APPLICATION OF CLIMATE INDICES IN THE REGIONAL CLIMATOLOGY OVER SOUTHEAST EUROPE

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Outline of the presentation

1. Preface – why climate indices?
2. Definitions, sets of climate indices and collected data bases
3. Climate indices for analysis of the recent past and present climate
4. Climate indices for the projected future climate
5. Some special climate indicators
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1. Preface – why climate indices?

The oncoming climate changes are the biggest challenge that the mankind faces. For decades, most analyses of long-term global climate change using observational temperature and precipitation data are focused on changes in mean values. However, immediate damages to humans and their properties are not obviously caused by gradual changes in these variables but mainly by so-called extreme climate events. The extreme weather phenomena are discussed in all reports of the IPCC. Indices derived from daily data are an attempt to objectively extract information from daily weather observations that answers questions concerning extremes that affect many human and natural systems. As many aspects of climate are well represented by monthly means, most indices derived from daily data generally focus on extremes. The analysis, based on climate indices (CI) has many strengths, including:

• The definition of the (most) CI is non-parametric

• The modern sets of indices are statistically robust, cover a wide range of climates, and have a high signal-to-noise ratio.

• They have internationally agreed (in some cases in frames of large collaborative projects) definitions which allows straightforward computation (most frequently with free-available software).

•They have great intuitive appeal, suitable for the expert community and broader audience

Internationally agreed indices derived from daily temperature and precipitation data allow results to be compared consistently across different countries and also have the advantage of overcoming most of the restrictions on the dissemination of daily data that are applied in many countries.

2. Definitions, sets of climate indices and collected data bases (1 from 3)

The relative big number of CIs and the popularity of the CIs-based analysis among the expert community impose standardization of the definitions world-wide. The use of approved indices allows comparison of analyses conducted in any part of the world and seamless merging of index data to produce a global picture as well. Many attempts were made some in frames of international collaborative projects – such are the European Commission funded CIRCE (Climate change and impact research: the Mediterranean environment, https://www.cmcc.it/projects/circe-climate-change-and-impactresearch-the-mediterranean-environment) and **STARDEX** (STAtistical and Regional dynamical Downscaling of EXtremes for European regions, http://www.cru.uea.ac.uk/projects/stardex). STARDEX is focused on relatively moderate extremes rather than the most extreme events.

The Commission for Climatology (CCl)/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) (previously known as the Expert Team on Climate Change, Detection, Monitoring and Indices (ETCCDMI), http://www.clivar.org/organization/etccdi/etccdi.php) defined a suite of indices that have subsequently become known as the **ETCCDI**-indices. **ClimData** is a suite of 26 datasets of climate indices on monthly (M), seasonal (S) and annual (Y) basis, as well as linear trend and statistical significance estimation for the considered time windows. They are calculated with the standard software of the STARDEX and ETCCDI international projects correspondingly, with data from the ECA&D E-OBS and CARPATCLIM gridded databases. ClimData is intended to serve as a convenient, barrier free and versatile tool for research.

Feature	STARDEX	ETCCDI
Total number	57	29
on Y-basis	57	29
on S-basis	54	0
on M-basis	0	13
Temperature based	24	18
Precipitation based	33	11
Input variables	tn, tx, td, prec.	tn, tx, prec.
Bootstrap correction	No	Yes
Trend & MK test	Yes	No

Main features of the STARDEX and ETCCDI CIs-suites. See the cited above web-pages for details.

2. Definitions, sets of climate indices and collected data bases (2 from 3)

CIs set Input Data	STARDEX	ETCCDI
CARPATCLIM		CIs - M-basis
	CIs - S-basis	*CIs - S-basis
	CIs - Y-basis	CIs - Y-basis
	LT estimation - S-basis	*LT estimation - S-basis
	LT estimation - Y-basis	*LT estimation - Y-basis
	MK test - S-basis	*MK test - S-basis
	MK test - Y-basis	*MK test - Y-basis
E-OBSv16.0		CIs - M-basis
	CIs - S-basis	*CIs - S-basis
	CIs - Y-basis	CIs - Y-basis
	LT estimation - S-basis	*LT estimation - S-basis
	LT estimation - Y-basis	*LT estimation - Y-basis
	MK test - S-basis	*MK test - S-basis
	MK test - Y-basis	*MK test - Y-basis

List of the ClimData output datasets. These, calculated a posteriori, are marked with asterisk

The VI–SEEM project (https://vi-seem.eu/), which is focused on the scientific communities of Life Sciences, Climatology and Digital Cultural Heritage, is convenient single point access to ClimData and thus it is made available at https://repo.vi-seem.eu/handle/21.15102/VISEEM-343 .

2. Definitions, sets of climate indices and collected data bases (3 from 3)

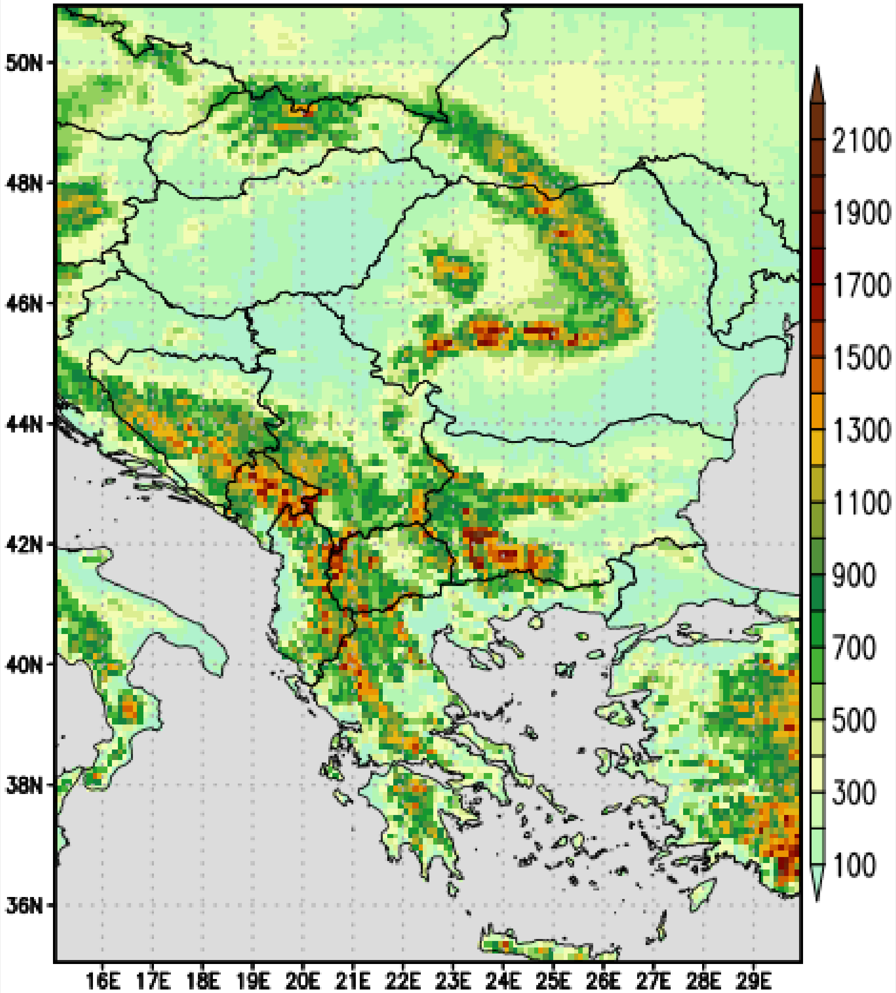
Acronym	Main Content	Spat. Coverage/ Resolution	Time Span, Scenario(s)	Institution	Basic Reference/ Access
SPI DB	4 data sets of SPI-1, SPI-3, SPI-6, SPI12 based on UDEL/ GEOG/CCR v3.02, GPCC v7.0, NOAA-CIRES 20CR v2c, ECMWF ERA20C	Global, 0.5°×0.5°; 1.5°×1.5°	1900-2010, 1901-2013, 1851-2011, 1900-2010	NIMH, Bulgaria	Chervenkov et al. (2016); ftp://xeo.cfd.meteo.bg/SPI/
CECILIA DB	152 CI based on RCMs	Central&SE Europe, 0.1°×0.1°	1961-1990 2021-2050 2071-2100 SRES A1B	CECILIA project	Belda et al. (2015); http://cecilia.dmi.dk
ClimData	STARDEX&ETCCDI Cis based on E-OBS &CARPATCLIM	E-OBS& CARPATCLIM domains; 0.25°×0.25°, 0.1°×0.1°	1951-2016 1961-2010	NIMH, Bulgaria	Chervenkov et al. (2019); https://repo.vi-seem.eu/handle/21.15102/VISEEM-343.
EIA	ETCCDI Cis based on CMIP5-GCMs	Global, varios res.	1850-2100; CMIP5 RCP2.6, RCP4.5,RCP8.5	Canadian Centre for Climate Modelling& Analysis	Sillmann et al. (2013a); http://www.cccma.ec.gc.ca/data/climdex/climdex.shtml
ISIMIP Fast Track	26 Cis based on CMIP5-GCMs	Global, 0.5°×0.5°	1951-2099; CMIP5 RCP2.6, RCP4.5, RCP6.0, RCP8.5	ISIMIP 1	CDS documentation; https://www.isimip.org/protocol/

