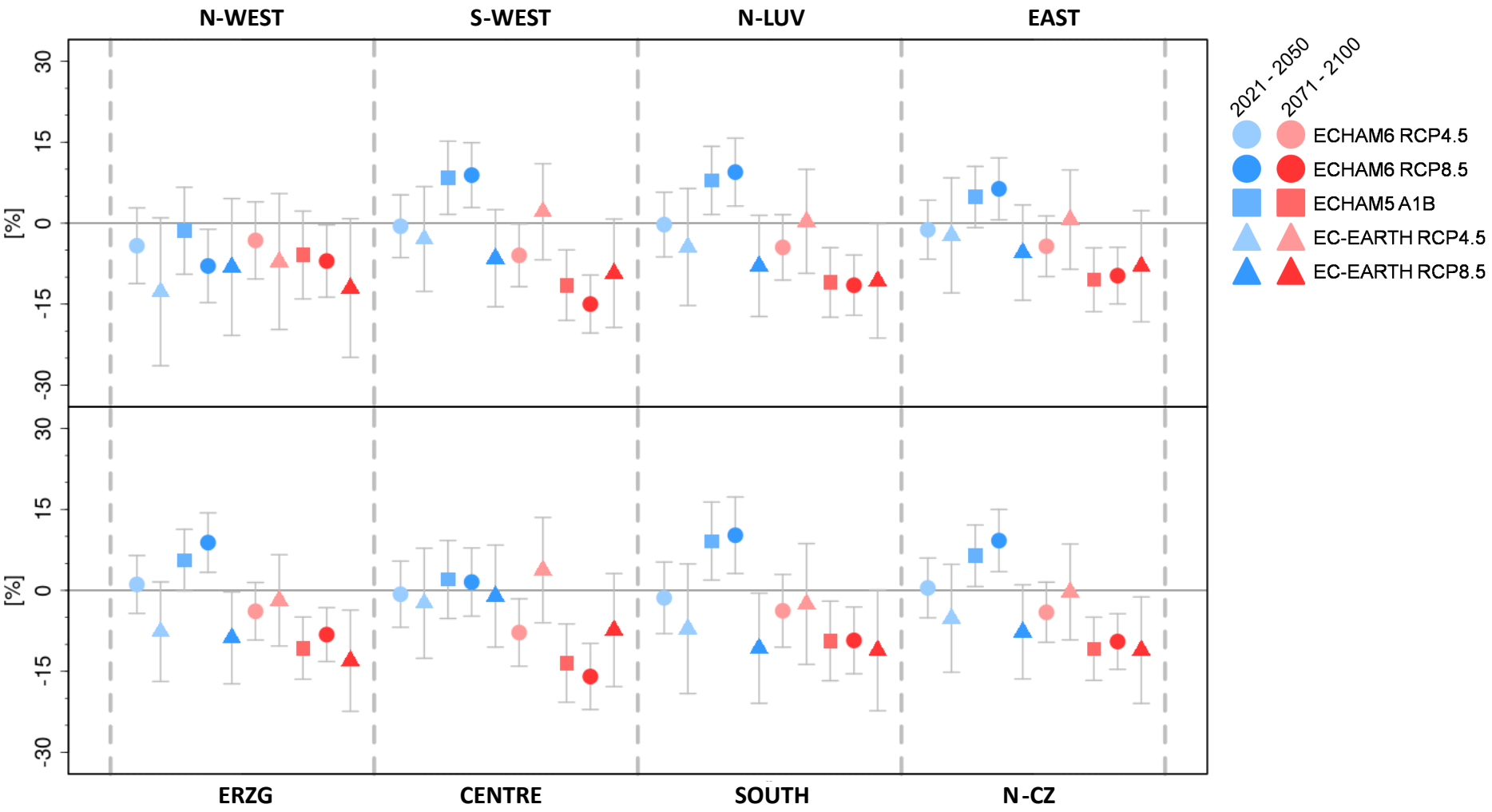


* 95% significance

- 2021-2050 mainly increases for RCP8.5 (up to +10%)
- decreases 2071-2100 (up to -16%) esp. for RCP8.5

Changes (%) of heavy precipitation amounts

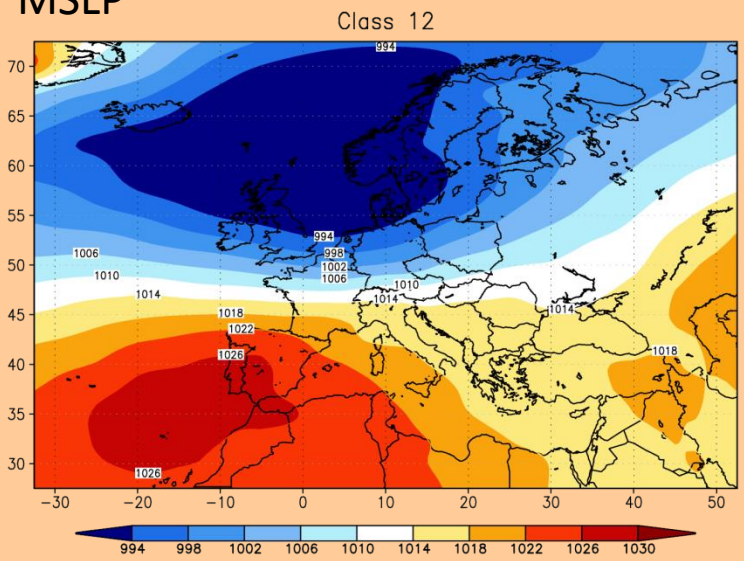
Predictors from different GCMs, **Summer**



