12th Workshop on the Theory and Use of Regional Climate Models
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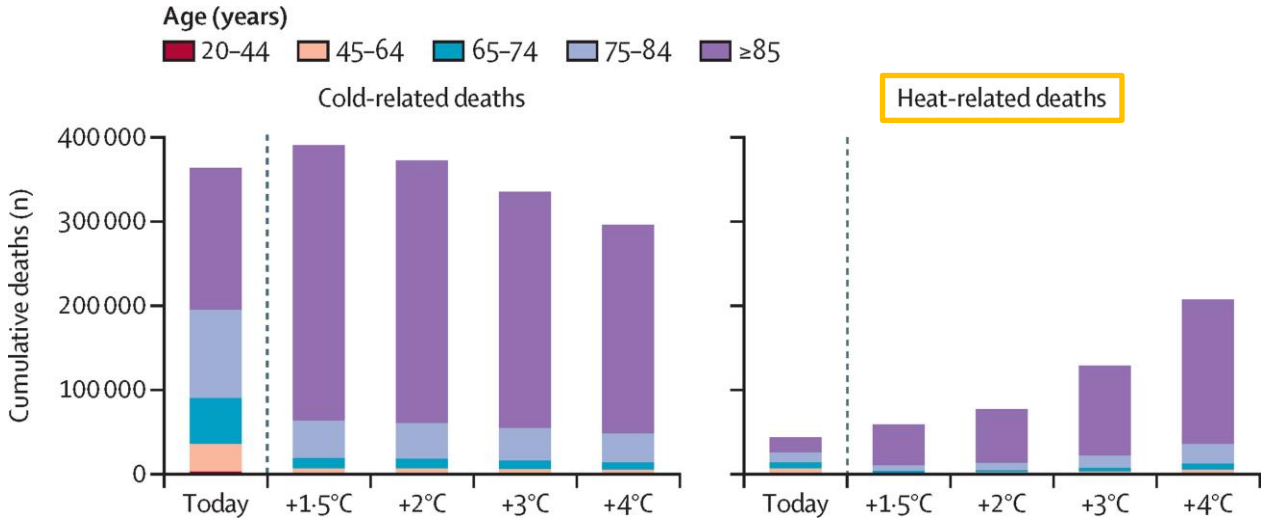
Bias correction in defining and predicting heatwaves over Croatia

Sara Ivasić[1], Lidija Srnec[1] and Renata Sokol Jurković

sara.ivasic@dhz.hr
[1]Croatian Meteorological and Hydrological Service
Zagreb, Croatia

Health risks associated with heat are projected to increase in the future



Cumulative number of deaths in Europe attributed to cold and heat by age group.

García-León et al. (2024)
Temperature-related mortality burden and projected change in 1368 European regions: a modelling study.
The Lancet Public Health, Volume 9, Issue 9, e644 - e653

Heatwave early warning system in Croatia

- established in 2012 → now issued 4 days in advance
- heatwave health risk algorithm input:
  Tmin, Tmax and mortality data