Mean features of the used data bases of climate indices

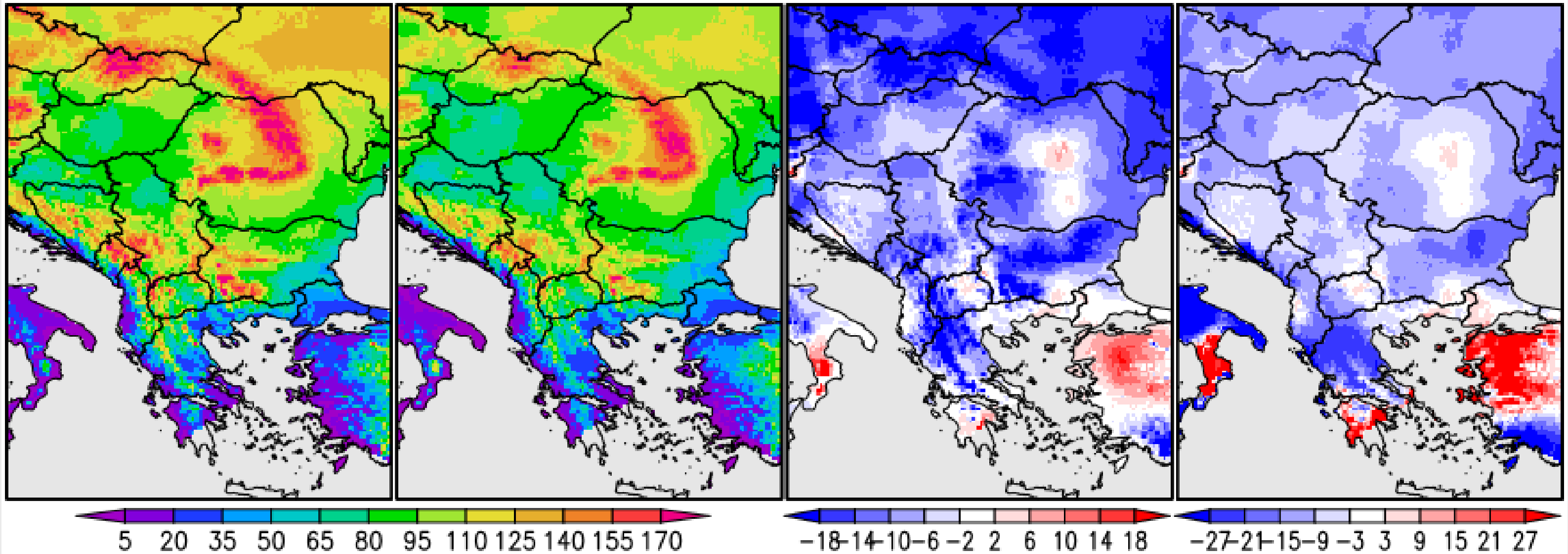
3. Climate indices for analysis of the recent past and present climate (1 from 6)

The Mediterranean region, in particular SE Europe, lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe and it is affected by interactions between mid-latitude and tropical processes. Because of these features, even relatively minor modifications of the general circulation, e.g. shifts in the location of mid-latitude storm tracks or sub-tropical high pressure cells, can lead to substantial changes in the Mediterranean climate.

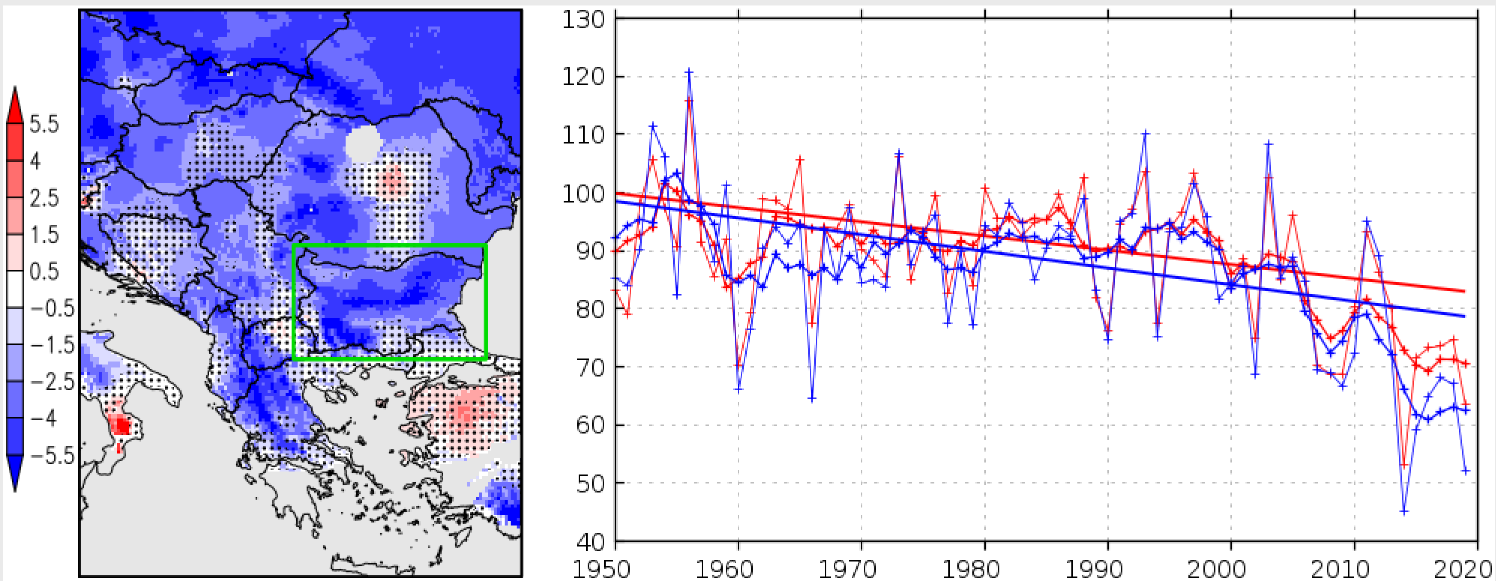
The popular in the expert community gridded daily dataset E-OBS was developed primarily for regional climate model evaluation, but it is also being used subsequently for various applications, including computation of CIs. It is well-known that the temperature extremes are highly sensitive to local conditions and gridded data have the tendency to underestimate the tails of the distribution. Besides the improved quantification of the uncertainty, the ensemble versions of the E-OBS (i.e. v12.0e+), represents generally better than predecessors the temperature extremes. In the present study, the analysis was performed for the period 1950–2019 using tn-values from E-OBS v.12.0e over CSE Europe with a spatial resolution of 0.1°×0.1°.



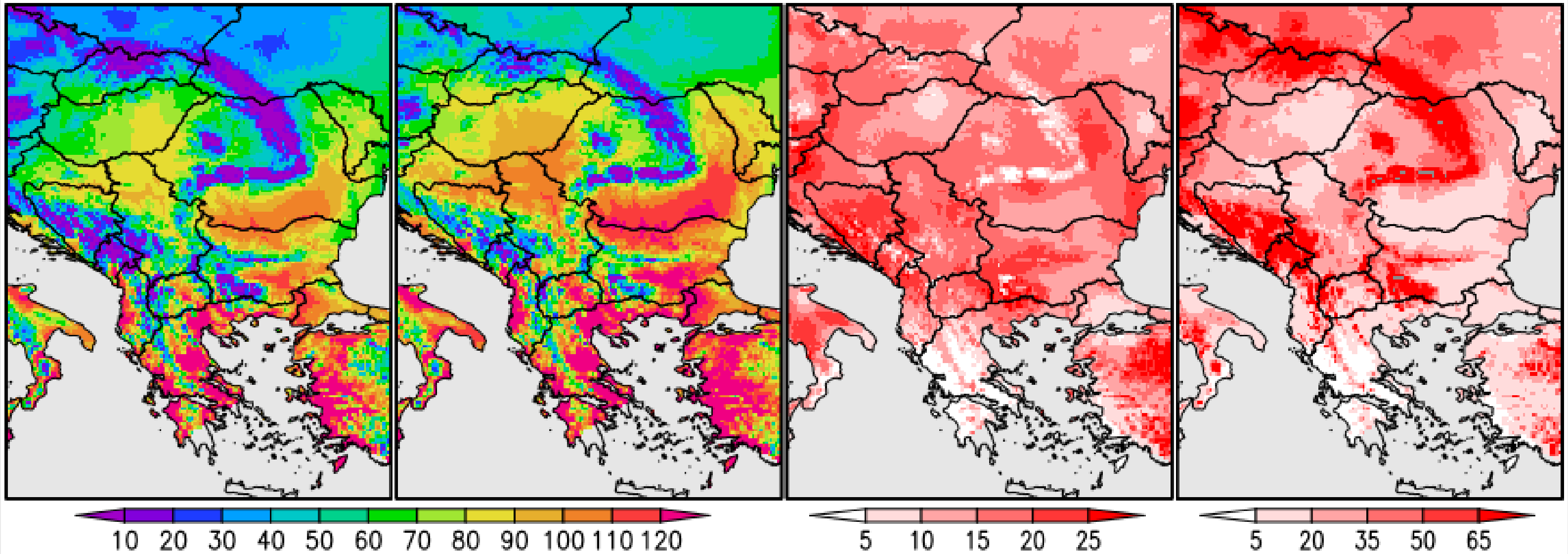
Topography of the domain (ECA&D data) in the E-OBS 0.1° ×0.1° resolution



