THE USE OF DYNAMIC CROP MODEL FOR SIMULATION OF MAIZE YIELD IN CURRENT AND CHANGED CLIMATE CONDITIONS

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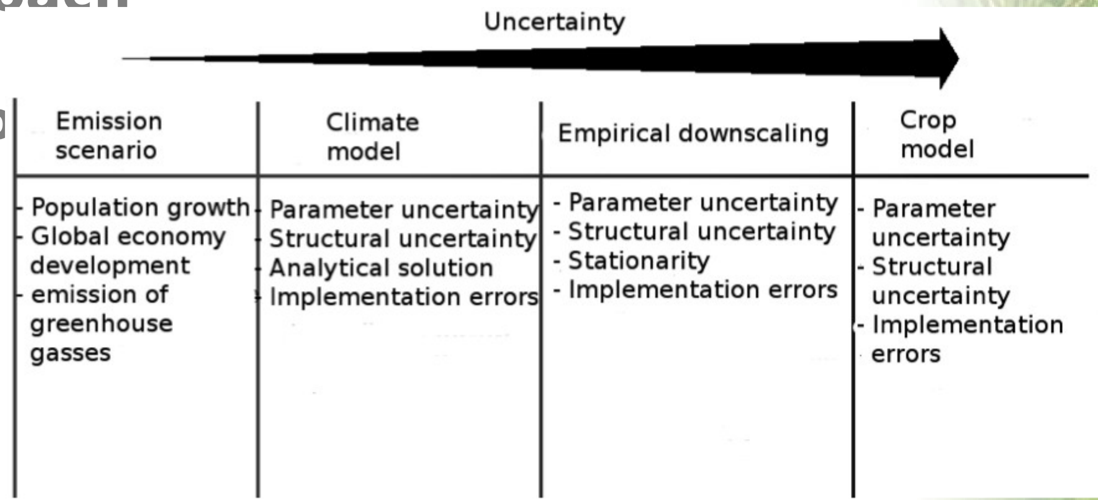
- INTRODUCTION

- Climatic conditions have a decisive impact on crop yield variability
- Devising an adaptation strategy – importance of understanding the impact of climate variability on crop production
- Estimating the impact of climate change on crop yield?
  - Climate change
    - **climate models**
    - **synthetic scenarios (weather generators)**
  - Crop yield
    - **statistical approach**
    - **dynamical approach**
  - **Top bottom appro**



- INTRODUCTION

- Crop selection: maize (*Zea mays* L.)
  - grown on 40 % of all fields
  - 1/3 - silage maize, 2/3 - grain maize
  - in last decades, maize production was decreasing due to unfavorable climate conditions (increased drought intensity, extreme weather events)

Photo: J. Rupreht

- INTRODUCTION

1st phase – selection and calibration of crop model

- dynamic crop model WOFOST (van Keulen et at., 1986; Boogard et al., 1998)
- selection of the study location
- Simulation of plant development – important part of dynamic crop simulation models (different phenological methods)
- how to account for uncertainty in crop model simulations
  - sensitivity analysis and calibration of the crop model

- INTRODUCTION

2nd phase – simulation of maize yield in changed climate conditions

- employ an ensemble based probabilistic approach, that accounts for uncertainties in climate model simulations as well as the parametric uncertainty in crop model
- determine the importance of bias correction in simulation of meteorological variables on regional level
- partition the variability of ensemble yield simulations among WOFOST model parameters, RCM selection an inter-annual variability
- sensitivity of maize growth to variable weather conditions during the growing season

- DATA

- Grain maize FAO 300-400.
  - *Furio* variety, grown from 1995 until 2008, stable and high yields
  - Maize yield data for each year (Agricultural institute of Slovenia)
  - Phenological data: sowing, emergence, tasseling and maturity dates (Agricultural institute of Slovenia)
- Meteorological data (Environmental Agency RS)

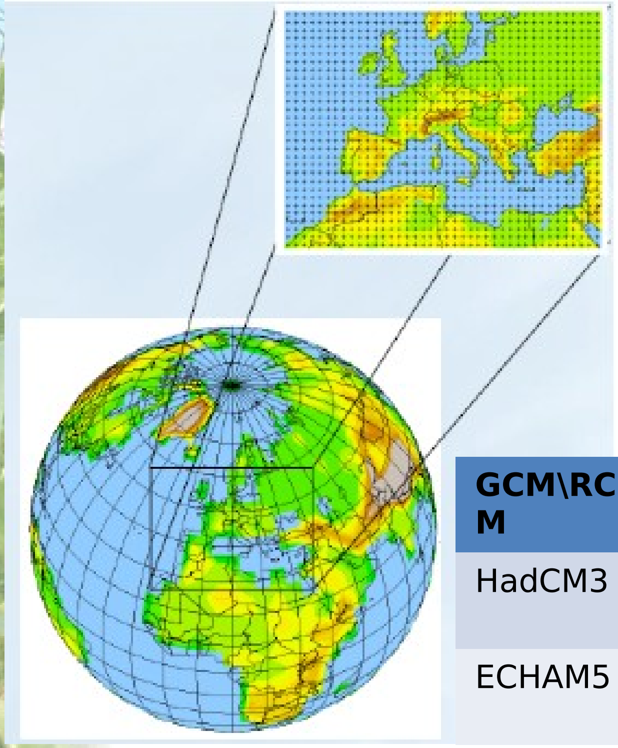
wilting point, ...)

Location	Saturation	Saturated hydraulic conductivity	Wilting point	Field capacity
Ljubljana	0,60			
Novo mesto	0,46	21,43	0,10	0,34
Murska Sobota	0,45	73,0	0,09	0,26

	Pridelek [t/ha]		
Leto	Murska Sobota	Jablje	Novo Mesto
1995	12,12	10,75	12,67
1996	10,47	8,47	12,22
1997	11,73	14,27	15,76
1998	8,17	13,93	12,87
1999	11,15	11,97	10,24
2000	6,55	/	10,38
2001	4,25	9,94	7,37
2002	11,73	15,37	16,20
2003	4,54	/	6,50
2004	11,04	11,87	13,47
2005	11,20	10,88	10,89
2006	9,35	/	/
2007	6,57	13,17	12,05
2008	10,47	11,24	11,07