Croatian Meteorological and Hydrological Service

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Warnings

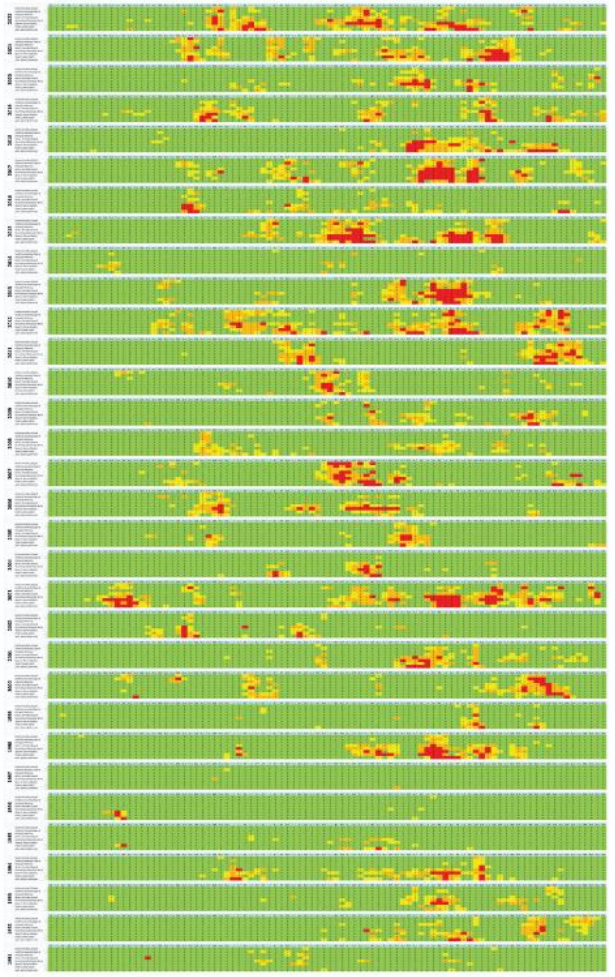
Home » Forecasts » Specialist forecasts

Heat wave warning

Region	Thu 07.08.2025.	Fri 08.08.2025.	Sat 09.08.2025.	Sun 10.08.2025.	Mon 11.08.2025.
Osijek	0	0	1	2	1
Zagreb	0	0	1	2	1
Karlovac	0	0	0	1	1
Gospić	0	0	1	1	1
Knin	0	0	1	2	3
Rijeka	0	1	2	2	3
Split	0	0	1	2	3
Dubrovnik	0	0	1	2	3

Risk: 0 none | 1 moderate | 2 high | 3 very high

Heat health risks:
green – no risk
yellow – moderate
orange – high
red – very high



Zaninović and Matzarakis (2014)
Impact of heat waves on mortality in Croatia.
International Journal of Biometorology, Vol 58:1135-1145.
https://doi.org/10.1007/s00484-013-0706-3

Reviews N° 34
CLIMATE MONITORING AND ASSESSMENT FOR 2022
https://klima.hr/razno/publikacije/prikazi/prikazi_34_2022.pdf

EURO-CORDEX climate projections

model	institution	reference
regional climate models (RCM)		
RegCM4	ICTP	Giorgi et al. (2012)
RCA4	SMHI	Wang et al. (2015)
CCLM4	CLM-Community	Rockel et al. (2008)
global climate models (GCM)		
CNRM-CM5	Centre National de Recherches Météorologiques	Voldoire et al. (2013)
EC-EARTH	ECMWF	Hazeleger et al. (2010)
MPI-ESM	Max-Planck-Institute for Meteorology	Giorgetta et al. (2013)

- climate projections at 12.5 km horizontal resolution → *daily* maximum and minimum temperature data
- P0 1991-2020 vs. P3 2041-2070
- RCP4.5 and RCP8.5 scenarios

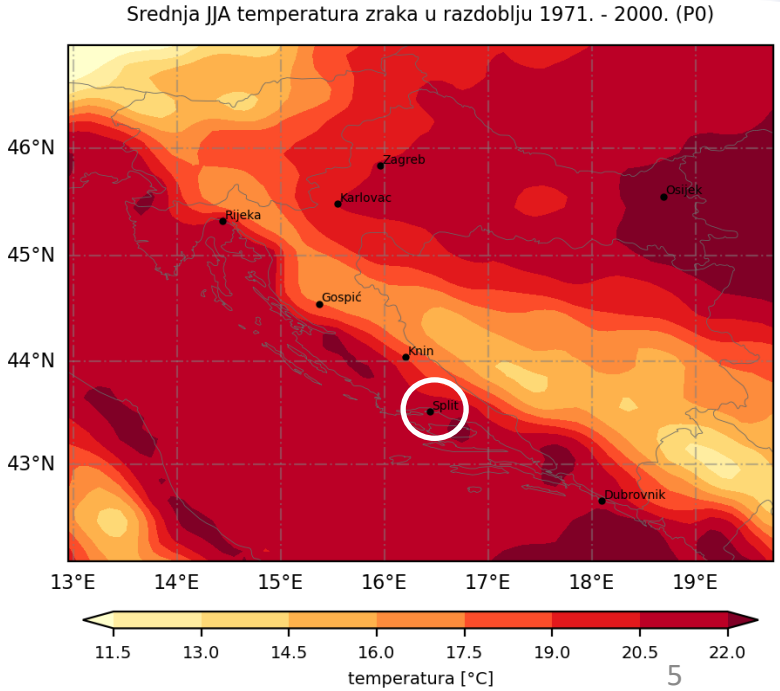
Bias correction methods

- following **Sokol Jurković et al. (2022)** parametric marginal distributions and a Gaussian copula → bivariate correction of *daily* maximum and minimum temperature from the RCM ensemble

- normal distribution used to model temperature

- previously, bivariate empirical method proved best for corrections of *monthly* mean temperature and precipitation data

- preliminary results:
  - season June-July-August (JJA)
  - station Split-Marjan (ST)
  - bivariate correction method with underlying normal distribution (2D teor)