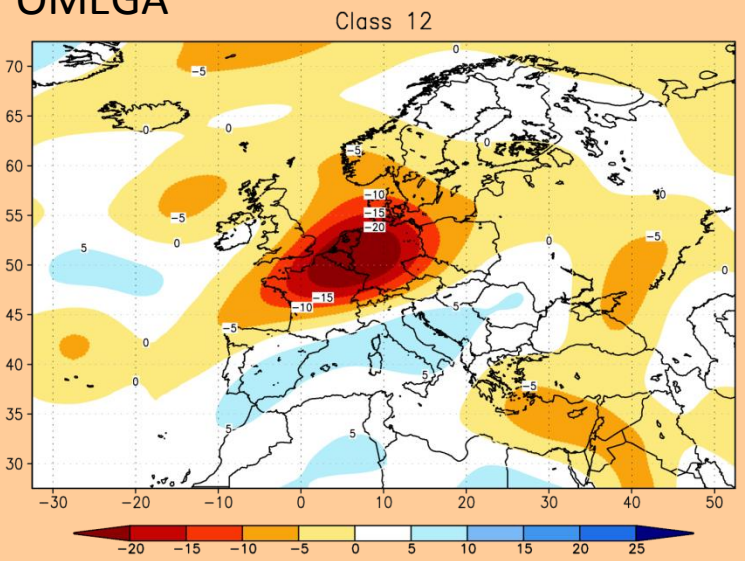
Changes for ensemble means with respect to 1971-2000
including 95% confidence intervals