- DATA

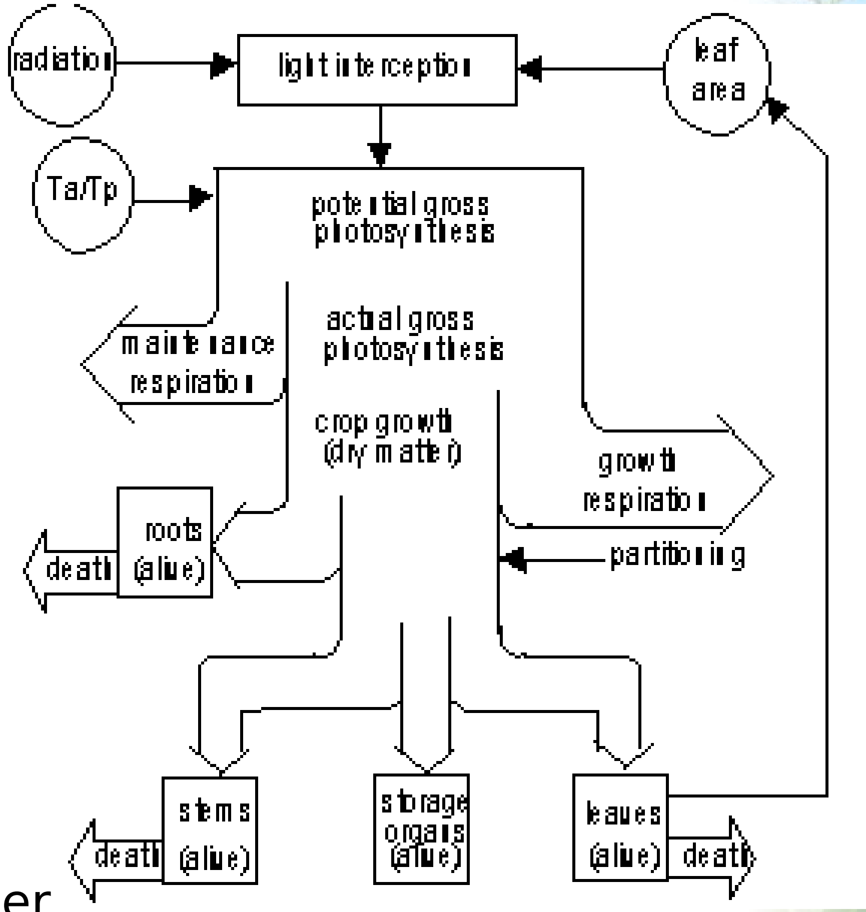
- Simulations of regional climate models (RCM) from the ENSEMBLES project (http://ensemblesrt3.dmi.dk)
- SRES A1B emission scenario
- 25 km horizontal resolution
- Period between 1961-2100



GCM\RCM	REMO	CLM	HIRHAM5	HadRM3	HIRHAM4	PROMES	RACMO
HadCM3							
ECHAM5							

- METHODS – crop model

- Crop model WOFOST
  - Simulation of physiological processes in plants on daily basis:
  - Phenology
  - Light absorption
  - Respiration
  - Partitioning of assimilates
  - Leaf area
  - leaf senescence
  - Evapotranspiration
  - Water balance
  - Nutrition application



Crop growth processes (De Koning et al., 1993)

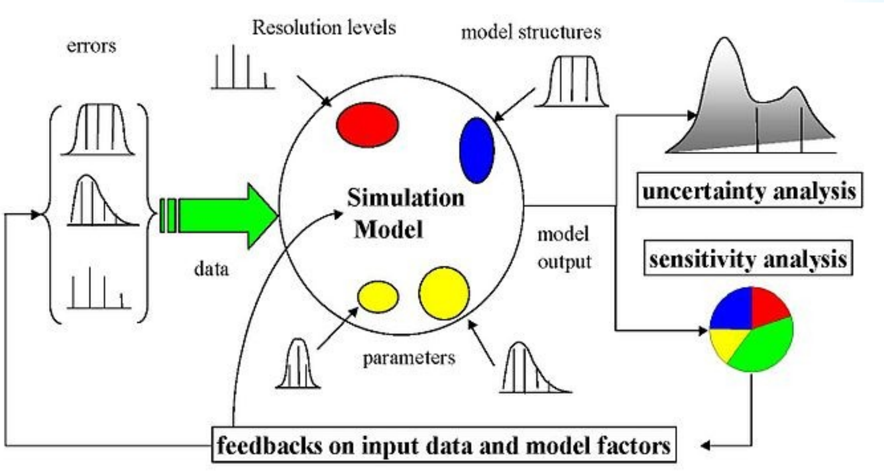
- For simulation purposes, R wrapper function has been made

WOFOST

- METHODS – sensitivity analysis

Table A1. WOFOST parameters and statistical settings used for sensitivity analysis. Shaded parameters were selected for subsequent model calibration.

Parameter acronym	Parameter description	Unit	Range	Literature
LAIEM	Leaf area index at emergence	ha ha−1	0.04–0.09	Driessen (1986), Boogard et al. (1998)
RGRLAI	Maximum relative increase in LAI	ha ha−1	0.02–0.04	Kajfež-Bogataj (1989), Boogard et al. (1998)
SLATB00	Specific leaf area at development stage 0	ha kg−1	0.0022–0.0035	Driessen (1986), Boogard et al. (1998)
SLATB078	Specific leaf area at development stage 0.78	ha kg−1	0.0010–0.0018	Kajfež-Bogataj (1989), Lehuger et al. (2009)
SLATB200	Specific leaf area at development stage 2	ha kg−1	0.0010–0.0018	Kajfež-Bogataj (1989), Lehuger et al. (2009)
SPAN	Life span of leaves, growing at 35 °C	d	30–35	Driessen (1986)
TBASE	Lower threshold temperature for ageing of leaves	°C	8–10	Kajfež-Bogataj (1989), Driessen (1986), Campos et al. (2004)
KDIFFTB00	Extinction coeff. for diffuse visible light at development stage 0		0.44–0.65	Kajfež-Bogataj (1989), Awal et al. (2006), Boons-Prins et al. (1993)
KDIFFTB200	Extinction coeff. for diffuse visible light at development stage 2		0.44–0.65	Kajfež-Bogataj (1989), Awal et al. (2006), Boons-Prins et al. (1993)
EFFTB0	Light use efficiency of single leaf (at temp. 0 °C)	kg ha−1 h−1 J−1 m2 s	0.45–0.55	Lindquist (2001)
EFFTB40	Light use efficiency of single leaf (at temp. 40 °C)	kg ha−1 h−1 J−1 m2 s	0.45–0.55	Lindquist (2001)
AMAXTB00	Maximum CO_2 assimilation rate as a function at 0 °C	kg ha−1 h−1	65–72	Kajfež-Bogataj (1989)
AMAXTB150	Maximum CO_2 assimilation rate as a function at 15 °C	kg ha−1 h−1	55–65	Kajfež-Bogataj (1989)
AMAXTB175	Maximum CO_2 assimilation rate as a function at 17.5 °C	kg ha−1 h−1	40–50	Kajfež-Bogataj (1989)
AMAXTB200	Maximum CO_2 assimilation rate as a function at 20.0 °C	kg ha−1 h−1	15–25	Kajfež-Bogataj (1989)
TMPFTB9	Reduction factor of AMAX at 9 °C		0.05–0.225	Kropff et al. (1993)



