

Application of Met&Roll Weather Generator in Climate Change Impact Studies in Czechia

Martin Dubrovsky

(Institute of Atmospheric Physics ASCR, Prague, Czech Republic)

Miroslav Trnka + Zdenek Zalud

Mendel University of Agriculture and Forestry, Brno, Czech Republic

Josef Hejzlar

Hydrobiological Institute ASCR, Ceske Budejovice, Czech Republic

Josef Buchtele + Martin Ruzicka

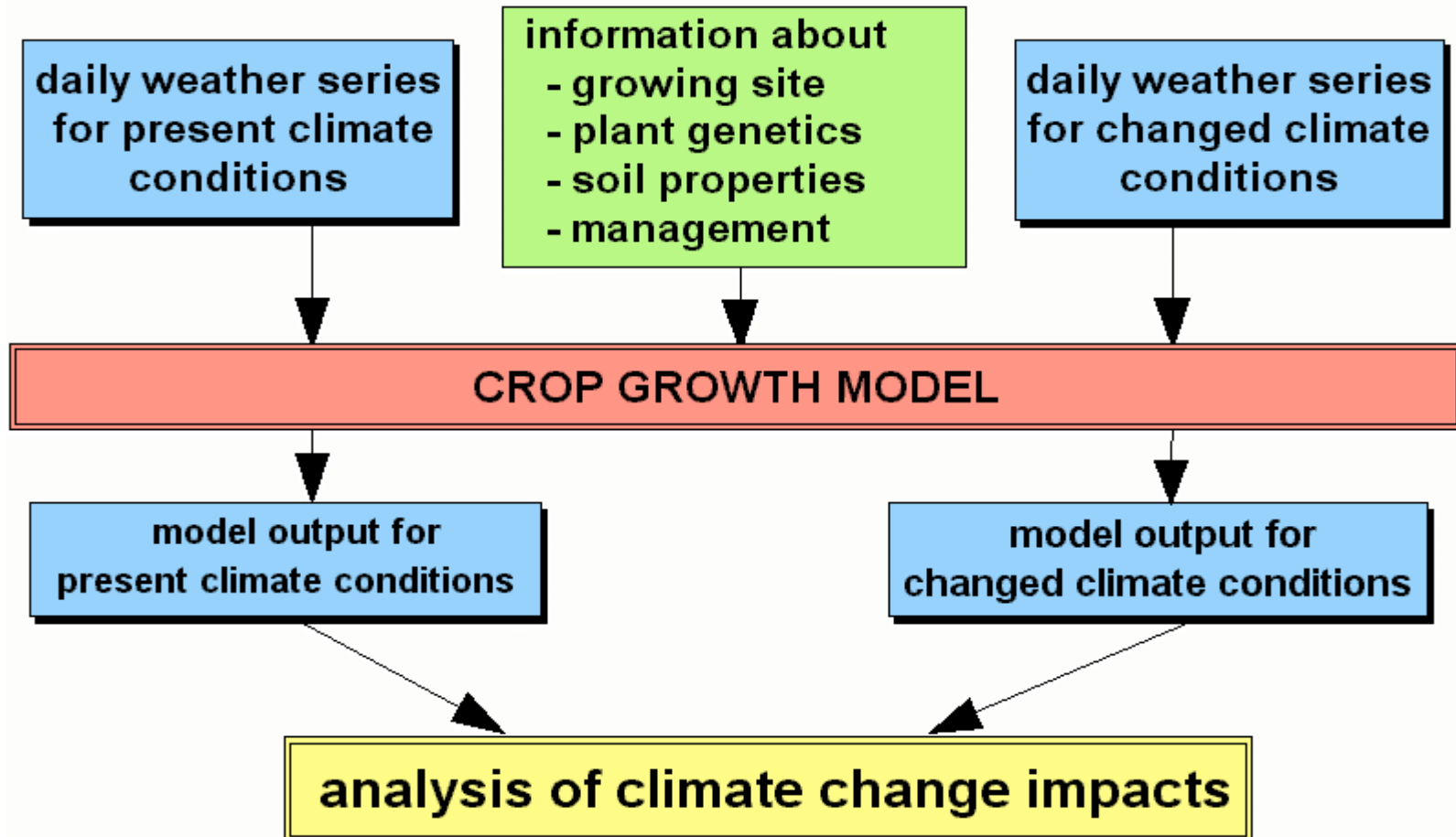
Institute of Hydrodynamics ASCR, Prague, Czech Republic