Circulation type 12, Winter 1951-2006

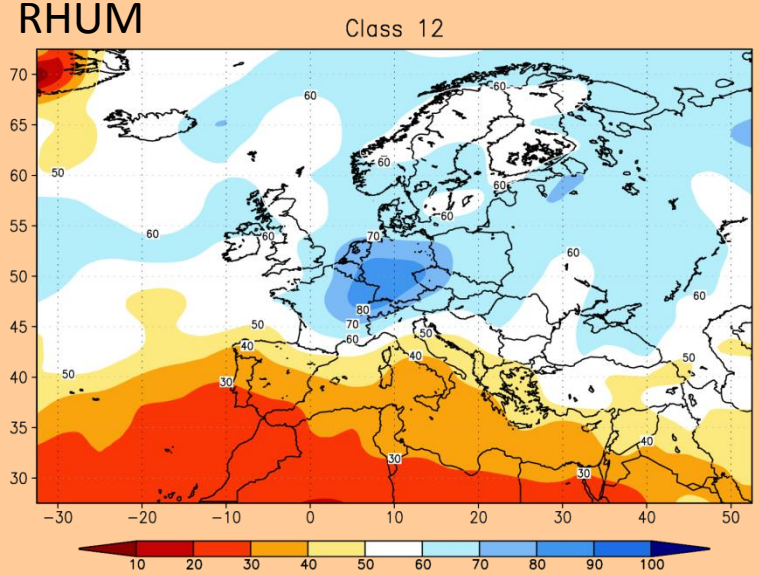
MSLP



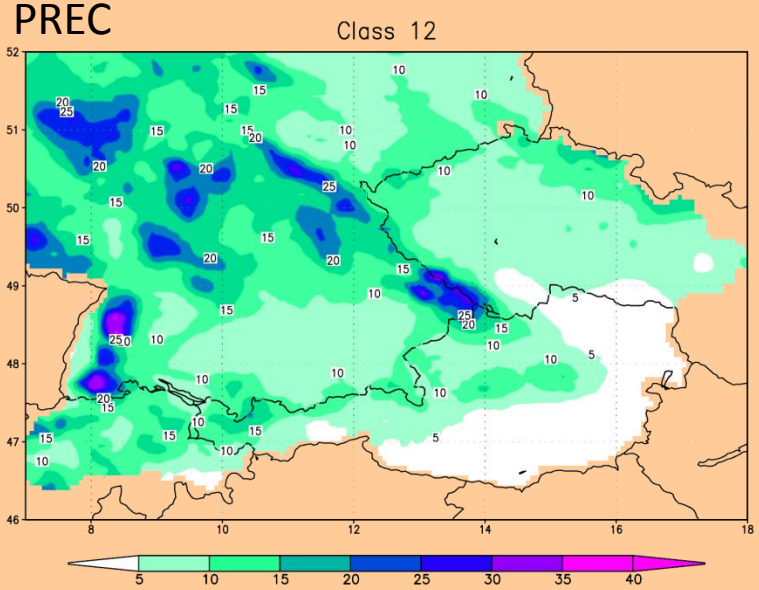
OMEGA



RHUM

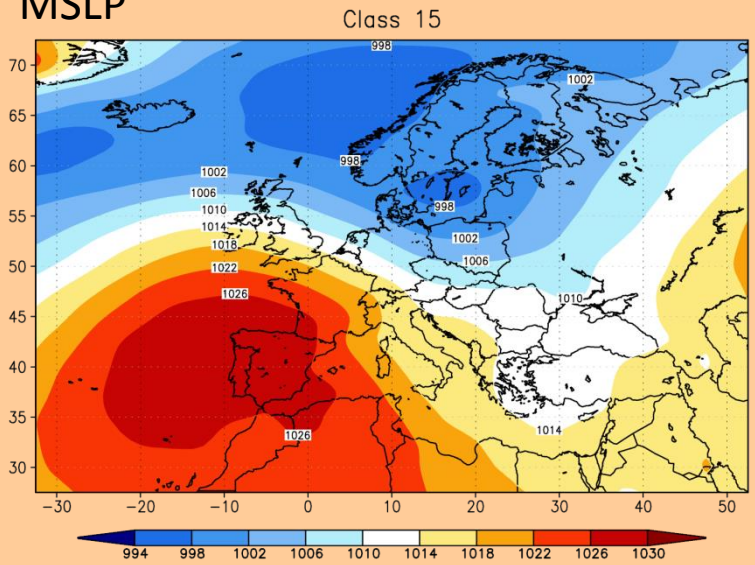


PREC

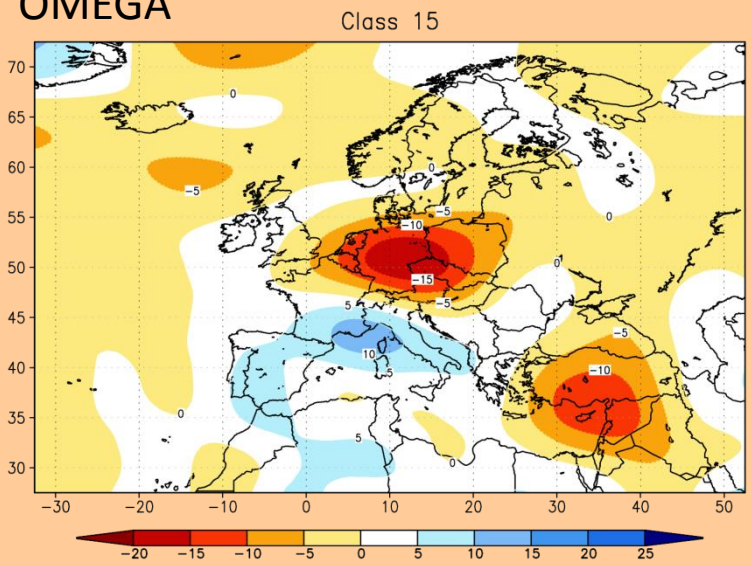


Circulation type 15, Winter 1951-2006

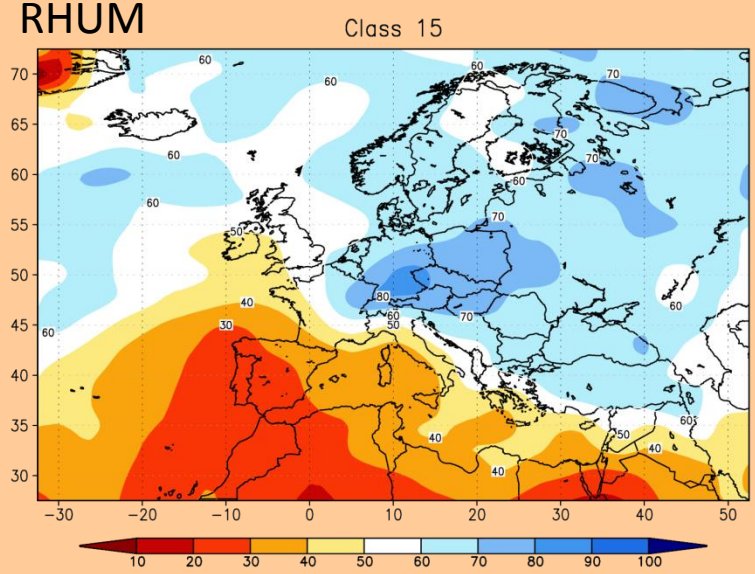
MSLP



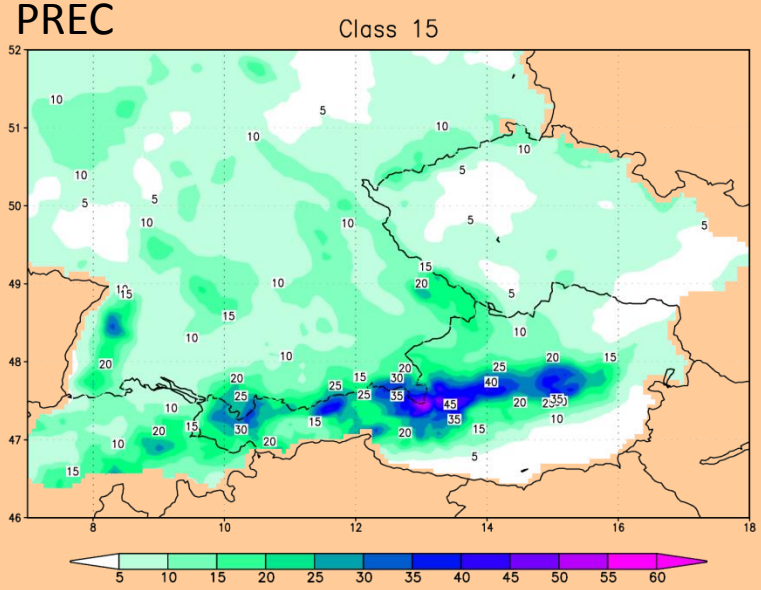
OMEGA



RHUM

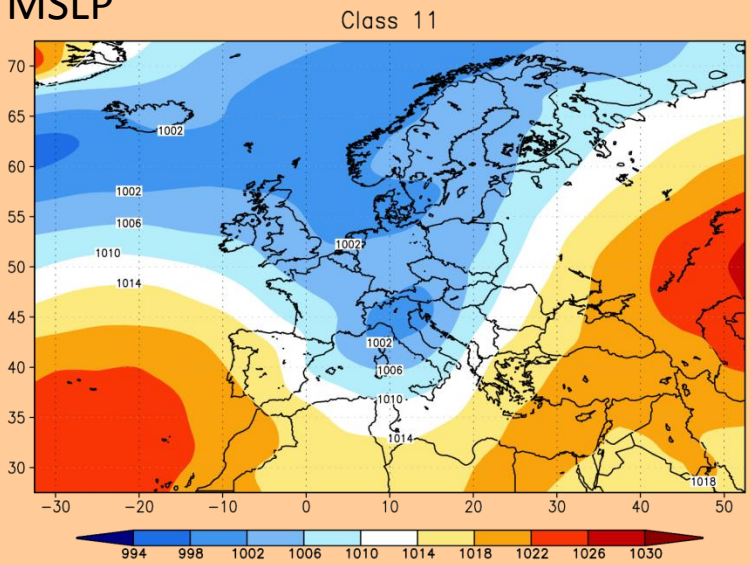


PREC

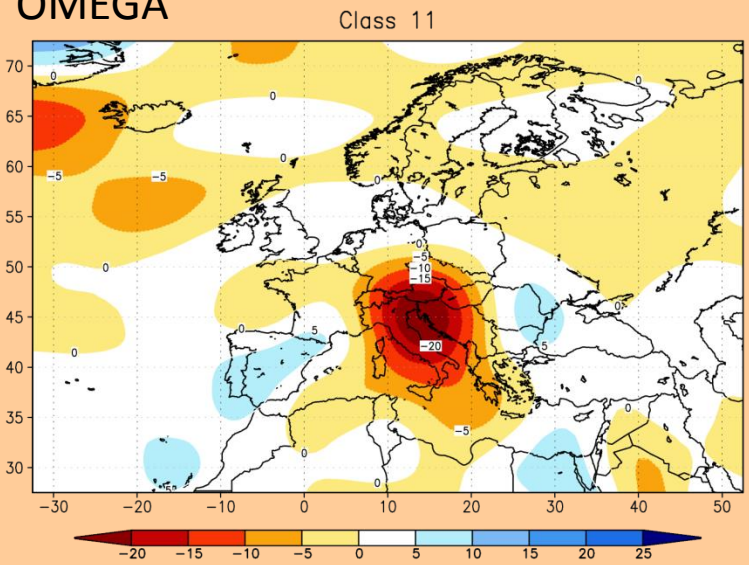


Circulation type 11, Winter 1951-2006

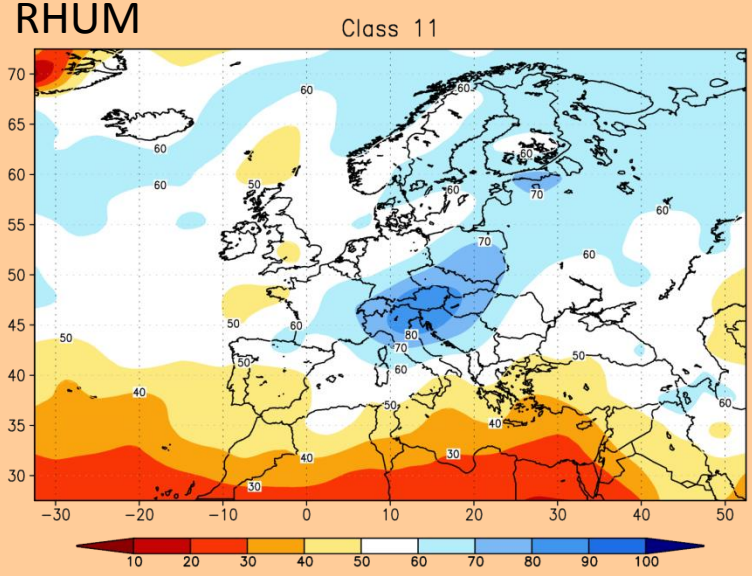
MSLP