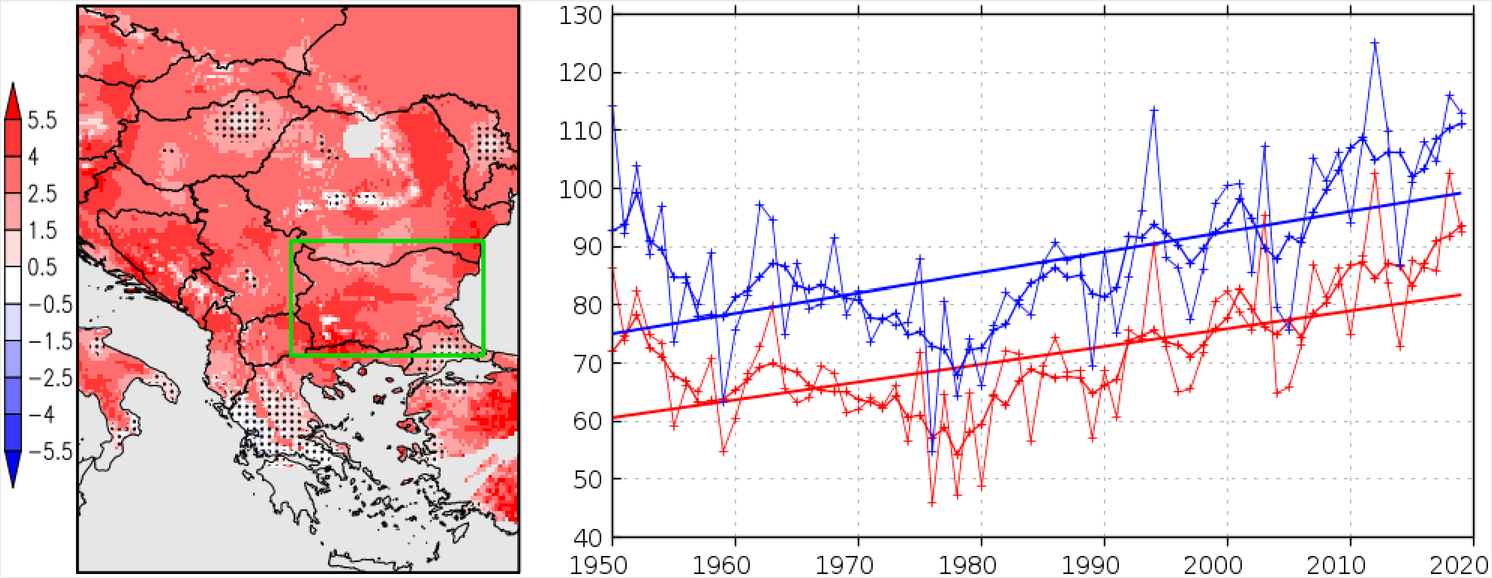
From left to right: Multiyear means of the frost days (**FD**, unit: days) for 1950-1979, 1990-2019, absolute and relative (in %) difference



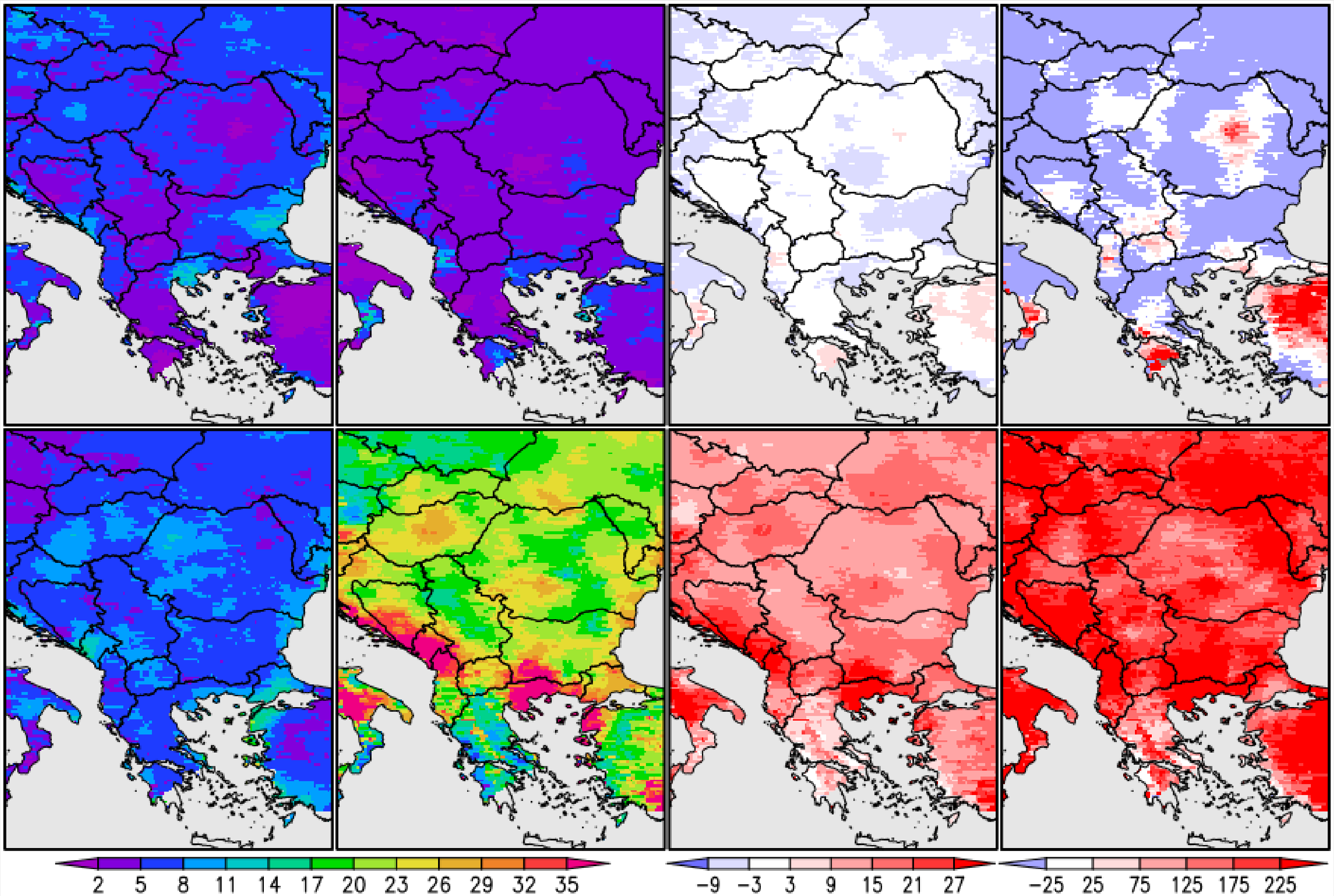
On left: Trend magnitude (unit: days/10 year) of the **FD**. Stippling indicates grid points with changes that are **not** significant at the 5% significance level. On right: Temporal evolution of the areal averages (red - whole domain; blue - area in green frame). The fat lines are the running 5-year means and the double fat lines – the trend lines.



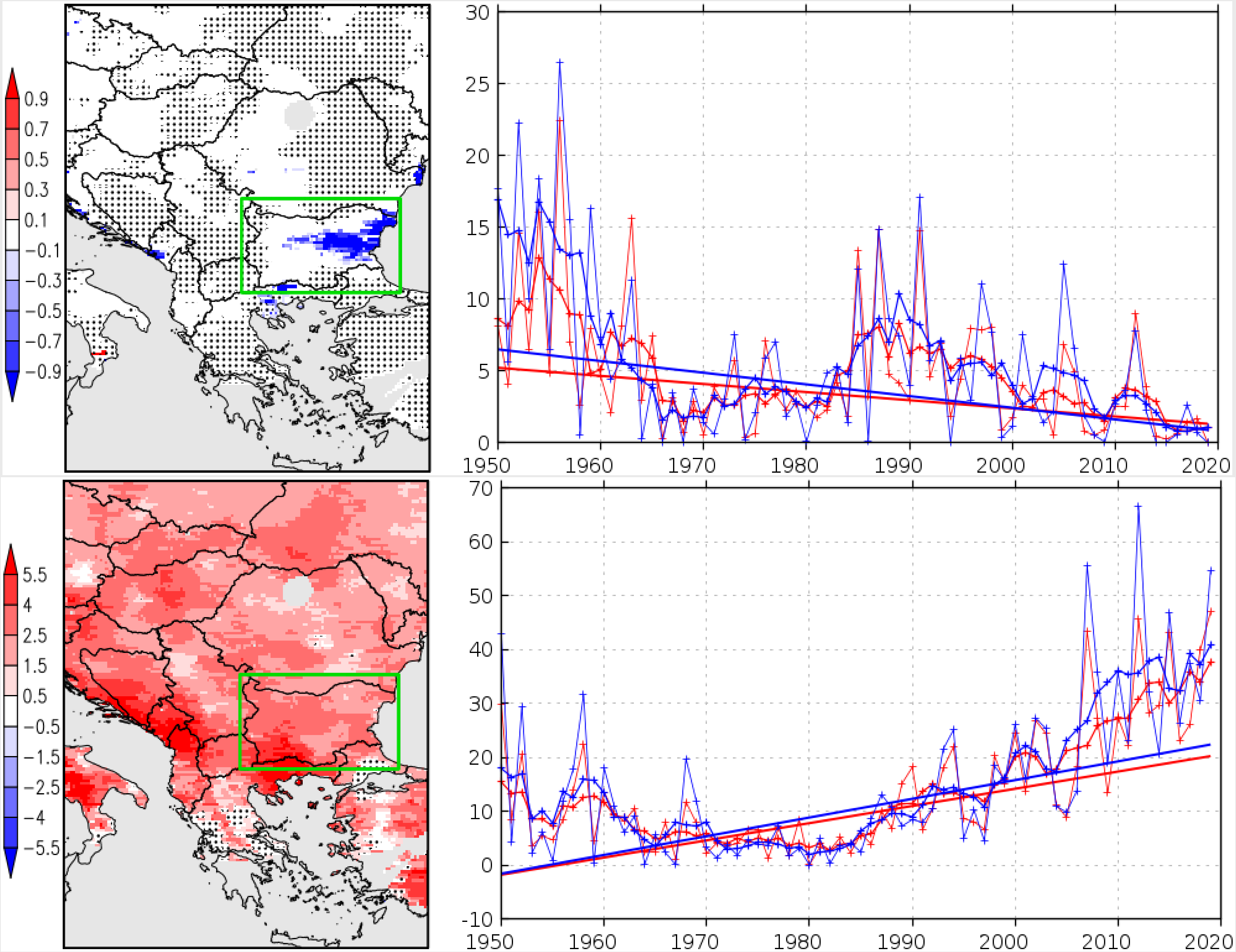
From left to right: Multiyear means of the summer days (**SU**, unit: days) for 1950-1979, 1990-2019, absolute and relative (in %) difference