Source: wikipedia.org

- METHODS – model calibration

- Calibration of the WOFOST model
- Bayesian approach – integration of the prior knowledge into parameter estimation

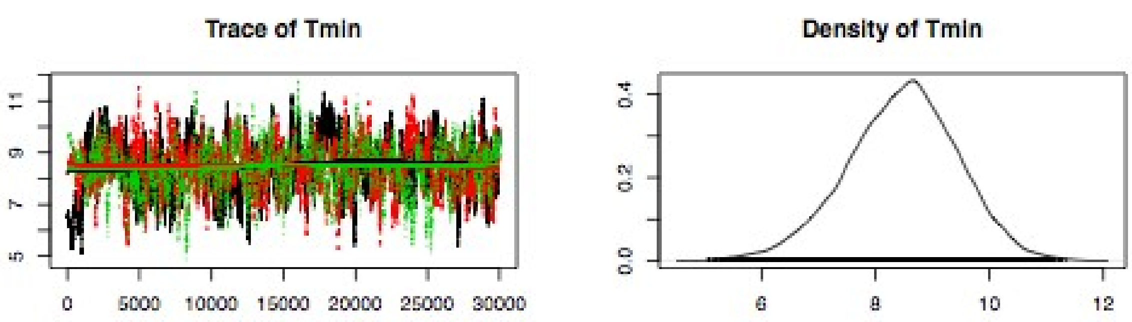
$$\pi(\Theta|y) = \pi(Y|\Theta)\pi(\Theta)/\pi(Y)$$

Prior parameter distribution

ld measurements and phenological o

Posterior parameter distribution

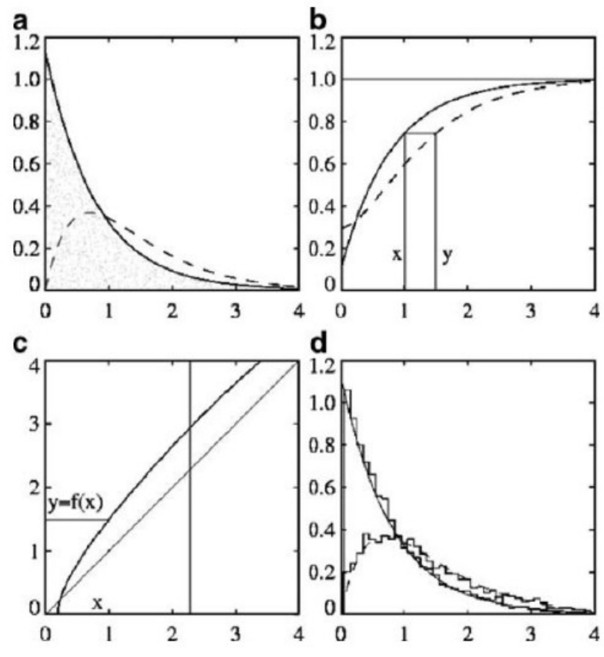
- Posterior distributions can’t be analytically derived
- Markov Chain Monte Carlo methods represent an effective way



- METHODS – bias correction

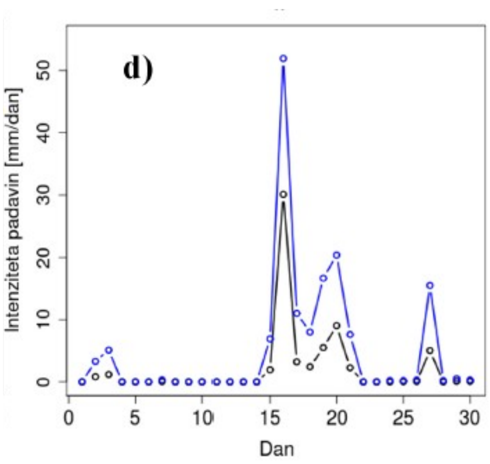
- Statistical “downscaling” of ENSEMBLES simulations
  - Input data to crop model:
    - raw RCM simulations
    - statistical bias correction (Pianni et al., 2009)
      - adjusting cumulative probability functions of simulated variables to those, measured at meteorological stations