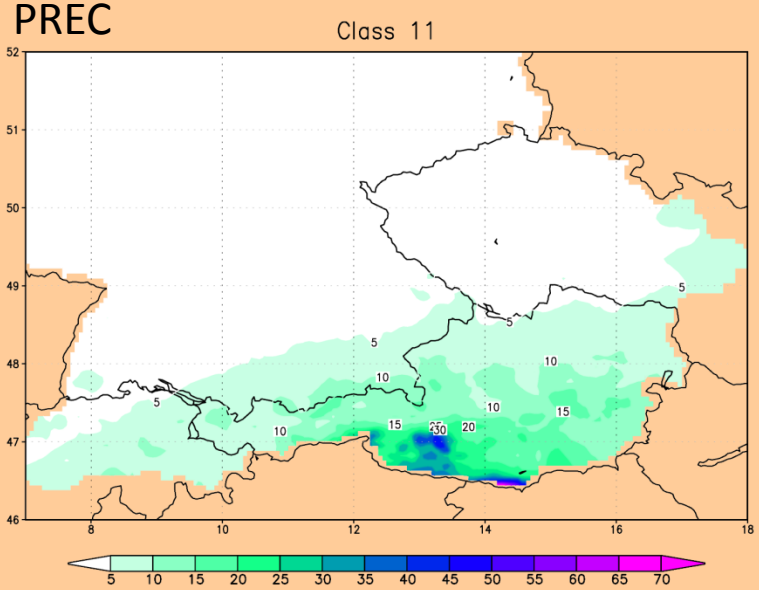
OMEGA



RHUM



PREC



Summary of Essentials:

Circulation types important for heavy precipitation:

Cut-off lows (with different positions)

Zonal circulation patterns (for northern and western parts)

Meridional circulation patterns (esp. for the southern part)

Mixed circulation patterns (esp. for the northern margin of the Alps)

Recent changes of CTs important for heavy precipitation:

significant only in some few cases

Future changes of CTs important for heavy precipitation:

In general: increase of zonal patterns in winter,
similar or decresing frequencies of „heavy prec. CTs“ in summer,
lowest number of significant changes in autumn

but also deviations for particular CTs
between the different global climate models

Future projections for heavy precipitation:

Spring:

increases confined to northern parts for RCP8.5 in 2071-2100

Summer:

2021-2050: mainly increases esp. für RCP8.5,
but not based on EC-EARTH!

2071-2100: decreases for RCP8.5 and mostly also A1B,
but often insignificant with EC-EARTH!

note: only valid for extreme areal precipitation!

Autumn:

no significant changes

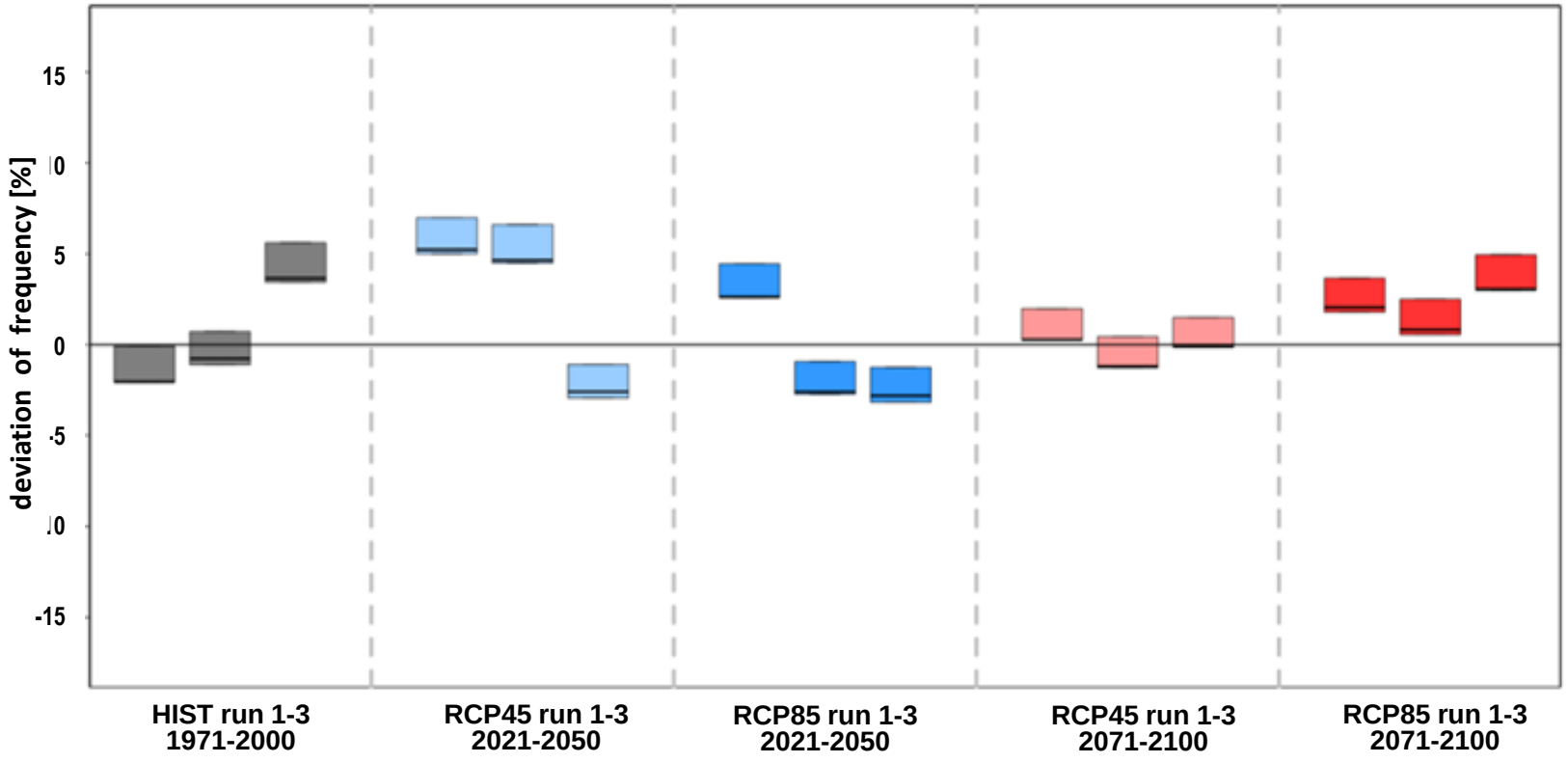
Winter:

increases in some regions for A1B esp. in 2071-2100,
but not with ECHAM6 and EC-EARTH!

Numerical and statistical uncertainties

based on ECHAM6-Predictors

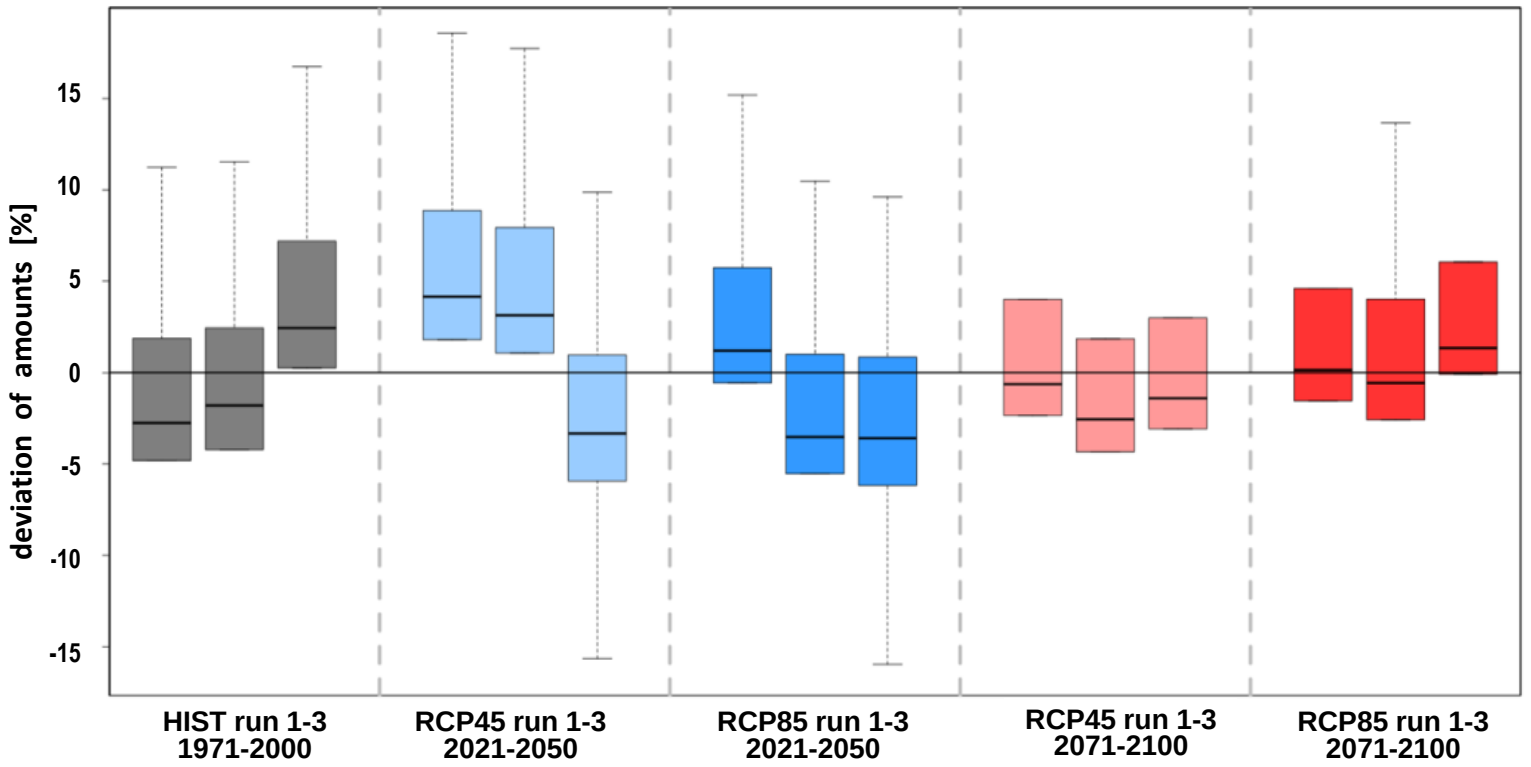
Uncertainties of heavy precipitation frequencies, Region S-West Spring