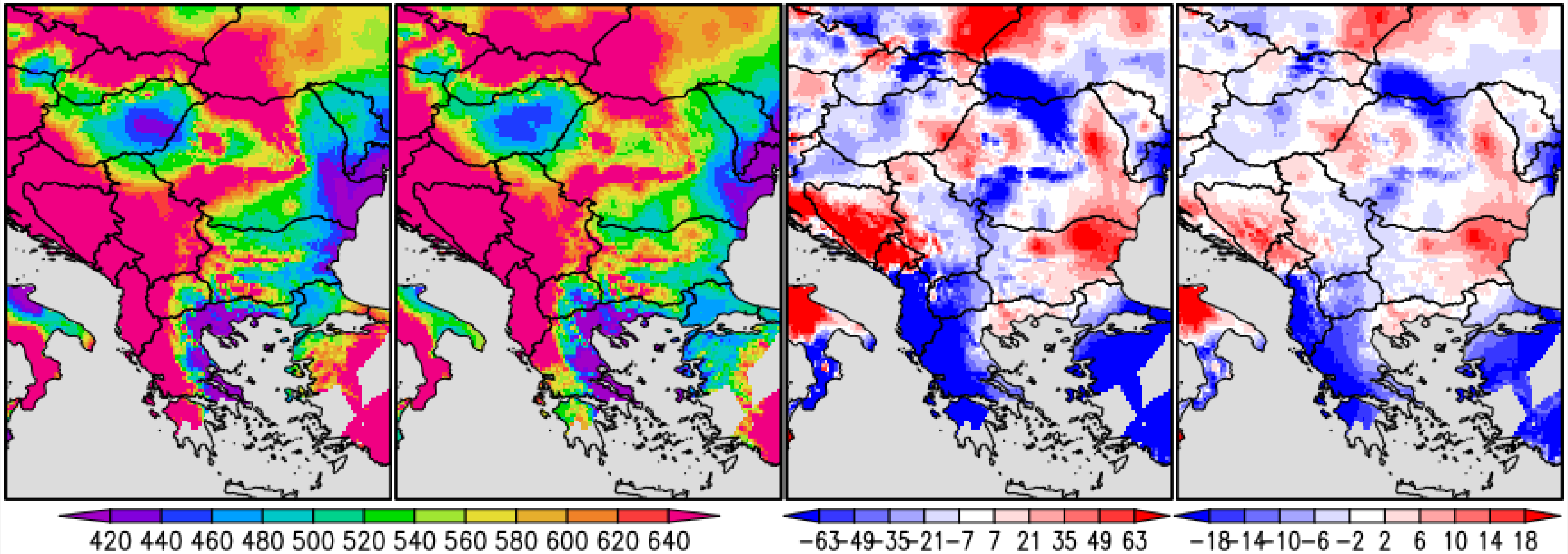
On left: Trend magnitude (unit: days/10 year) of the **SU**. Stippling indicates grid points with changes that are **not** significant at the 5% significance level. On right: Temporal evolution of the areal averages (red - whole domain; blue - area in green frame). The fat lines are the running 5-year means and the double fat lines – the trend lines.



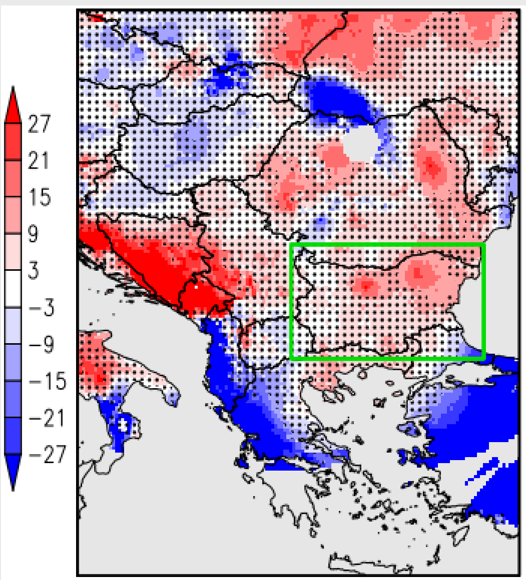
From left to right: Multiyear means of the **CSDI** (unit: days) in the first and of the **WSDI** (unit: days) in the second row for 1950-1979, 1990-2019, absolute and relative (in %) difference

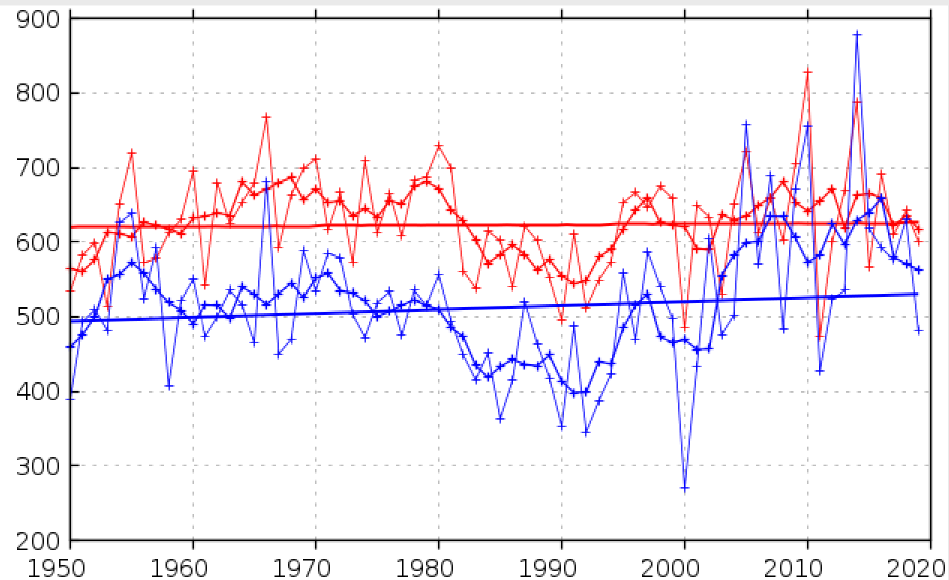


On left: Trend magnitude (unit: days/10 year) of the **CSDI** on the first and of the **WSDI** on the second row. Stippling indicates grid points with changes that are **not** significant at the 5% significance level. On right: Temporal evolution of the areal averages (red - whole domain; blue - area in green frame). The fat lines are the running 5-year means and the double fat lines – the trend lines.



From left to right: Multiyear means of the prec. Sum in wet days (**PRCPTOT**, unit: mm) for 1950-1979, 1990-2019, abs. and rel. (in %) difference





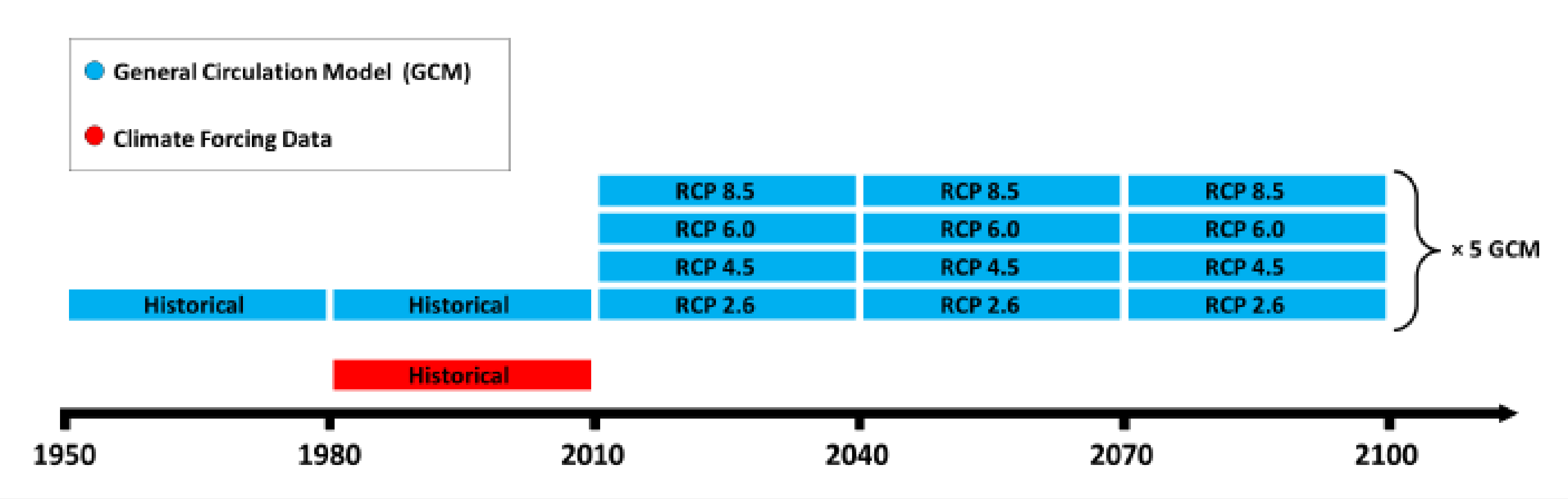
On left: Trend magnitude (unit: mm/10 year) of the **PRCPTOT**. Stippling indicates grid points with changes that are **not** significant at the 5% significance level. On right: Temporal evolution of the areal averages (red - whole domain; blue - area in green frame). The fat lines are the running 5-year means and the double fat lines – the trend lines.

4. Climate indices for the projected future climate (1 from 8)

The present study is based entirely on the data from ISIMIP Fast Track. Although this project is intended to be a collection of agroclimatic indicators datasets, most of the indices in scope, inclusive all considered in this study, are based on the ETCCDI definitions which makes them universal. Agricultural indicators in ISIMIP Fast Track have been pre-calculated for this complete matrix of **5 GCMs×4 RCPs** combinations. In addition, as a proxy for historical observations, the "Watch Forcing Data methodology applied to ERA-Interim (WFDEI)" were used to generate observational historical Agroclimatic indicators. This dataset is available at the same spatial resolution of ISIMIP climate datasets, covers the time range of 1979 to 2013 and its 30 year long part 1981-2010 is used in the study as reference for the current climate:

- **5 GCMs × 2 historical periods**
- **5 GCMs × 4 RCPs x 3 future periods**
- **1 historical from climate forcing data (WFDEI)**

N.B.: The input data (i.e. daily temperatures and precipitation sums) are bias-corrected, prior the computations of the indices.