$$y_{pp} = F_{obs}^{-1}(\alpha_{obs}, F_{RCM}(\alpha_{RCM}, y_{RCM}))$$



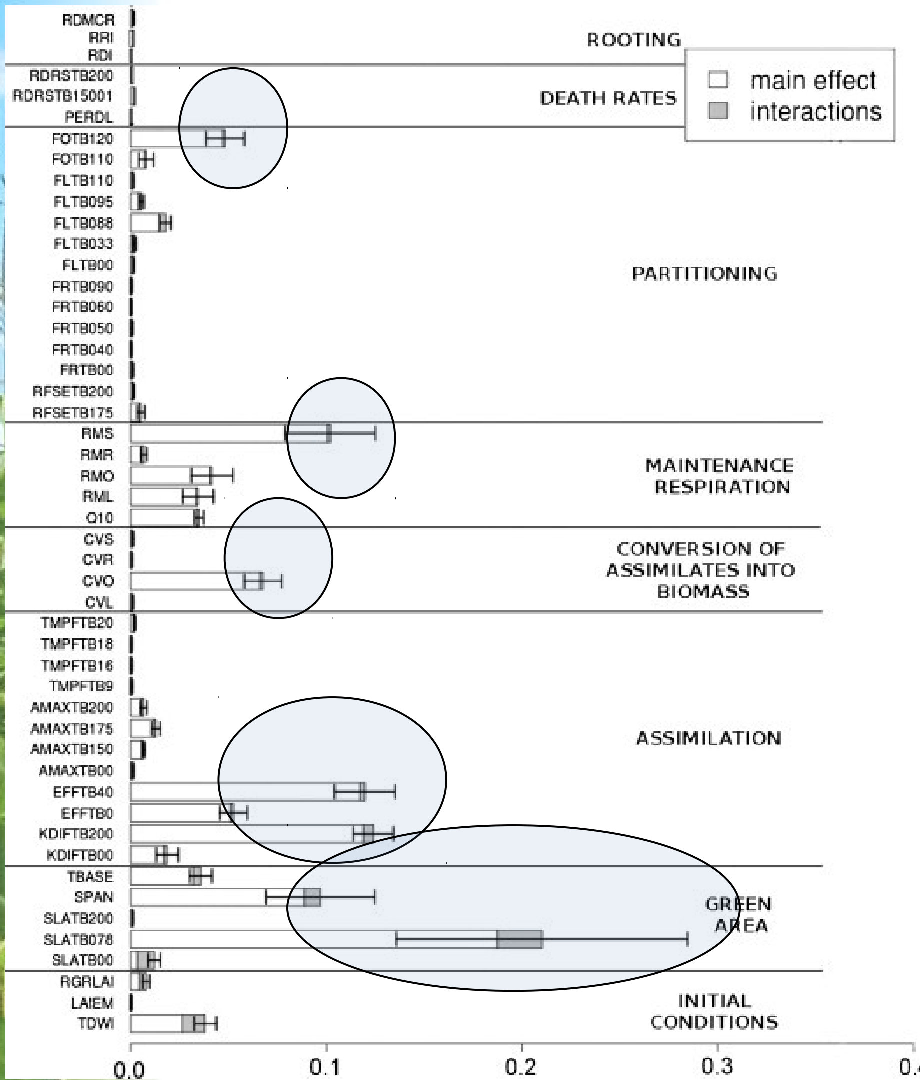
Piani et al., 2009

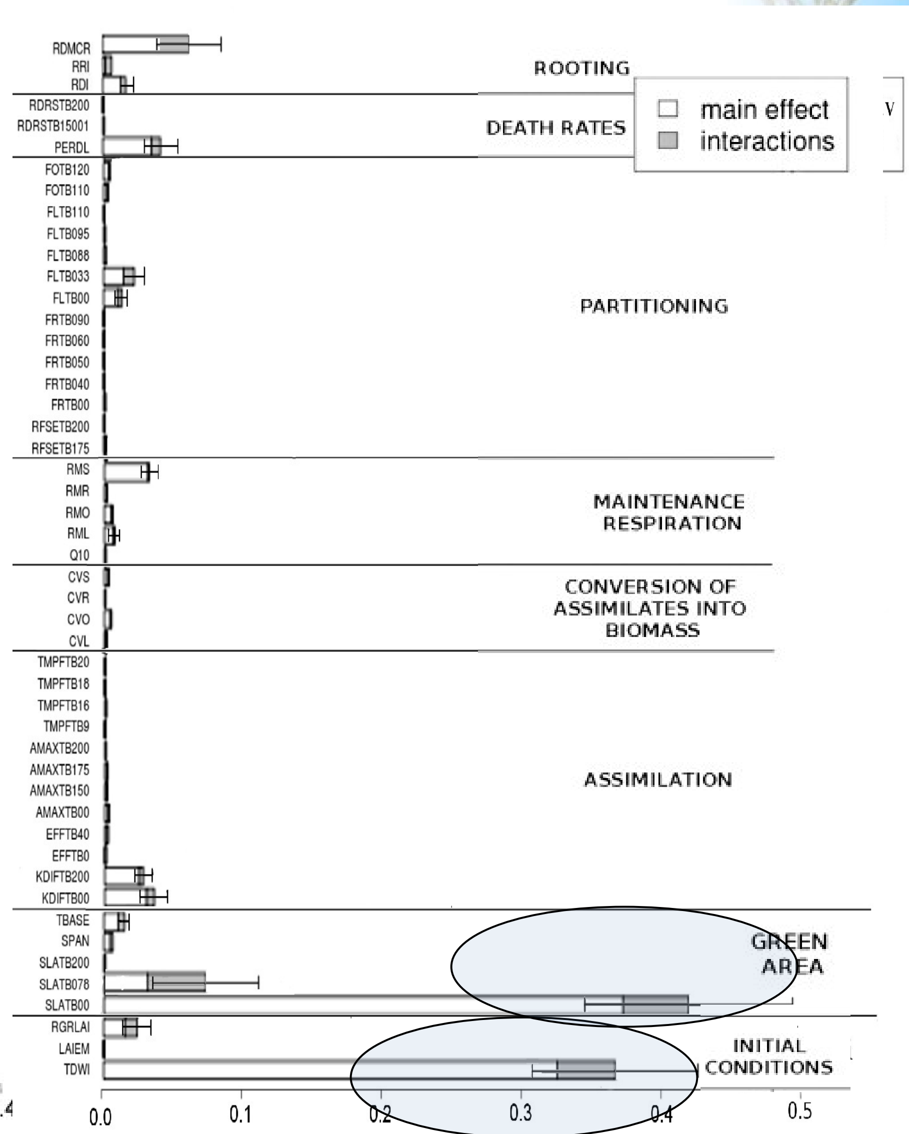
- Precipitation: gama distribution
- Minimum air temp., maximum air temp., water vapor pressure: Gaussian distribution
- Global radiation: beta distribution