Numerical and statistical uncertainties

based on ECHAM6-Predictors

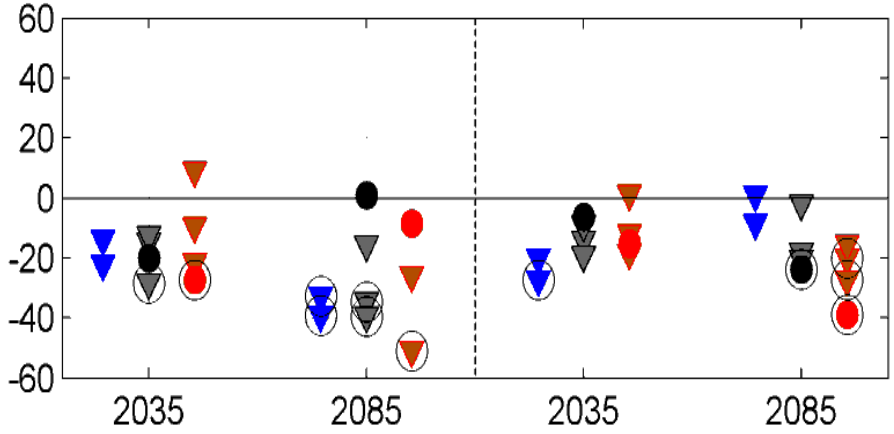
Uncertainties of heavy precipitation amounts, Region S-West Spring



Future projection for cyclone track Vb (ZAMG)

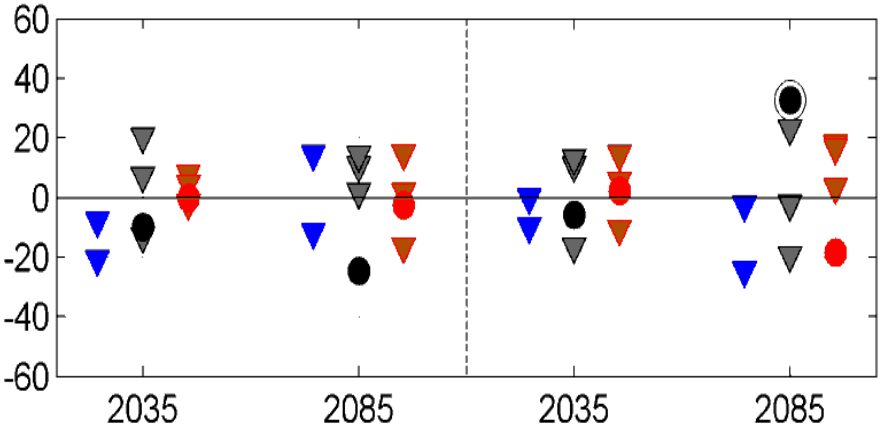
Summer (May-Sep)

700 hPa SLP



Winter (Nov-Mar)