***** SICCIA, 28 June - 2 July 2004, Eibsee *****

outline

- **methodology of climate change impact analysis**
- **weather generator**
 - direct validation
 - indirect validation
 - + crop modelling
 - + hydrological modelling
- **climate change scenarios (including uncertainties)**
- **results of selected experiments** (only crop modelling)
 - sensitivity of maize yields to stochastic structure of weather series
 - impacts of climate change on maize, wheat, barley
 - direct and indirect effects
 - adaptation analysis
- **conclusion**

impacts on crops - methodology



- multi-year simulation is made to assess mean and variability
- *similar approach is used in hydrological modelling*

Two approaches to multi-year crop growth simulations (using crop model):

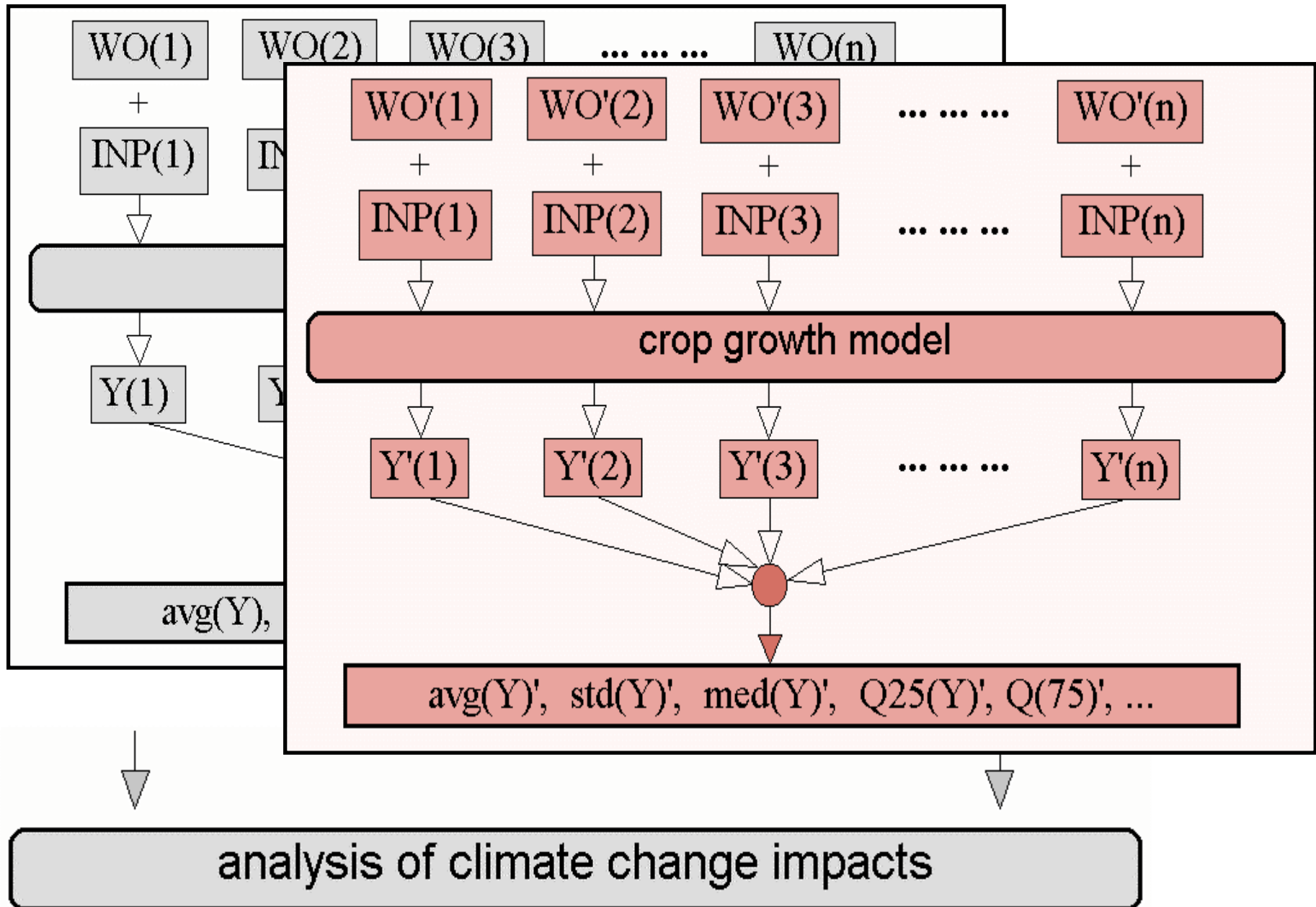
1) Direct Modification approach:

- **non-meteo input** (pedological, physiological and cultivation data):
observed, specific for each individual year
- **meteo input:**
 - **present climate:** observed weather series
 - **changed climate:** observed series directly modified according to the climate change scenario.

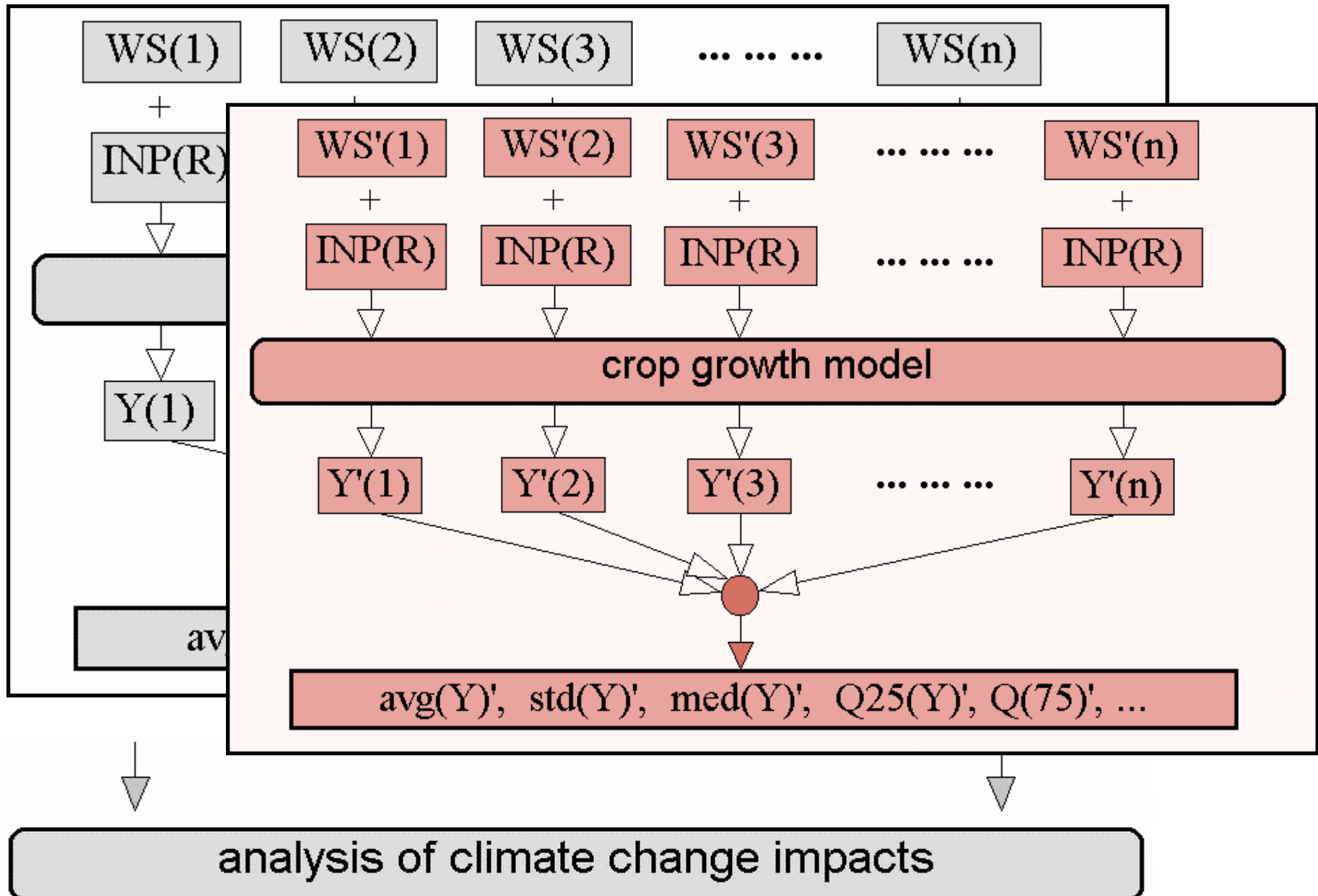
2) Weather Generator approach:

- **non-meteo input:** taken from a single “representative” year
- **meteo input:**
 - **present climate:** arbitrarily long synthetic weather series is created by the stochastic weather generator; parameters of the generator are derived from the observed series
 - **changed climate:** parameters of the generator are modified in accordance with climate change scenario to generate series representing changed climate

methodology - DM

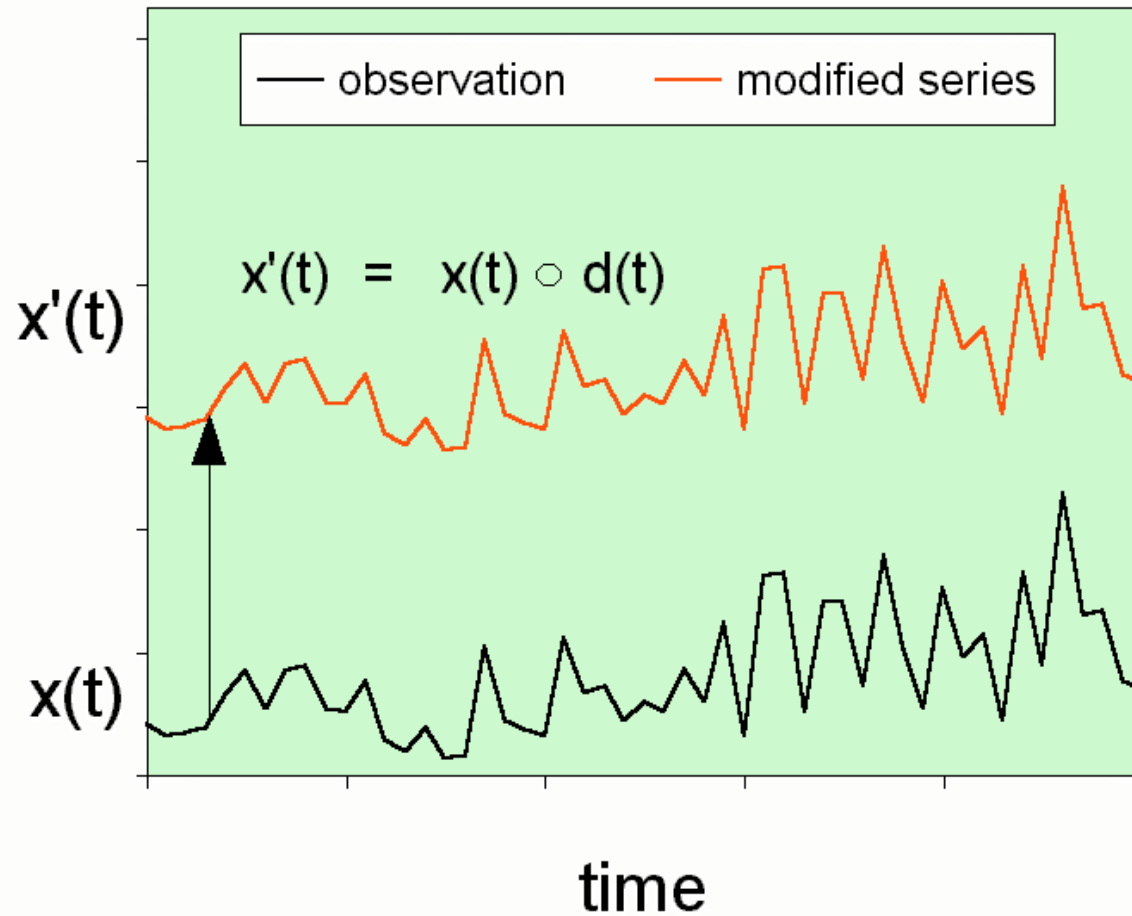


methodology - WG



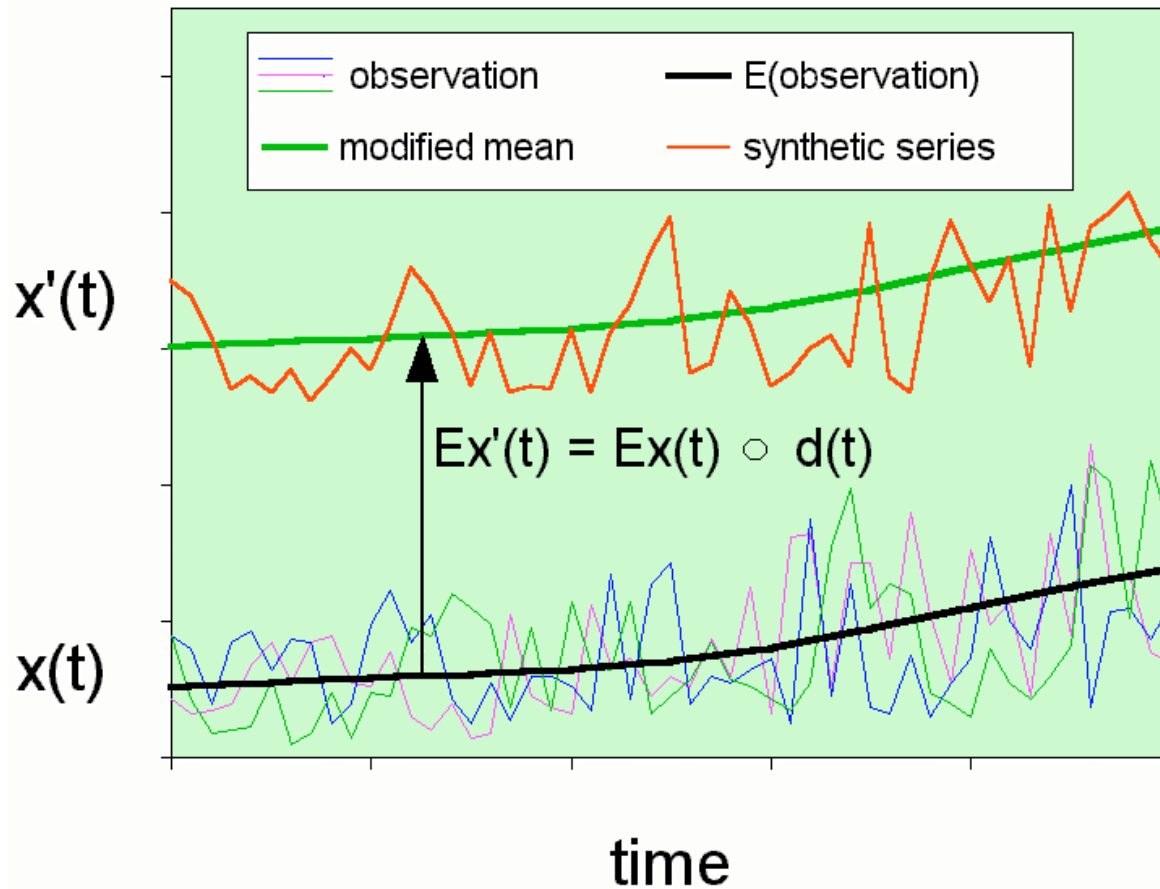
preparing daily weather series for changed climate