Graphical illustration of the time periods covered for each indicator

4. Climate indices for the projected future climate (2 from 8)

Model Acronym	Institution	Spat. Resolution (Lon×Lat~Lev.)
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, USA	144×90L24
HadGEM2-ES	Met Office Hadley Centre, UK	192×145L40
IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France	96×96L39
MIROC-ESM-CHEM	AORI, NIES, JAMSTEC, Japan	128×64L80(T42)
NorESM1-M	Norwegian Climate Centre, Norway	144×96L26

Mean Features of the Considered Models

Acronym	Description	Unit	Application
CDD	Maximum number of consecutive dry days (Drought spell)	days	Drought monitoring, drought damage indicator
CFD	Maximum number of consecutive frost days (Cold spell)	days	General frost damage indicator
CSDI	Cold-spell duration index	days	Provides information on reduced blossom formation or reduced growth
WSDI	Warm-spell duration index	days	Provide an indication concerning the occurrence of heat stress on reduced blossom formation or reduced growth.
CSU	Maximum number of consecutive summer days (Hot spell)	days	Provides information on heat stress or on optimal growth for C4 crops (e.g. maize)
CWD	Maximum number of consecutive wet days (Wet spell)	days	Provides information on drought/oxygen stress/crop growth (i.e. less radiation interception during rainy days)
WW	Warm and wet days	days	Provides an indication concerning the crop development, especially leave formation.
DTR	Mean of diurnal temperature range	^{o}C	Provides information on climate variability and change. Also serves as the proxy for information on the clarity (transmittance) of the atmosphere
BEDD	Biologically Effective Degree Days	^{o}C	Determines crop development stages/rates. Crop development will decelerate/accelerate below and above certain threshold temperatures.
GSL	Growing Season Length	days	Provides an indication whether a crop or a combination of crops can be sown and subsequently reach maturity within a certain time frame
FD	Frost Days	days	Provides information on frost damage
ID	Ice Days	days	
R10mm	Heavy Precipitation Days	days	Provides information on crop damage and runoff losses
R20mm	Very Heavy Precipitation Days	days	
RR	Precipitation Sum	mm	Provides information on possible water shortage or excess
RR1	Wet Days	days	Provides information on intercepted reduction
SDII	Simple Daily Intensity Index	mm	Provides information on possible run off losses
SU	Summer days	days	Provide an indication concerning the occurrence of heat stress. Also base for crop specific variants for heat/cold stress (above/below the crop specific optimal temperature thresholds)
TG	Mean of daily mean temperature	^{o}C	Provides information on long-term climate variability and change
TN	Mean of daily minimum temperature	^{o}C	
TNn	Minimum Value of the Daily Minimum Temperature	^{o}C	
TN.x	Maximum value of the daily minimum temperature	^{o}C	
TR	Tropical Nights	^{o}C	Provide an indication of occurrence of various pests
TX	Mean of daily maximum temperature	^{o}C	Provides information on long-term climate variability and change
TX.n	Minimum value of daily maximum temperature	^{o}C	
TX.x	Maximum value of daily maximum temperature	^{o}C	

List of agroclimatic indicators, their description and general application in agriscience. The annual, seasonal and decadal (i.e. 10-day) temporal resolution is shown in green, blue and brown background respectively.

4. Climate indices for the projected future climate (4 from 8)

After the download (via purpose-build python scripts) from the CDS the ISIMIP-datasets are significantly post-processed. The most essential stages are:

• The datasets for each model and RCP which are downloadable in 30-years time slices are merged in common data streams for 2011-2099

• The indices with equal temporal resolution are joined in common netCDF4 files

• Multi-model (MM) ensemble quantities as multi-model mean (MMM), MM 25-, 50- and 75-percentile which are often refereed as lower quartile, median and upper quartile and traditionally noted as X25, X50 and X75 are computed.

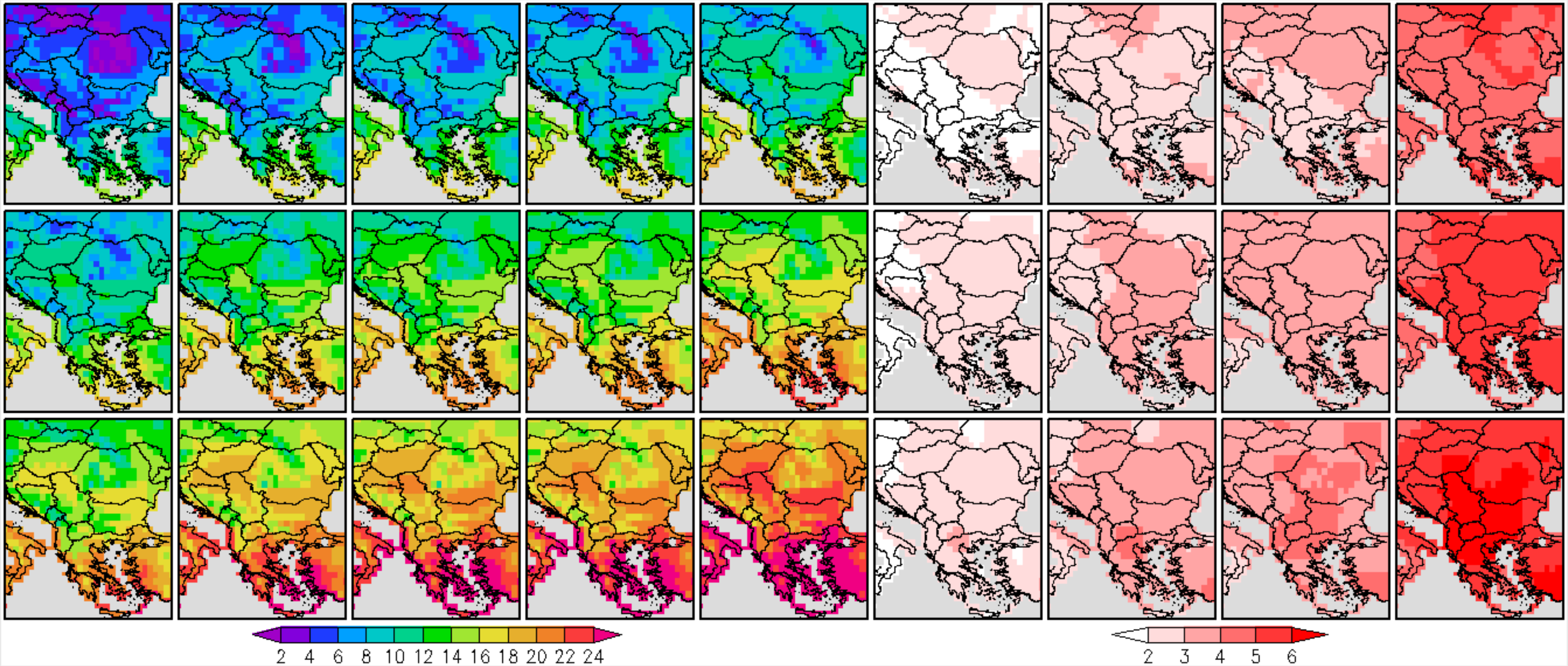
• Due to storage constrains only a spatial subset over Europe is preserved.

All netCDF manipulations are performed with the powerful tool Climate Data Operators (cdo). Additionally, for the current study only, all of the considered indices are aggregated in time on annual basis. The aggregation method depend on the indicator, e.g. *min, max, sum, mean*.

• The magnitude of the trend in time as well as its statistical significance are estimated individually for all grid cells and separately for each scenario by means of the Theil-Sen slope estimator (TSE) and the Mann-Kendall (MK) test correspondingly. Thus far, the study is constrained over SE Europe only.

4. Climate indices for the projected future climate (5 from 8)

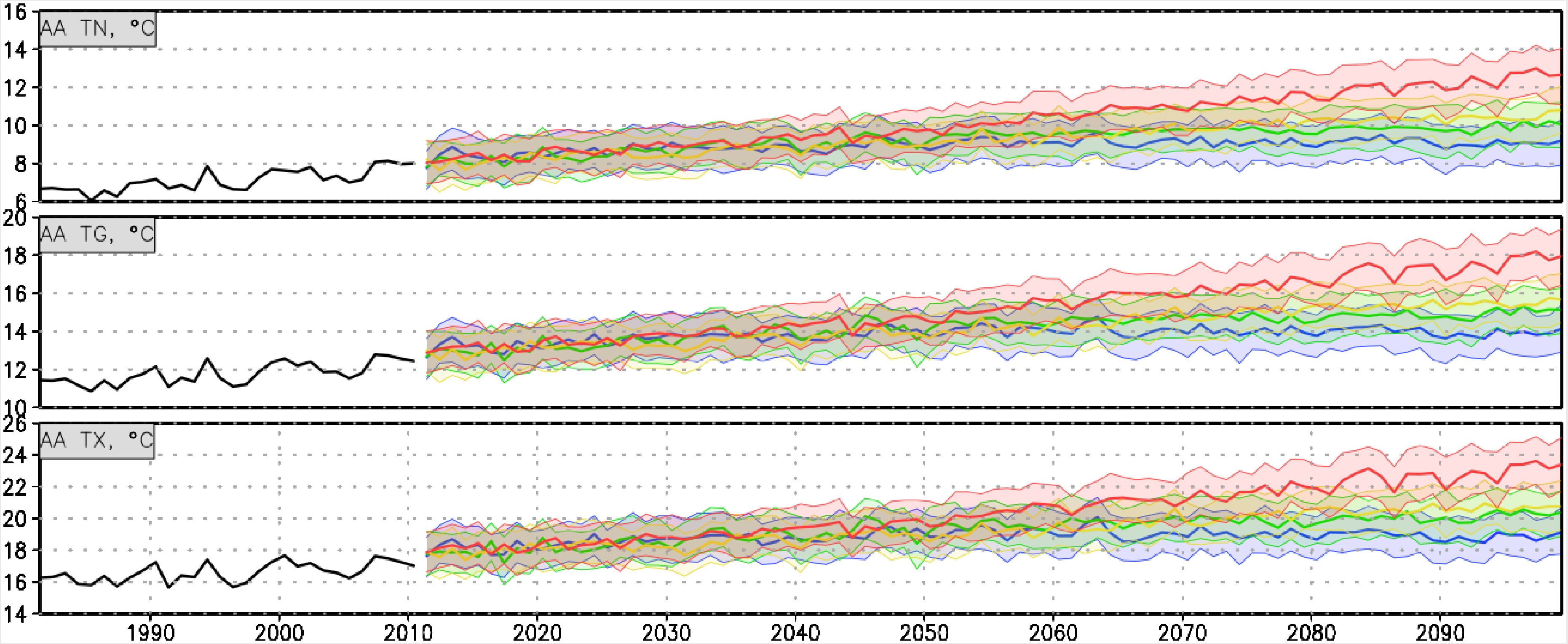
Results for the average mean and extreme temperatures