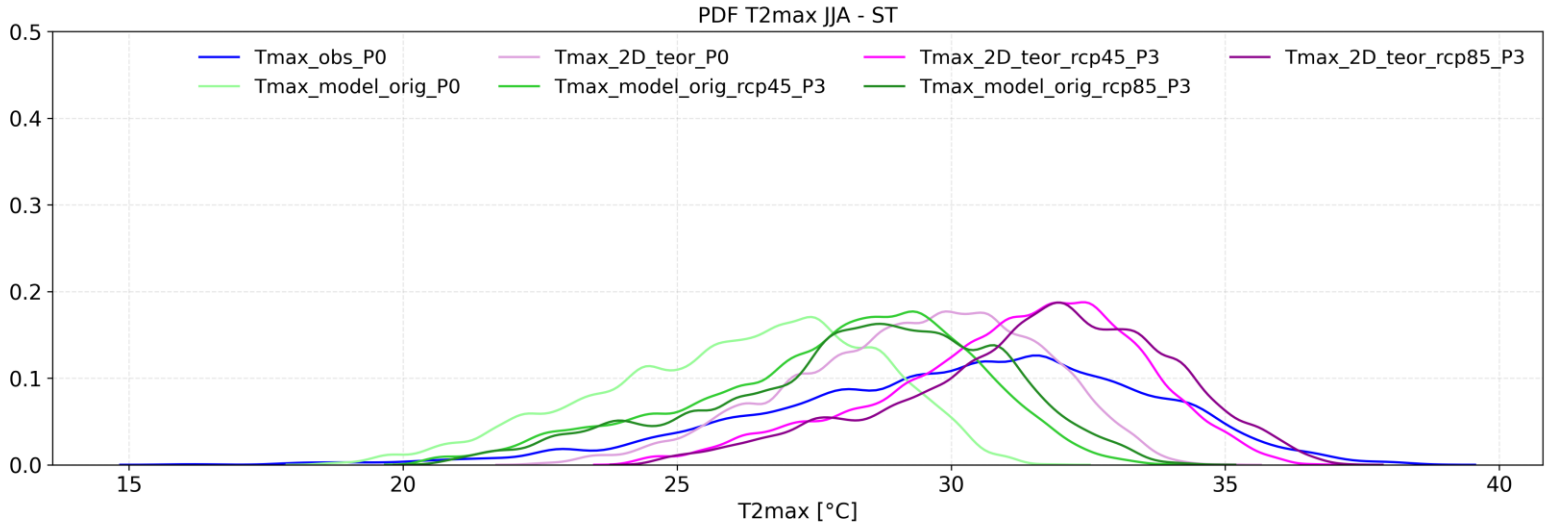
Sokol Jurković et al. (2022)
Bivariate bias correction of the regional climate model ensemble over the Adriatic region.
International journal of climatology 42.11: 5826-5847. https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.7564

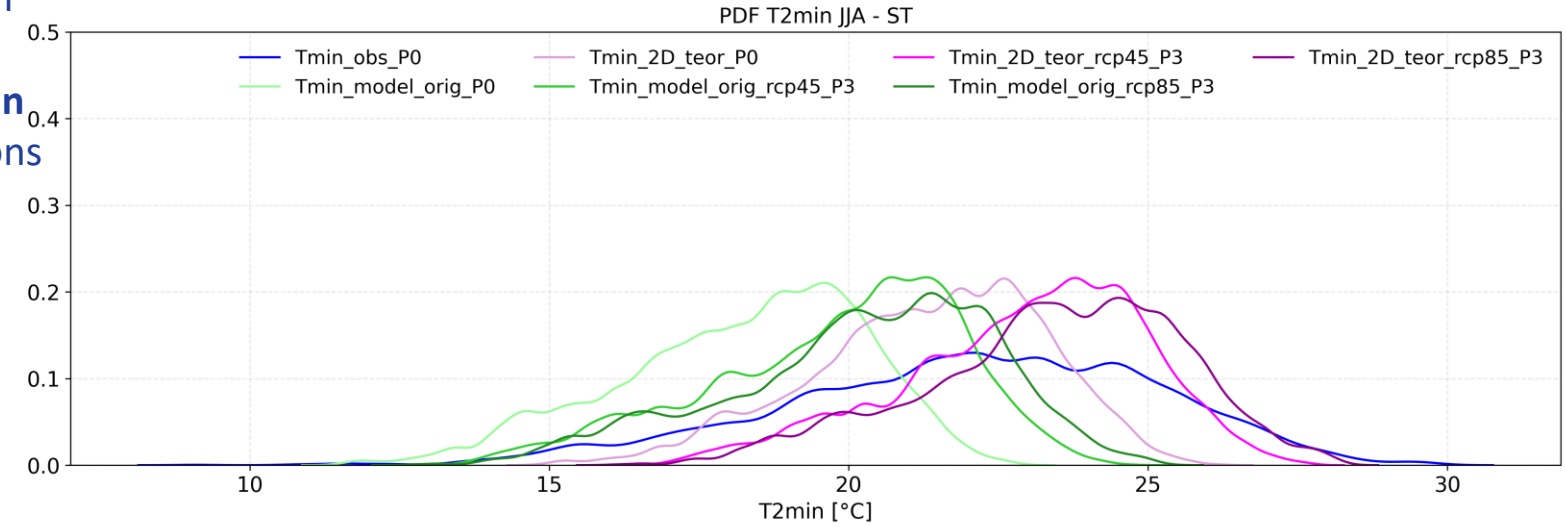
P0: 1991 – 2020
P3: 2041 – 2070
RCP4.5 and RCP8.5