a) direct modification of observed series:



preparing daily weather series for changed climate

b) stochastic weather generator:



stochastic daily weather generator Met&Roll - model

PREC: - occurrence \sim Markov chain
- amount \sim Gamma distribution

SRAD, TMAX, TMIN \sim AR(1)

basic version \sim WGEN (Richardson, 1981)

improvements:

- 1) lag-0 and lag-1 correlations in AR(1) have annual cycle
- 2) order of Markov chain \sim 1, 2, 3
- 3) coupled with monthly AR-1 generator
- 4) additional variables may be added by nearest neighbours resampling

to be done: *user-friendly environment*

A) 4-variate → 6-variate:

4-variate series:

@DATE	SRAD	TMAX	TMIN	RAIN
...				
99001	1.9	-2.7	-6.3	0.3
99002	2.1	-3.6	-3.7	0.7
99003	1.5	0.1	-1.3	2.4
99004	2.4	0.3	-2.7	0.6
99005	1.4	-1.4	-5.1	0.1
...				
...				

learning sample:

@DATE	SRAD	TMAX	TMIN	RAIN	VAPO	WIND
...						
xx001	1.6	1.3	-1.5	3.3	0.63	1.0
xx002	1.6	-0.8	-3.8	0.3	0.53	1.7
xx003	3.9	-2.3	-9.9	0.0	0.23	2.0
xx004	4.5	-2.3	-11.4	0.0	0.38	1.0
xx005	1.6	-6.1	-12.9	0.0	0.33	1.3
xx006	1.6	-1.8	-12.4	1.1	0.23	3.3
xx007	3.8	1.2	-2.3	0.0	0.52	4.7
xx008	1.7	-0.1	-4.3	0.0	0.39	1.3
xx009	1.7	-1.8	-6.7	0.4	0.42	4.0
xx010	1.7	-3.8	-8.0	1.0	0.36	2.0
xx011	1.7	0.0	-3.9	8.3	0.46	2.0
xx012	2.9	3.7	-0.3	2.8	0.57	1.7
xx013	1.8	2.6	-0.8	1.0	0.62	2.0
xx014	4.0	2.9	-3.3	0.0	0.45	2.7
xx015	4.0	2.4	-5.9	0.0	0.37	1.3
...						

6-variate series:

@DATE	SRAD	TMAX	TMIN	RAIN	VAPO	WIND
...						
99001	1.9	-2.7	-6.3	0.3	0.34	3.0
99002	2.1	-3.6	-3.7	0.7	0.28	3.0
99003	1.5	0.1	-1.3	2.4	0.61	3.0
99004	2.4	0.3	-2.7	0.6	0.57	3.0
99005	1.4	-1.4	-5.1	0.1	0.47	3.0
...						