700 hPa SLP



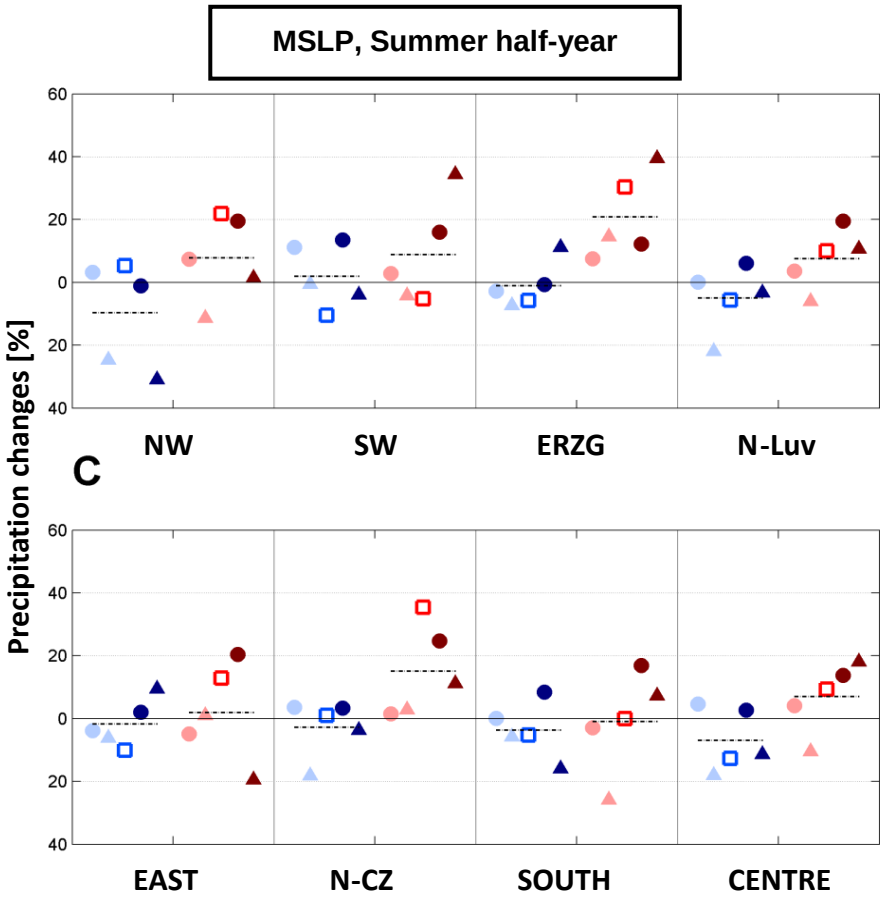
triangle: Echam
circle: EC-Earth

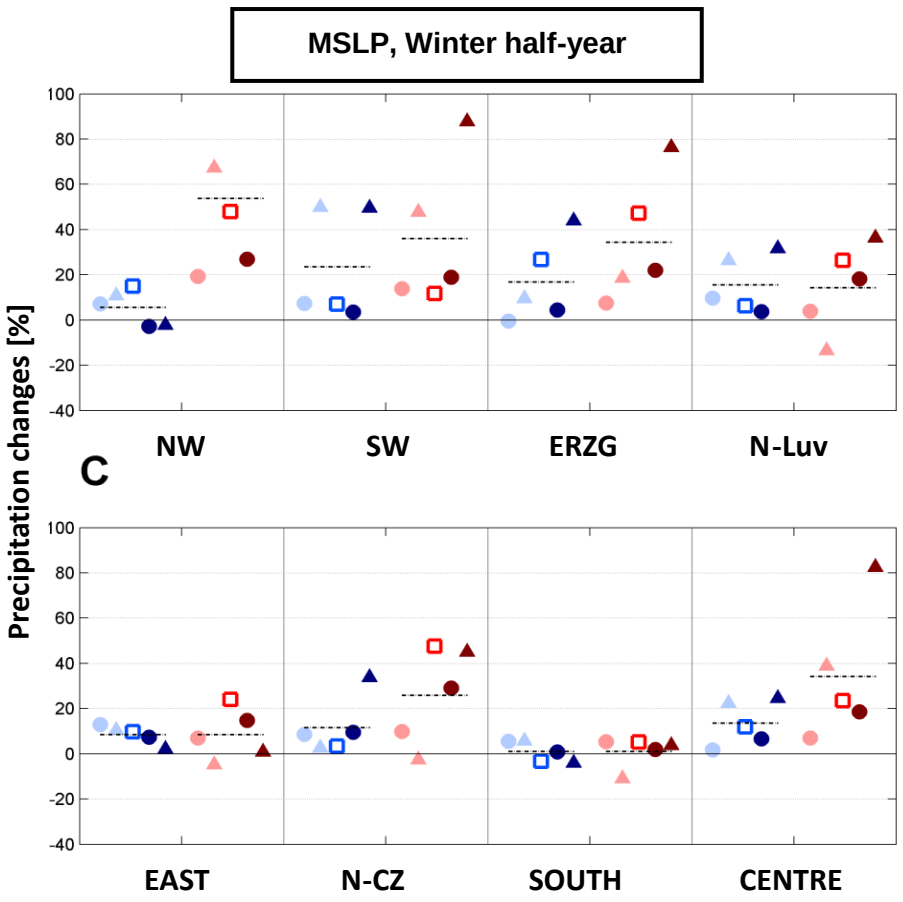
a1B
grey/black: 4.5
red: 8.5

2035= 2021-2050
2085= 2071-2100

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Future projection for Vb-precipitation (ZAMG)





Precipitation changes for Vb-events during summer and winter half-years

Symbols: Ensemble mean of specific runs; dashed line: overall mean

Future improvements by consideration of

Soil moisture

Persistence of circulation types

type-internal characteristics

Non-stationarities

…

Atmospheric circulation types and extreme areal precipitation in southern central Europe – impacts of present and future climate change

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Markus Homann, Andreas Philipp, Christoph Beck

Institute of Geography, University of Augsburg