maximum temperature

PDFs of maximum and minimum temperature at 2 m height based on the **ensemble mean** of 9 RCM simulations

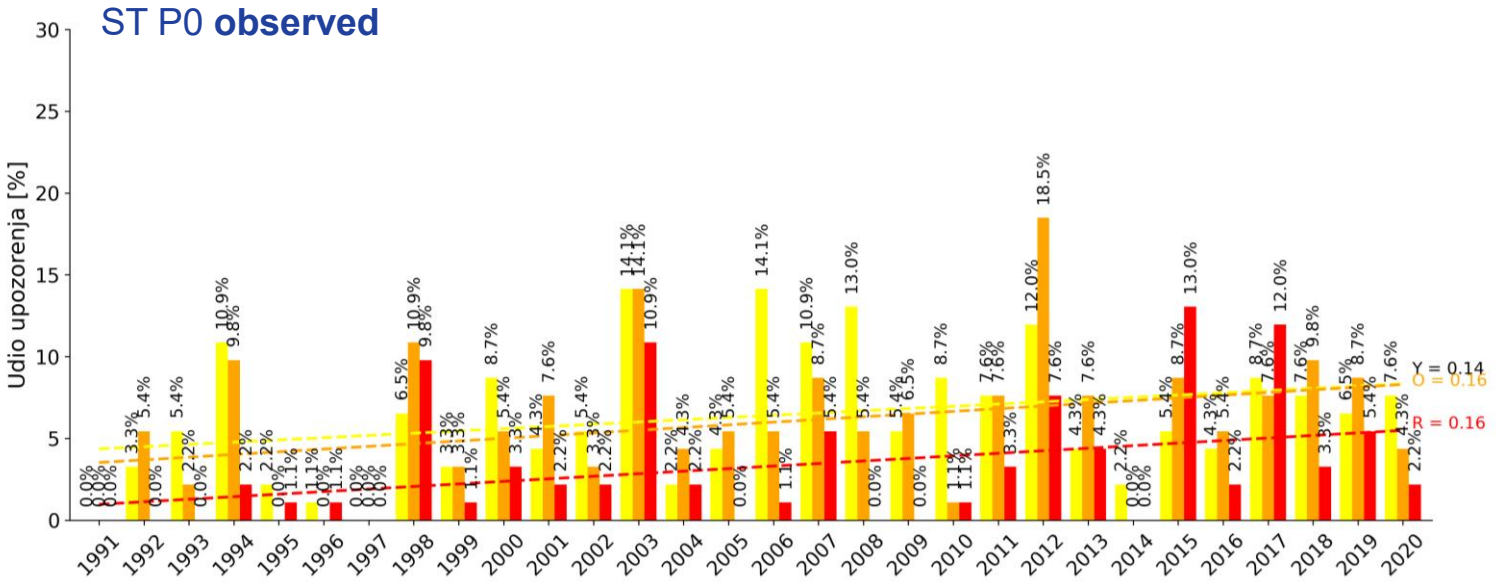
minimum temperature





1991 - 2020

Percentage of days with different levels of heatwave risk in JJA season

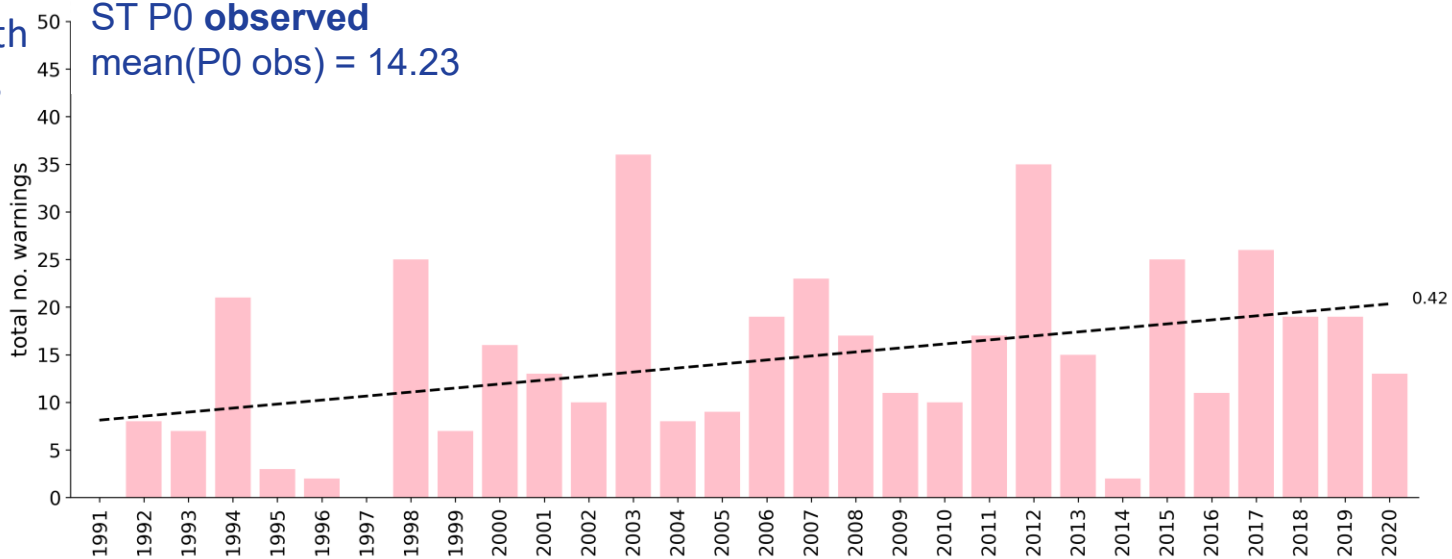


- 1991 – 2020 & 2041 – 2070 → original RCM data → trend smaller than observed and with inconsistent sign
- 2041 – 2070 RCP8.5 → 2D teor bias corrected RCM ouput → consistently increasing trend of days with orange and red warnings in JJA season

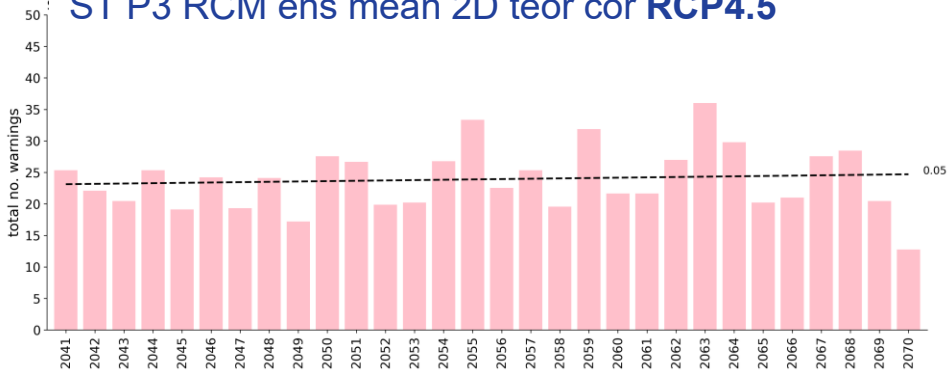
Total number of days with heatwave risk conditions of any level in JJA season