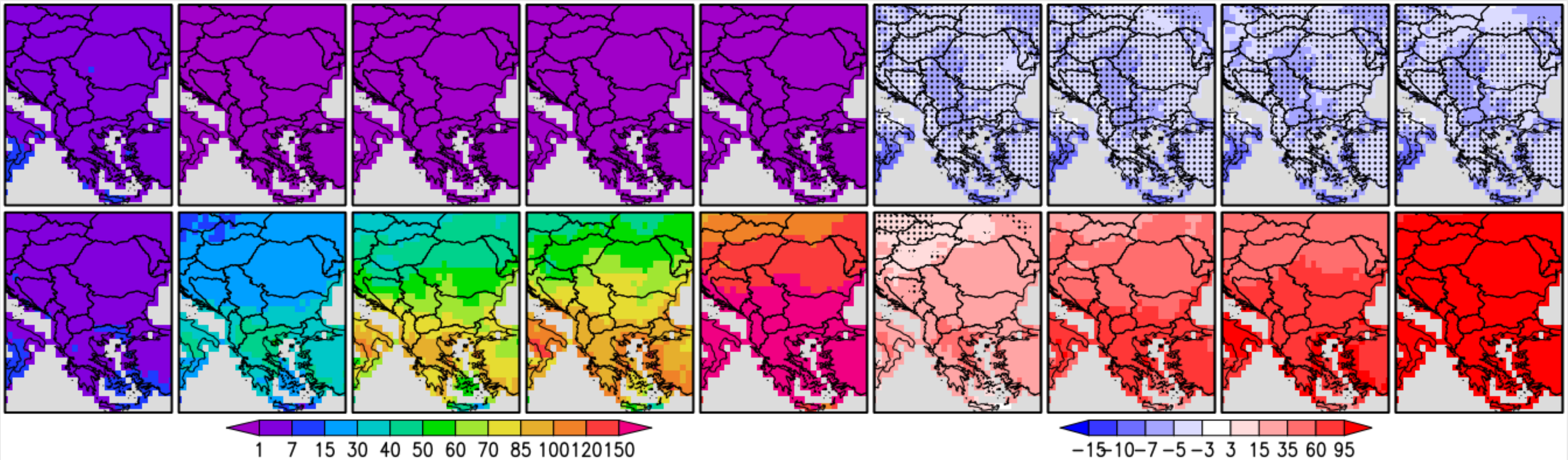
MMX50 of the multiyear means of the **TN** (first row) **TG** (second row) and **TX** (third row) for the reference period (1981-2010) in the first column and multiyear means for 2070-2099 for RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in the second, third, fourth and fifth column correspondingly. The absolute changes of the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 relative to the reference period are shown in the sixth seventh eighth and ninth column correspondingly. The units are ^{o}C.

4. Climate indices for the projected future climate (6 from 8)

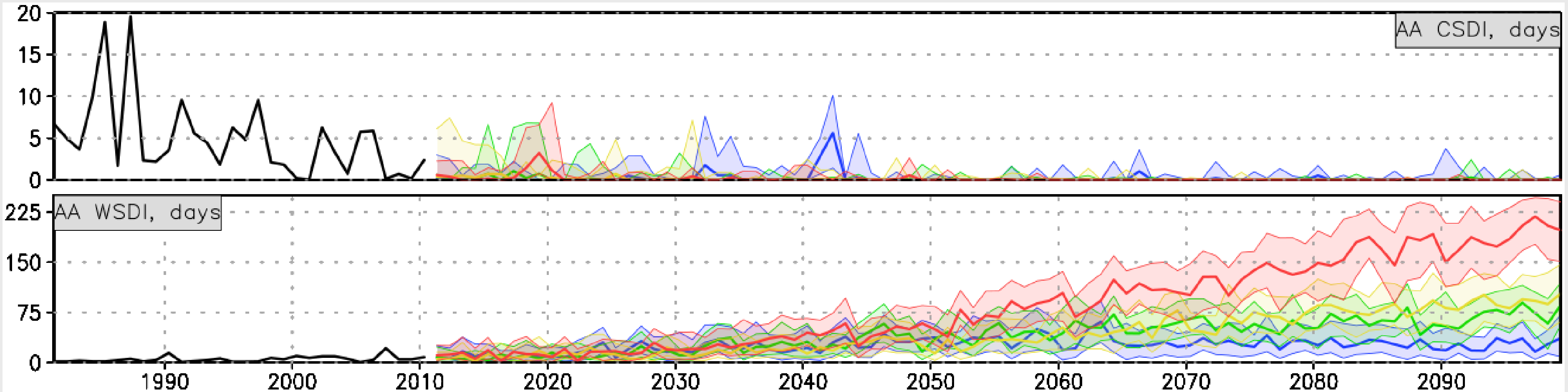
Results for the average mean and extreme temperatures



Area-weighted regional averages (AA, index and unit according subplot title) for the reference (solid black line) and simulated by the CMIP5 ensemble for the RCP2.6 (blue), RCP4.5 (green), RCP6.0 (yellow) and RCP8.5 (red). Solid lines indicate the ensemble median (i.e. the 50th quantile) and the shading, respectively the thin lines, indicates the interquartile ensemble spread (25th and 75th quantiles).



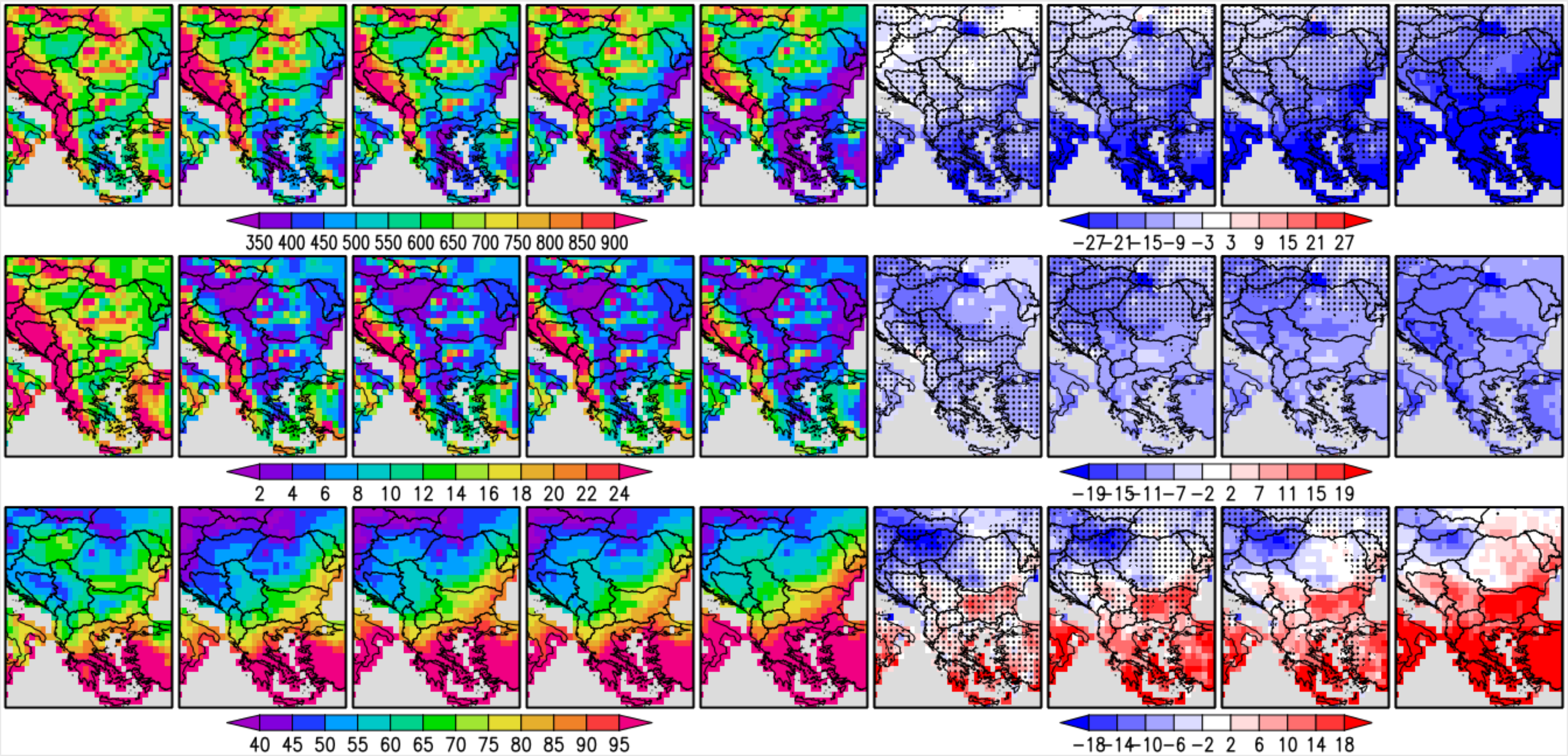
MMX50 of the multiyear means of the **CSDI** (first row) and **WSDI** (second row) for the reference period (1981-2010) in the first column and multiyear means for 2070-2099 for RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in the second, third, fourth and fifth column correspondingly. The absolute changes of the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 relative to the reference period are shown in the sixth seventh eighth and ninth column correspondingly. The units are days.