- RESULTS – sensitivity analysis

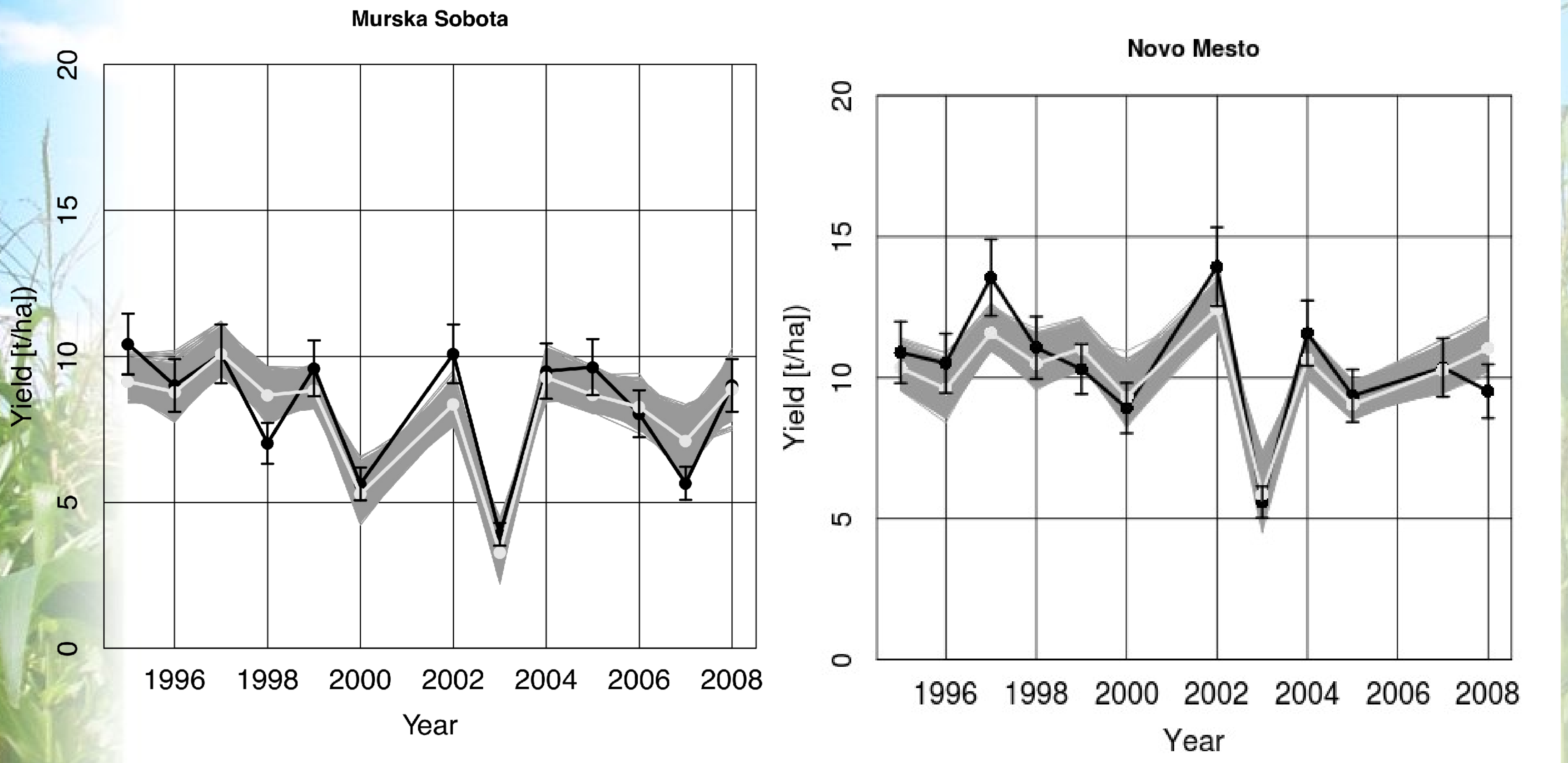
- Year 2002 – good growing conditions
- Year 2003 – drought and heat stress





- RESULTS – posterior simulation of maize yield

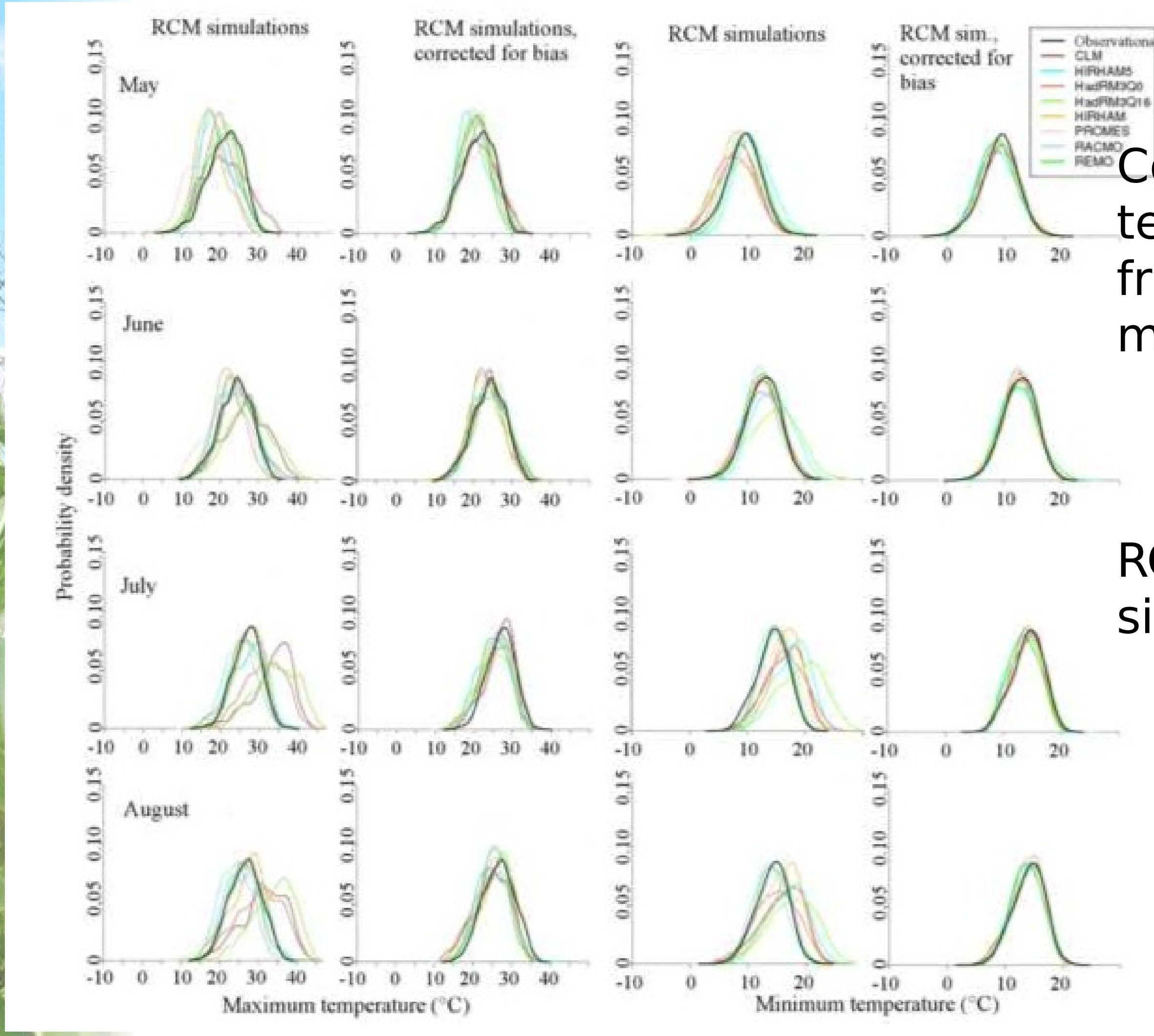
Posterior simulations of maize yield



Lokacija	R^2	$RMSE$ [t/ha]
Murska Sobota	0,72	1,0
Ljubljana	0,51	1,44
Novo mesto	0,76	0,96