P0: 1991 – 2020
P3: 2041 – 2070

ST P0 **observed**
mean(P0 obs) = 14.23

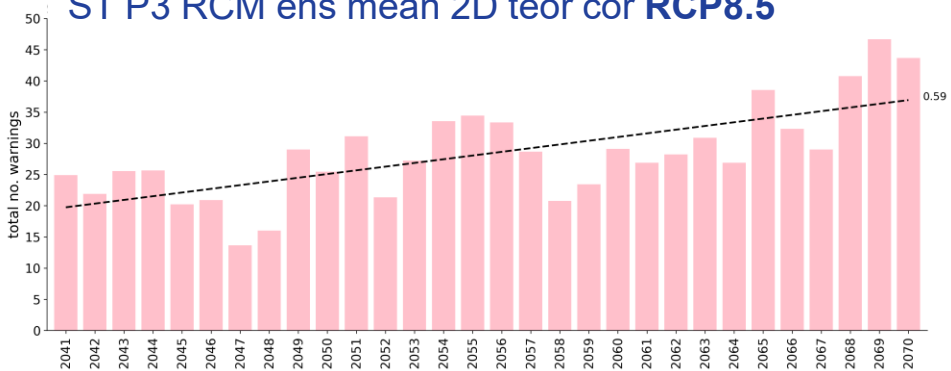


ST P3 RCM ens mean 2D teor cor **RCP4.5**



mean(P3 2Dteor) - mean(P0 2D teor) = 13.34

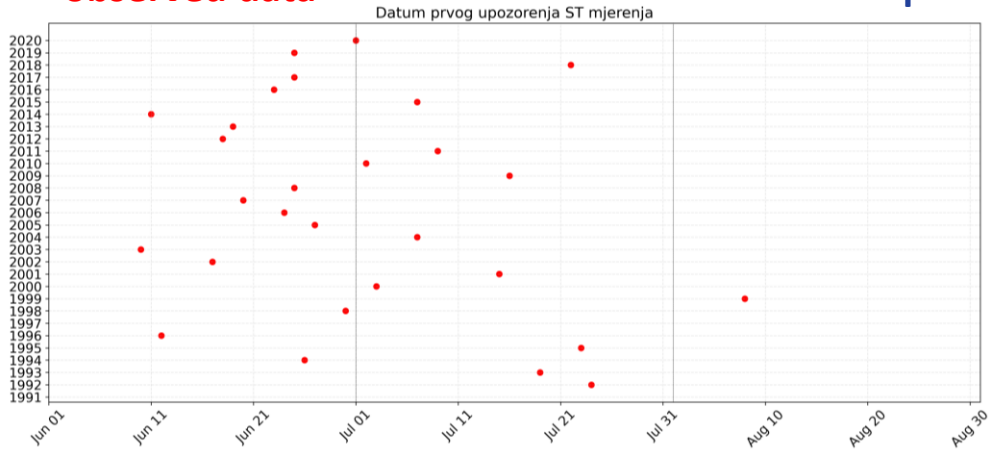
ST P3 RCM ens mean 2D teor cor **RCP8.5**