Area-weighted regional averages (AA, index and unit according subplot title) for the reference (solid black line) and simulated by the CMIP5 ensemble for the RCP2.6 (blue), RCP4.5 (green), RCP6.0 (yellow) and RCP8.5 (red). Solid lines indicate the ensemble median (i.e. the 50th quantile) and the shading, respectively the thin lines, indicates the interquartile ensemble spread (25th and 75th quantiles). The units are days.

4. Climate indices for the projected future climate (8 from 8)

Results for some precipitation-based indices



Same as Figure 5 but for the **RR** (first row), **RR10mm** (second row) and **CDD** (third row). Relative instead of absolute changes of the **RR** are considered. The units of the **RR** are mm and of the **RR10mm** and **CDD** as well as their changes – days. The relative changes of the **RR** are expressed in %.

5. Results for some special climate indicators (1 from 5)

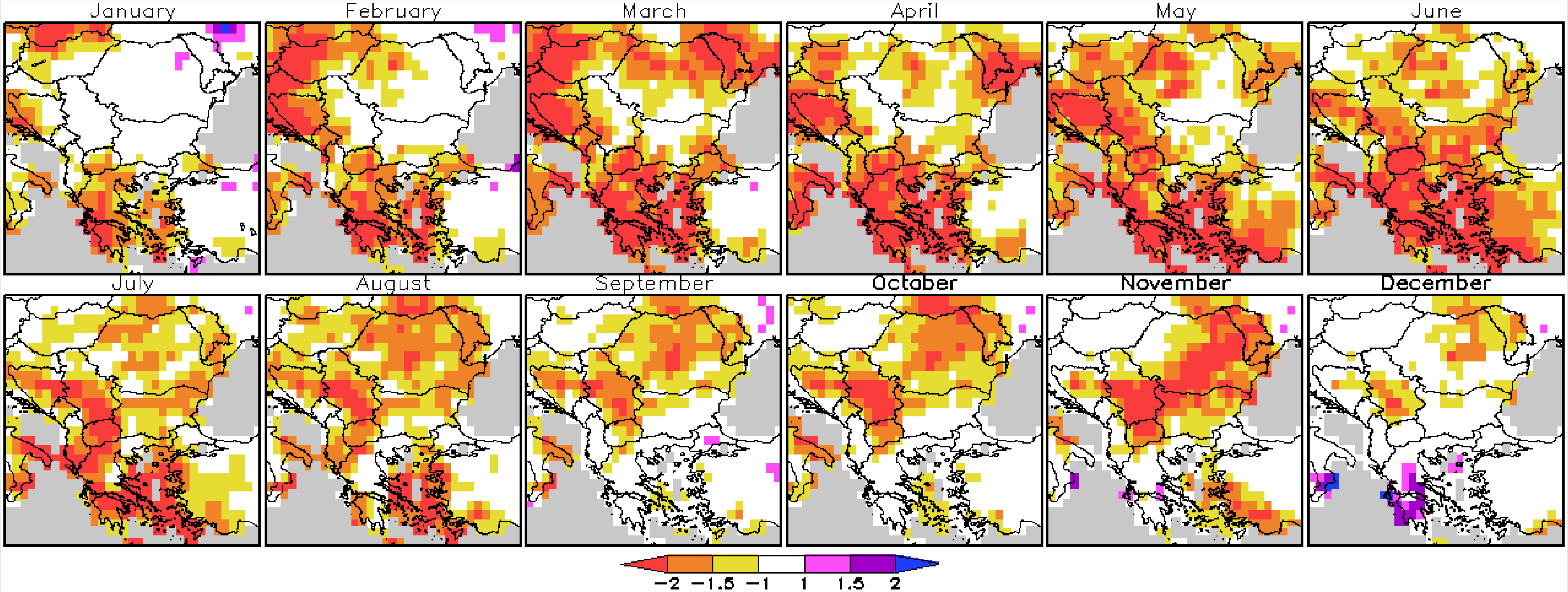
Data base of the standardized precipitation index (**SPI**)

Data-set	Source	Coverage	Resolution	Time window	Reference
Version 3.02 of the “Terrestrial Precipitation: 1900-2010 Gridded Monthly Time Series”	Department of Geography of the University of Delaware	Global, land surface only	0,5°× 0,5°	1900-2010	Peterson et al. (1998)
Global Precipitation Climatology Centre (GPCC) Full Data Reanalysis version 7.0	WMO-DWD	Global, land surface only	0,5°× 0,5°	1901-2013	Schneider et al. (2015)
Version v2c of the NOAA-CIRES 20CR	NOAA-CIRES	Global	*1,5°× 1,5°	1851-2011	Compo et al. (2011)
ERA 20C	ECMWF	Global	0,5°× 0,5°	1900-2010	Stickler et al. (2014)

*Regridded from the original (Gaussian) grid prior the SPI calculation

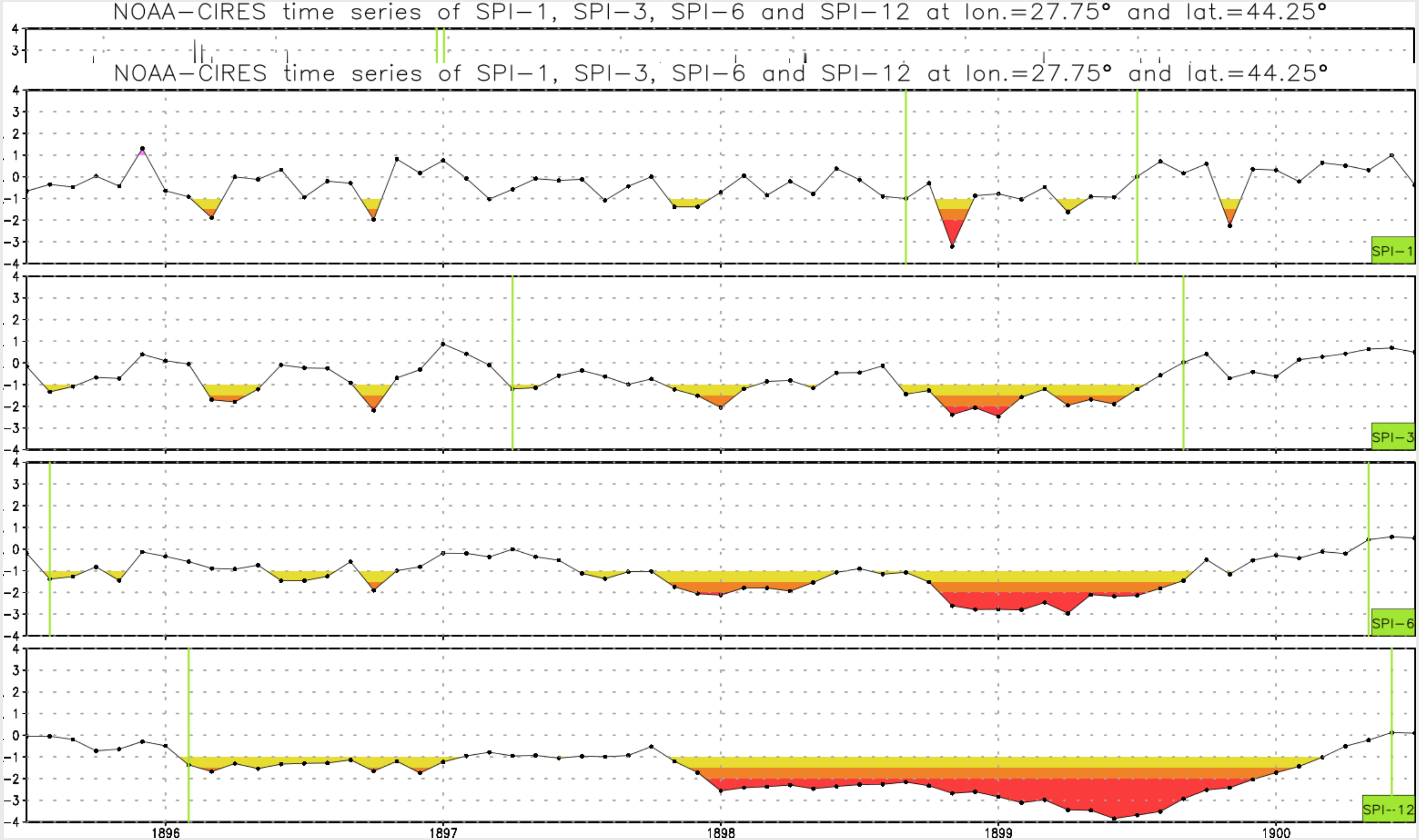
Applied precipitation inventories for the computation of SPI-1, SPI-3, SPI-6 and SPI-12

5. Results for some special climate indicators (2 from 5)



Spatial distribution SPI-6 for the listed months of 1990 (recognizable droughty year).