- RESULTS – climate models simulations

- Bias correction performance
  - Minimum and maximum temperature

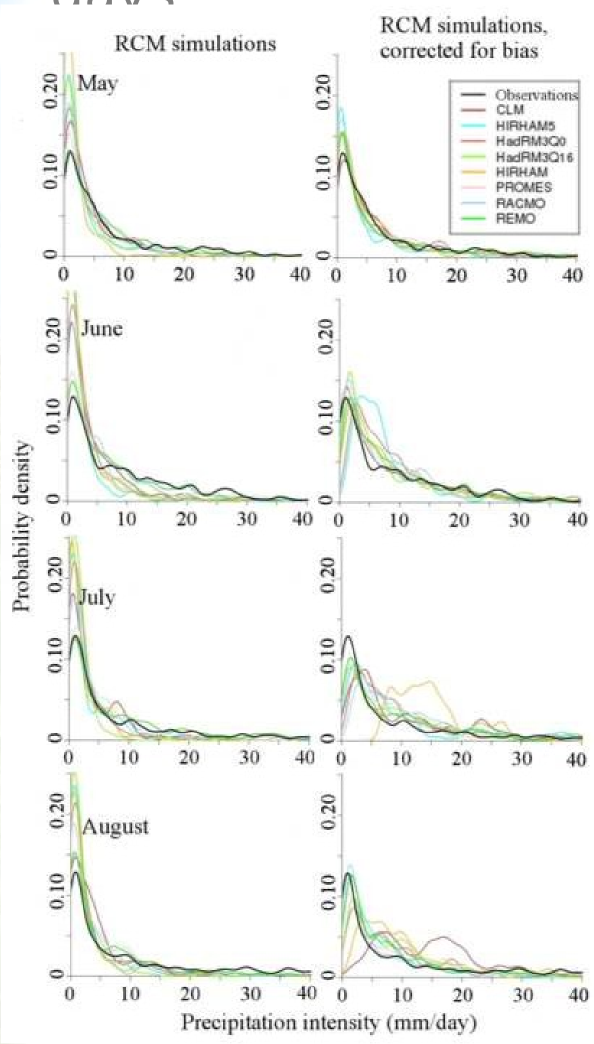


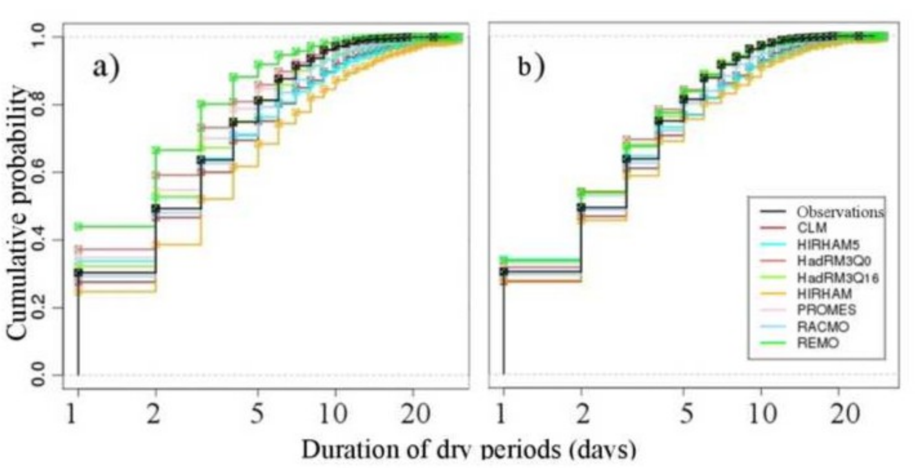
Corrected values for maximum temperature were lower from 0.5 °C to 1 °C from measurements

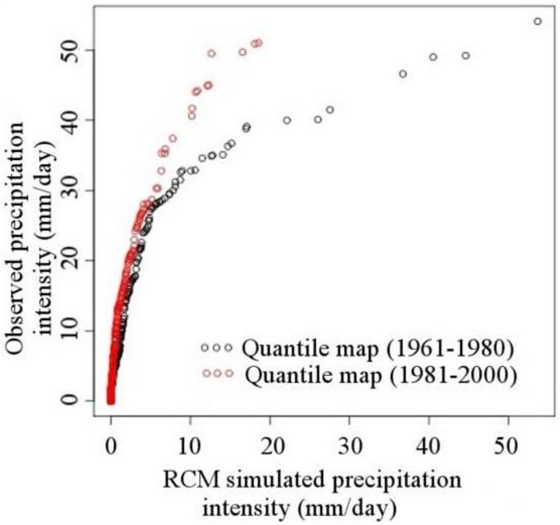
RCMs inability to realistically simulate trends

RESULTS – climate models simulations

- Bias correction performance
  - Precipitation – rainfall intensity and frequency of wet days