mean(P3 2D teor) - mean(P0 2D teor) = 17.76

Date of 1st heatwave warning
during JJA season in 1991 – 2020

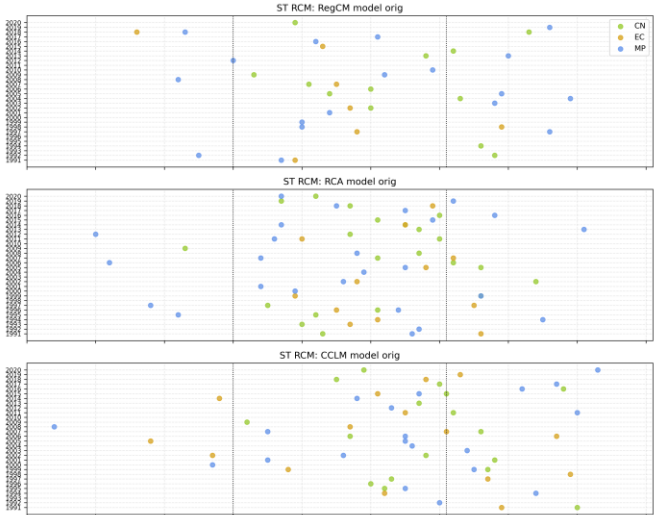
observed data



→ 1 Jun – 31 Aug →

1991 – 2020 →

original model output

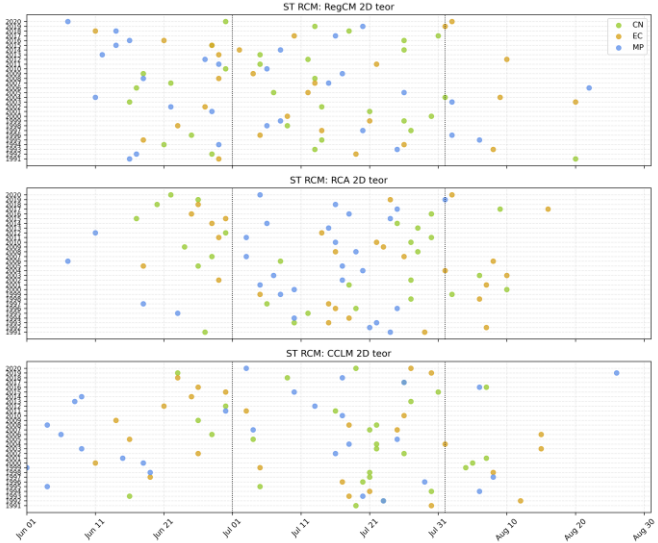


RegCM

RCA

CCLM

2D teor correction

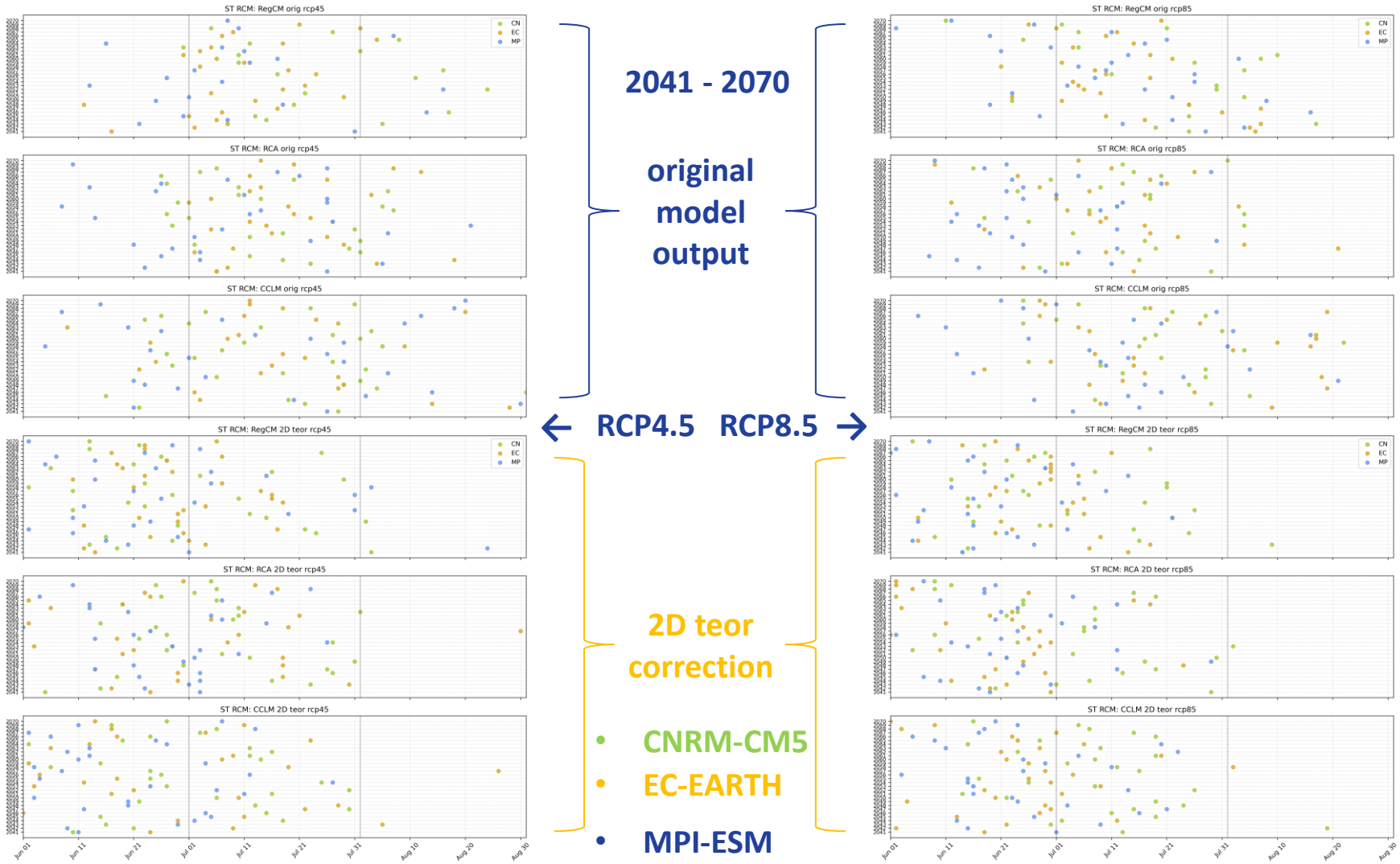