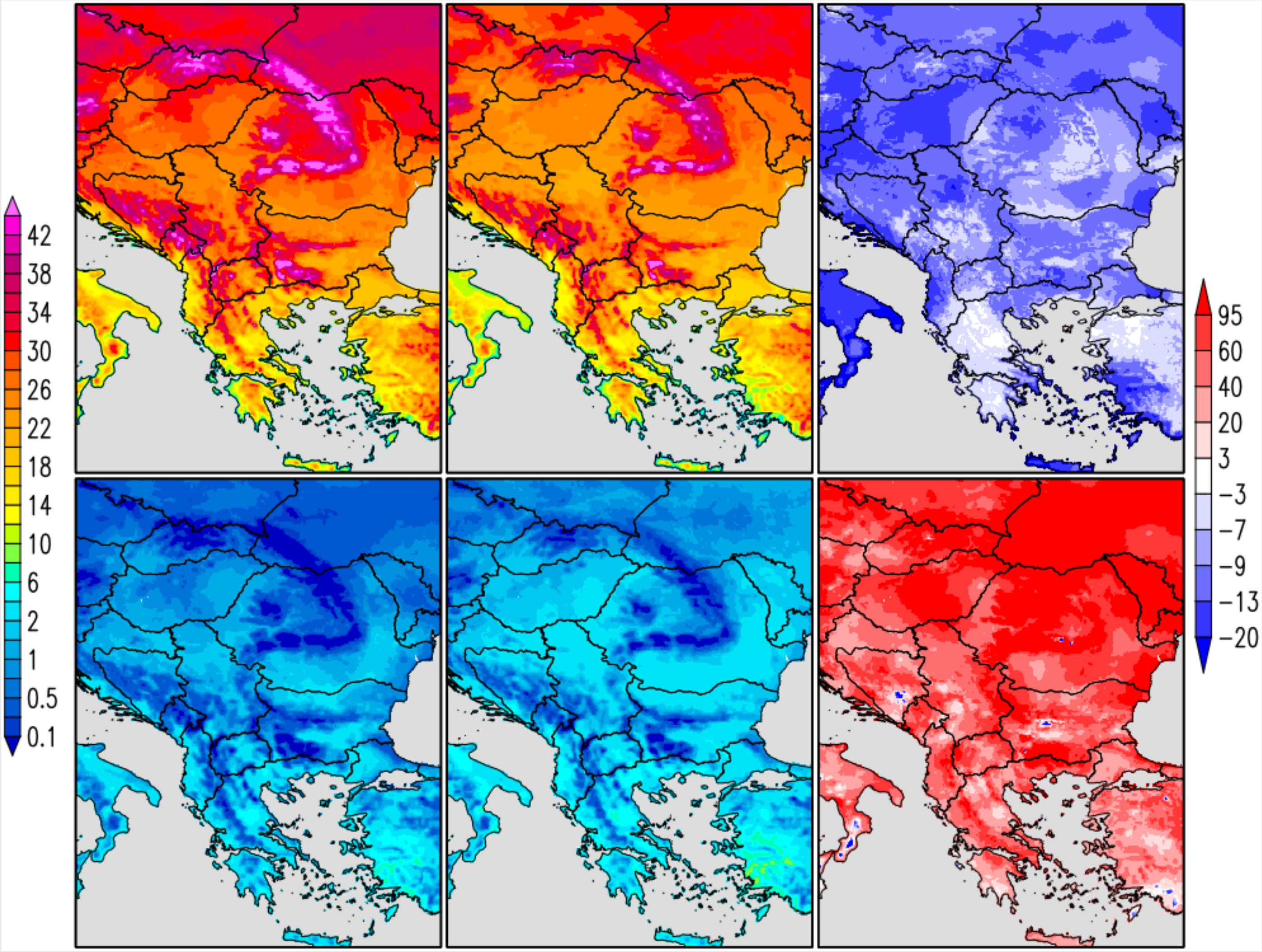
5. Results for some special climate indicators (3 from 5)



Time series of SPI-1, SPI-3, SPI-6 and SPI-12 *According McKee et al. (1993) the drought begins by negative values of SPI reaching -1 and lasts till upward transition trough 0.*

5. Results for some special climate indicators (4 from 5)

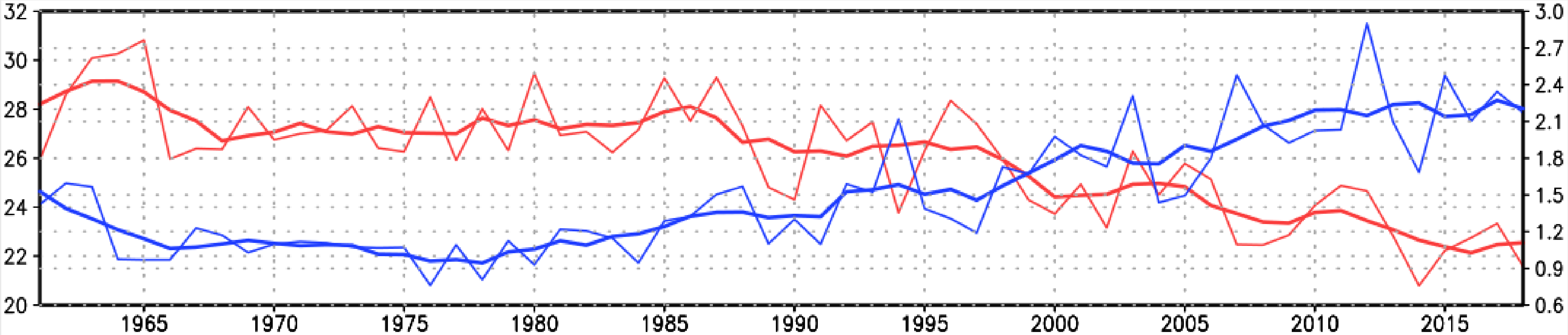
Heating and cooling degree days (**HDD** and **CDD**)



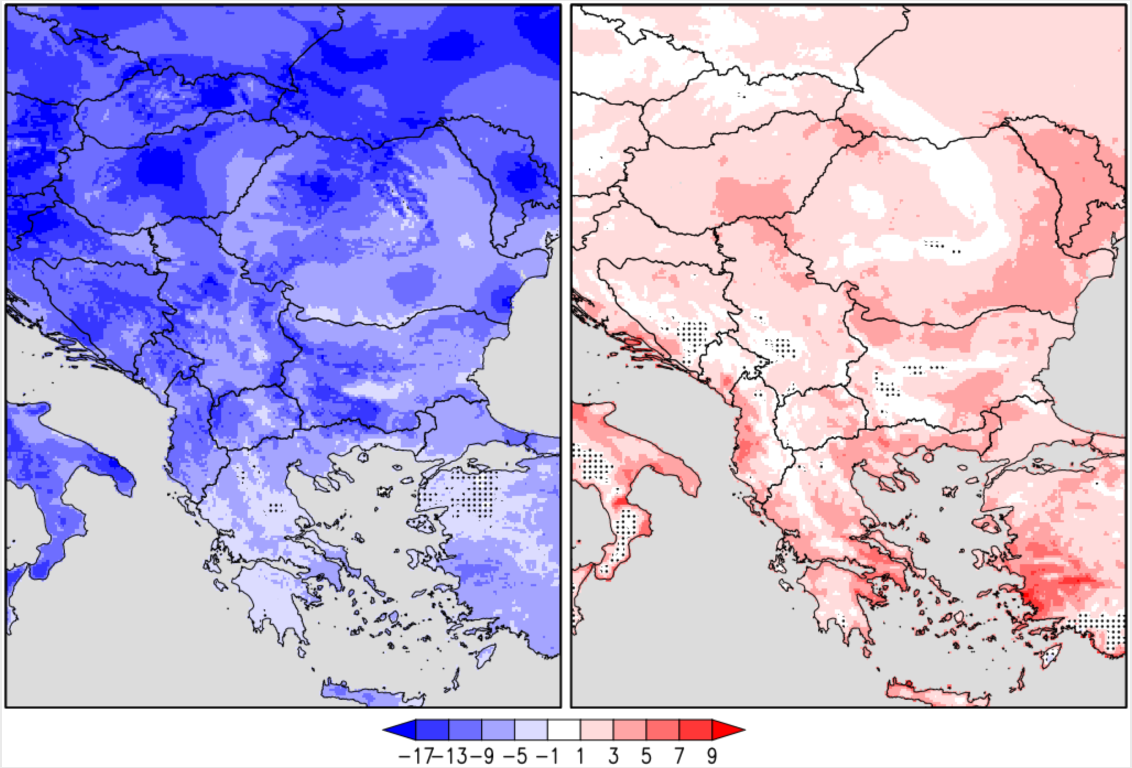
Multiyear means (source of the temperature data: UERRA-MESCAN SURFEX) of HDD (first row) and CDD (second row) in the first and second column correspondingly for 1961-1990 and for 1989-2018. The units are 100 °D. The relative biases (in %) are shown in the third column

5. Results for some special climate indicators (5 from 5)

Heating and cooling degree days (**HDD** and **CDD**)



▲Temporal evolution of the HDD (red line, left ordinate) and CDD (blue line, right ordinate). The units are 100 °D. The fat lines are the running 5-year means



►Trend magnitude of the HDD and CDD in the first and second column respectively. The units are °D per 1 year. Stippling indicates grid points with changes that are **not** significant at the 5% significance level

6. Summary and Conclusions

• The spatial patterns and temporal evolution of changes presented in this work are in principal agreement with previous studies based on reanalyses, station measurements, GCM output data, RCM simulations or such based on combined analysis of GCMs and RCMs.

• The results of this study (for the future) are also coherent with the consolidated outcomes from all Assessment Reports (AR) of the Intergovernmental Panel on Climate Change (IPCC) concerning the expected long-term regional changes. However, the present results are not directly comparable, at least not quantitatively, to theirs, due to different factors.

• The most general and important conclusion of the study is the distinct warming (in the recent past, present and in the future), expressed in the spatial patterns and time evolution of all of the considered thermal indices. The climate change of the considered temperature-based indices is consistent with the tendencies of the annual means of the daily mean and extreme temperatures. The warming dominates practically over the whole domain and is statistically significant over its essential part in the most cases. The revealed patterns of climate change in the future intensify gradually with the increasing radiative forcing in the considered scenarios, which also agrees generally with the outcome of the prevailing number of the recent studies.

• Concerning the precipitation-based indices, the study confirms the complexity of the expected precipitation-related changes and their inherent ambiguity. The latter is clearly evidenced by the lower level of statistical significance for the scenarios RCP2.6-RCP6.0 when compared with temperature changes. It is worth emphasizing that the projected precipitation reduction over the SE part of the domain in the future and increase of the **CDD** could amplify the negative impact of the expected hotter climate.

7. Acknowledgement

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