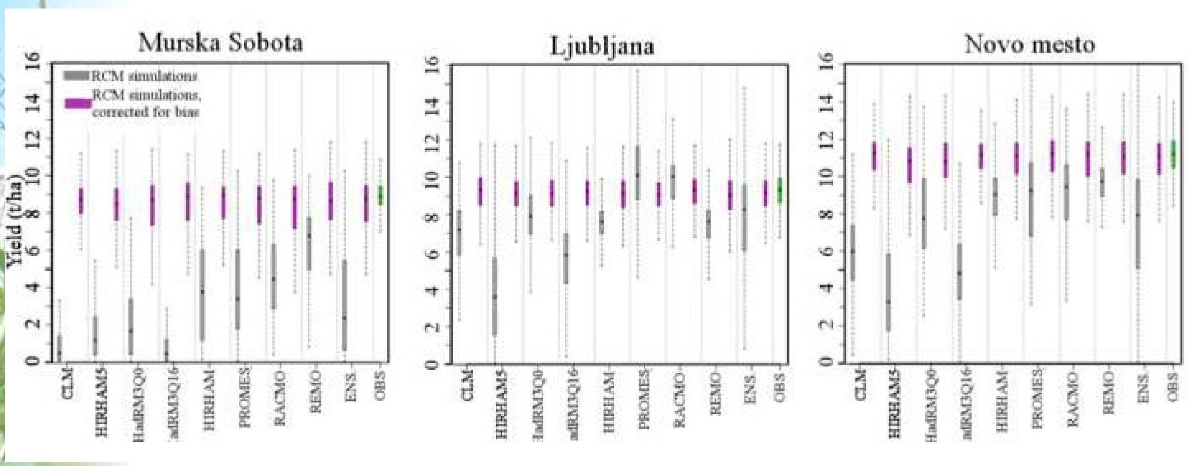


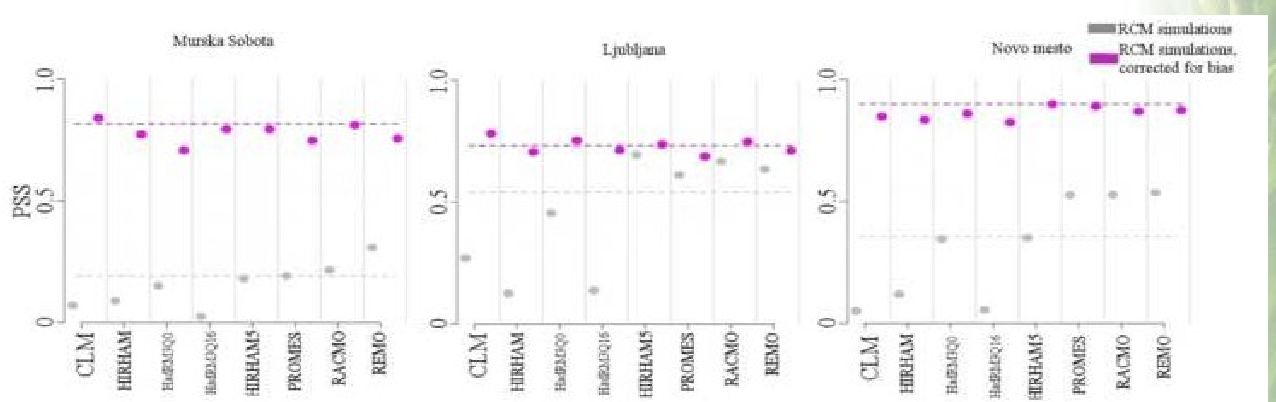


- RESULTS – using raw and bias corrected simulati

- Simulation of yield, using raw and bias corrected RCM simulations
  - Highest deviations in the case of raw RCM simulations (models, that underestimated rainfall frequency in summer)

significantly

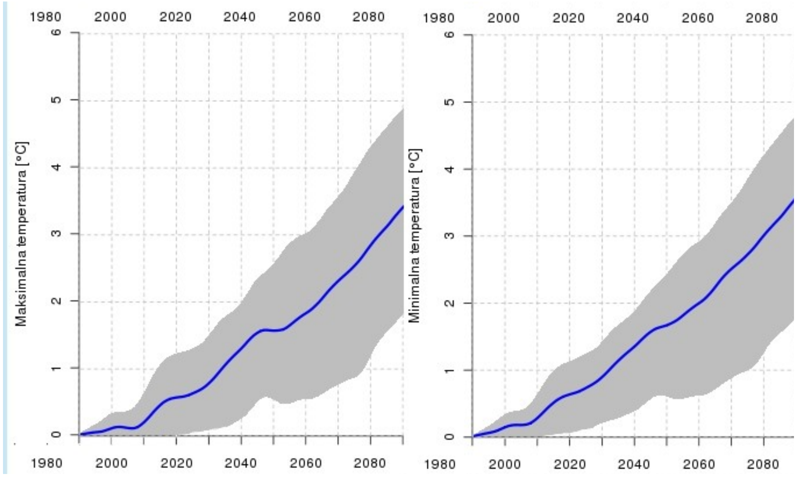


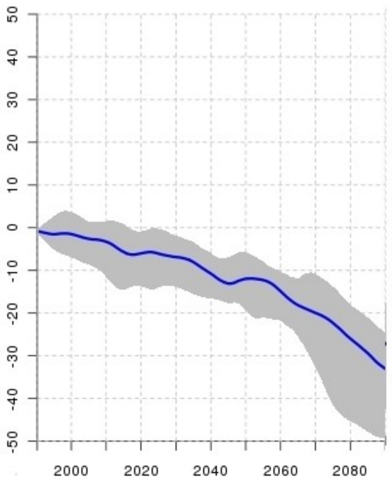


- RESULTS – climate projections

- Climate projections – summer temperature and precipitation changes

In Murska Sobota

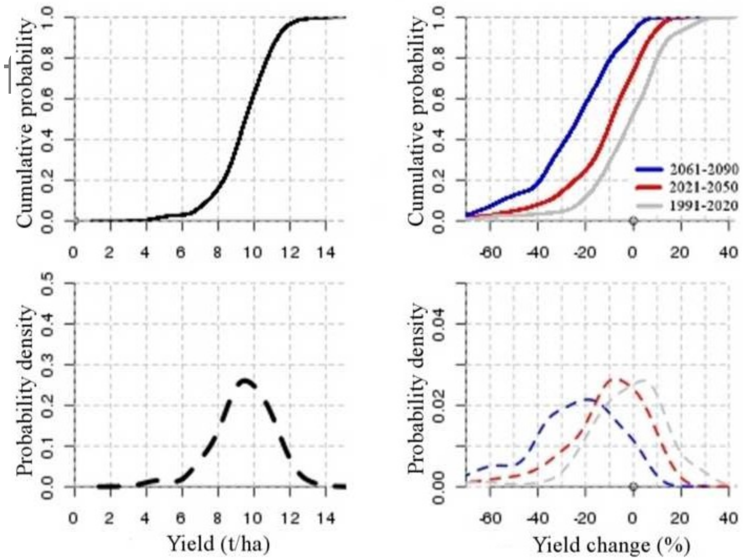




- Higher uncertainty in the case of daily rainfall intensity projections
  - different models disagree in the sign of the change
  - all models, however, agree on the sign of change of precipitation frequency (drying in summer)