RegCM

RCA

CCLM

- CNRM-CM5
- EC-EARTH
- MPI-ESM



2041 - 2070

original model output

← RCP4.5 RCP8.5 →

2D teor correction

- CNRM-CM5
- EC-EARTH
- MPI-ESM

RegCM

RCA

CCLM

RegCM

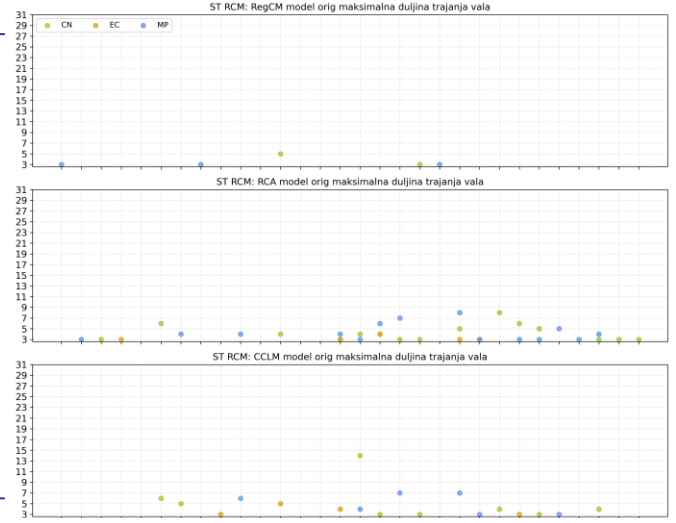
RCA

CCLM

Maximum number of consecutive days with heatwave risk conditions during JJA season in 1991 – 2020

observed data

original model output

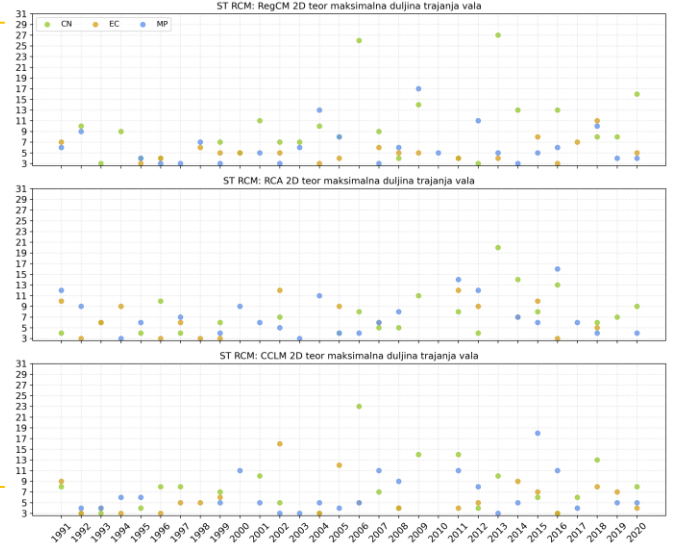


RegCM

RCA

CCLM

2D teor correction



RegCM

RCA

CCLM

<u>minimum duration threshold</u>
→ three consecutive days with heatwave risk conditions

- **CNRM-CM5**
- **EC-EARTH**
- **MPI-ESM**

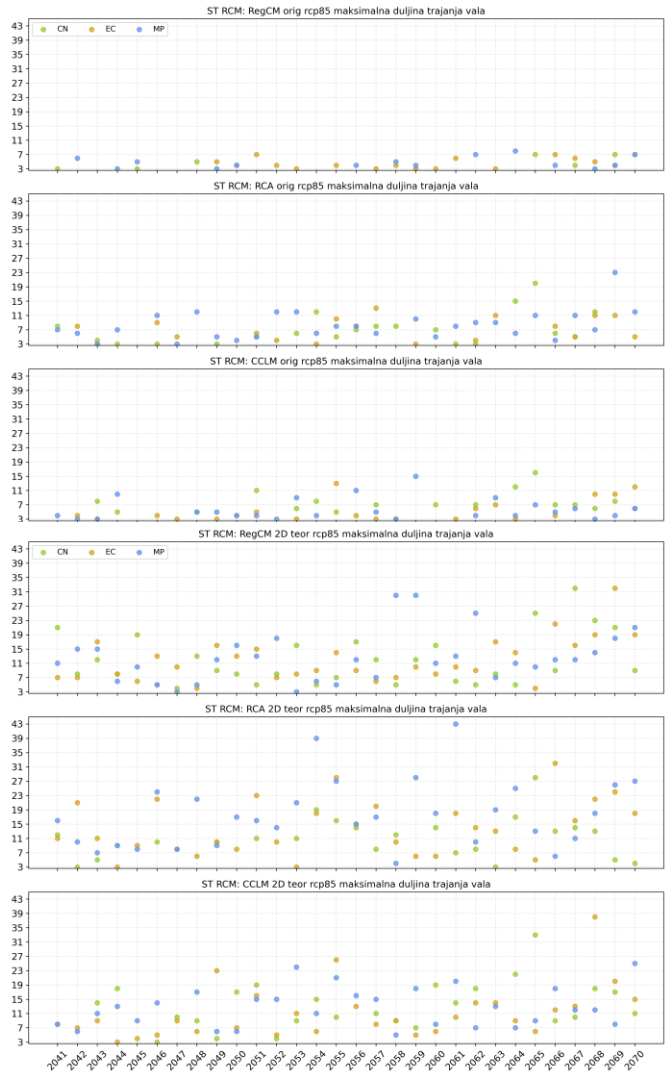
2041 - 2070

original model output

← RCP4.5 RCP8.5 →

2D teor correction

- CNRM-CM5
- EC-EARTH
- MPI-ESM



RegCM

RCA

CCLM

RegCM

RCA

CCLM

Observations

→ the number of heatwave warnings in Croatia is increasing

RCM ensemble

→ bias corrected data closer to observations
→ number of heatwave warnings and their duration increases in the future, especially under the high-emission scenario

Future work...

→ expand analysis to all Croatian regions
→ compare results from other bias correction methods to the bivariate theoretical method