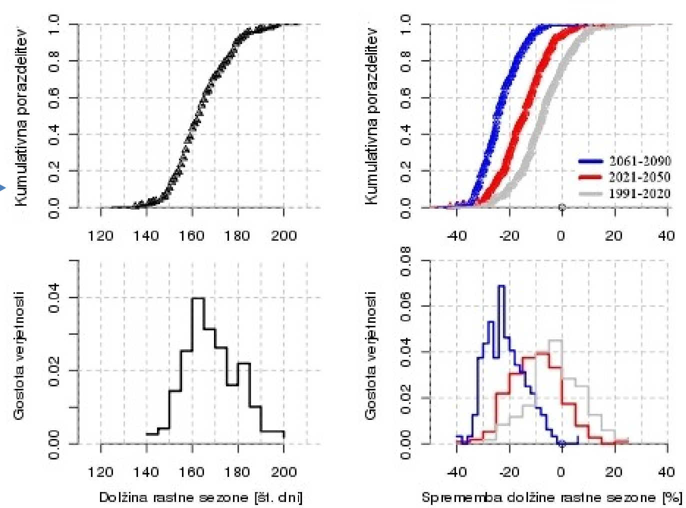
- RESULTS – climate projections

- Simulation of maize yield and phenological development
  - 8 RCMs, 30 years, 10000 posterior sets of the WOFOST parameters
- density



	Average yield (1961-1990) (t/ha)	Period	Yield change (%)	S. D. (%)
Murska Sobota				
Water limited production	8.6	1991-2020	-4	17*
		2021-2050	-16	20**
		2061-2090	-34	17*
Potential production	9.2	1991-2020	-3	-1**
		2021-2050	-13	-8**
		2061-2090	-29	-2**
Novo mesto				
Water limited production	10.4	1991-2020	-3	21**
		2021-2050	-12	21*
		2061-2090	-31	33*
Potential production	10.9	1991-2020	-1	-9**
		2021-2050	-9	-18*
		2061-2090	-32	-12*
Ljubljana				
Water limited production	8.1	1991-2020	0	35*
		2021-2050	-10	50*
		2061-2090	-27	31*
Potential production	8.6	1991-2020	1	-13**
		2021-2050	-8	6*
		2061-2090	-24	5*

Reference period



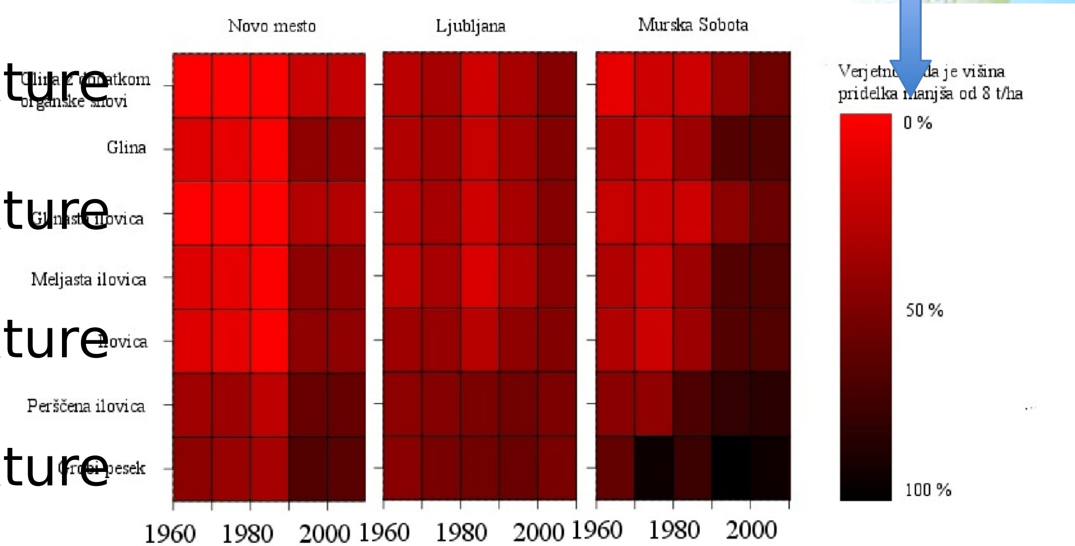
- RESULTS – climate projections

- Adaptation possibilities – earlier sowing, soil with higher water holding capacities

Setev [datum]	Povp. višina pridelka (1961-1990) [t/ha]	Obdobje	Povprečje [%]
1. april	9,4 [10,0][6]	1991-2020	-2
		2021-2050	-14
		2061-2090	-26
	9,6 [10,1][6]	1991-2020	-2
		2021-2050	-10
		2061-2090	-22
10. april	9,30 [9,8][6]	1991-2020	-4
		2021-2050	-16
		2061-2090	-28
	9,5 [9,8][6]	1991-2020	-3
		2021-2050	-11
		2061-2090	-24
20. april	8,9 [9,5][6]	1991-2020	-4
		2021-2050	-15
		2061-2090	-32
	9,2 [9,6][6]	1991-2020	-4
		2021-2050	-13
		2061-2090	-27
30. april	8,6 [9,2][6]	1991-2020	-4
		2021-2050	-16
		2061-2090	-34
	8,9 [9,2][6]	1991-2020	-3
		2021-2050	-13
		2061-2090	-29
9. maj	8,2 [8,7][6]	1991-2020	-3
		2021-2050	-13
		2061-2090	-34
	8,5 [8,7][6]	1991-2020	-2
		2021-2050	-11
		2061-2090	-30

Probabiltiy of maize yield being lower than 8 t/ha

Texture 1
Texture 2
Texture 3
Texture 4
Texture 5
Texture 6
Texture 7



Texture 1: clay with organic matter

Texture 2: clay

Texture 3: clay loam

Texture 4: silt loam

Texture 5: loam

Texture 6: sandy loam

Texture 7: coarse sand

- CONCLUSIONS

1. The WOFOST model was used to study the impact of climate change on maize yield

   - Sensitivity analysis revealed the subset of influental model parameters in terms of their impact on simulated weight of storage organs at the end of growing season

   - Bayesian approach for model calibration resulted in posterior parameters and maize yield distribution – estimate the impact of parameter uncertainty on simulated maize yield

- CONCLUSIONS

2. RCM simulation, corrected for bias, significantly improved statistical properties of climate variables in the validation period. Corrected RCM simulations also significantly improved maize yield estimations, when used as input to the WOFOST model.

3. Climate scenarios for selected study locations:

- Increase of minimum and maximum temperature in all seasons

- Higher degree of uncertainty when simulating changes in daily precipitation intensity (especially in the warm half of the year). Seasonal precipitation is expected to increase during winter and decrease in summer

- Maize yield is expected to decrease between 12% and 16% in the middle and between 27% and 34% at the end of the 21st Century (in comparison to the reference period 1961-1990).

- CONCLUSIONS

4. Study has taken into account uncertainties, entering at different levels of modeling

    - Ensembles probabilistic approach enabled the quantification of uncertainties, related to RCM selection and WOFOST parameter uncertainty
    - Used approach could be also applied for other crops and regions

THANK YOU FOR YOUR ATTENTION