→ nearest neighbours
resampling

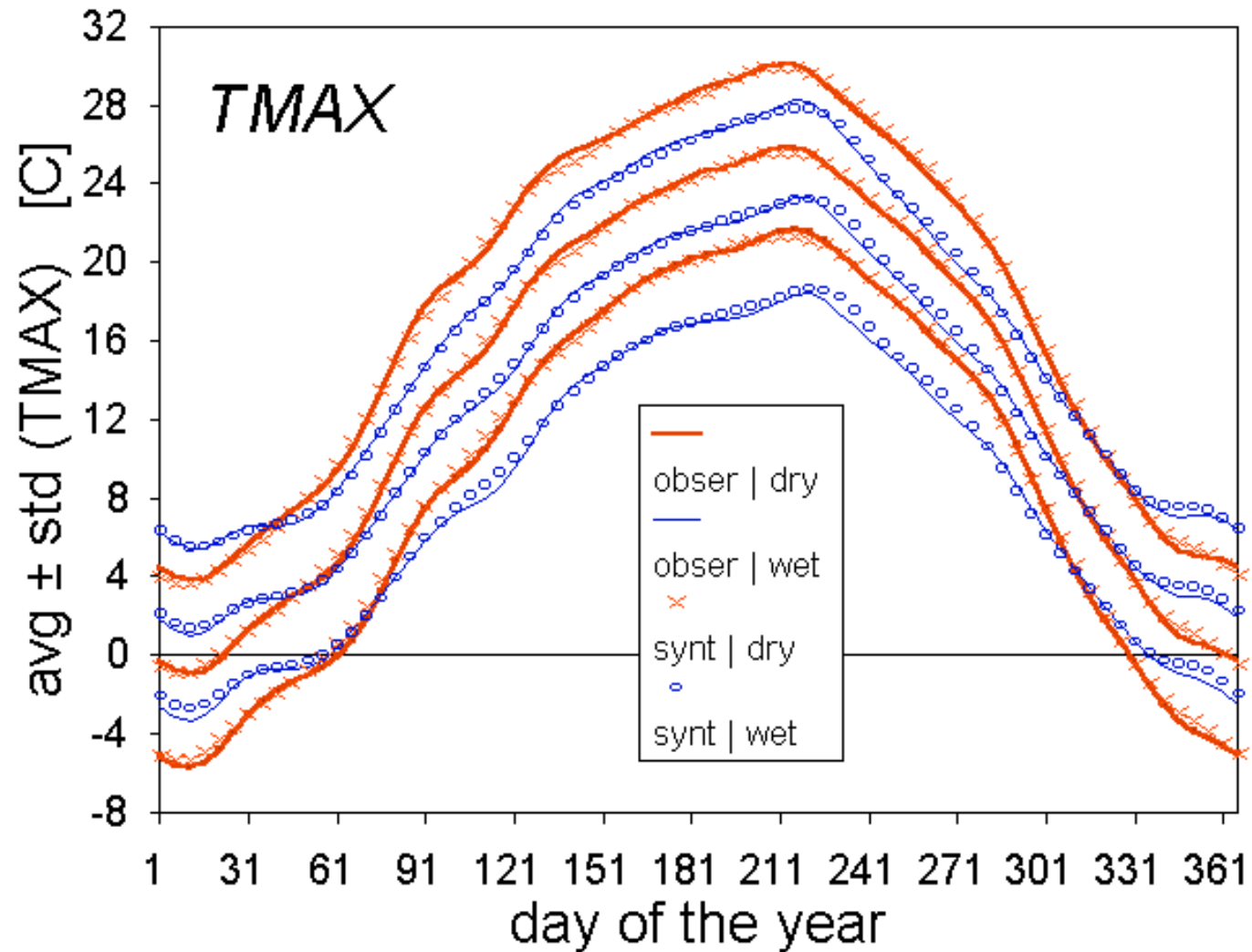
stochastic daily weather generator Met&Roll - validation

motivation: stochastic structure of observed and synthetic weather series should be the same

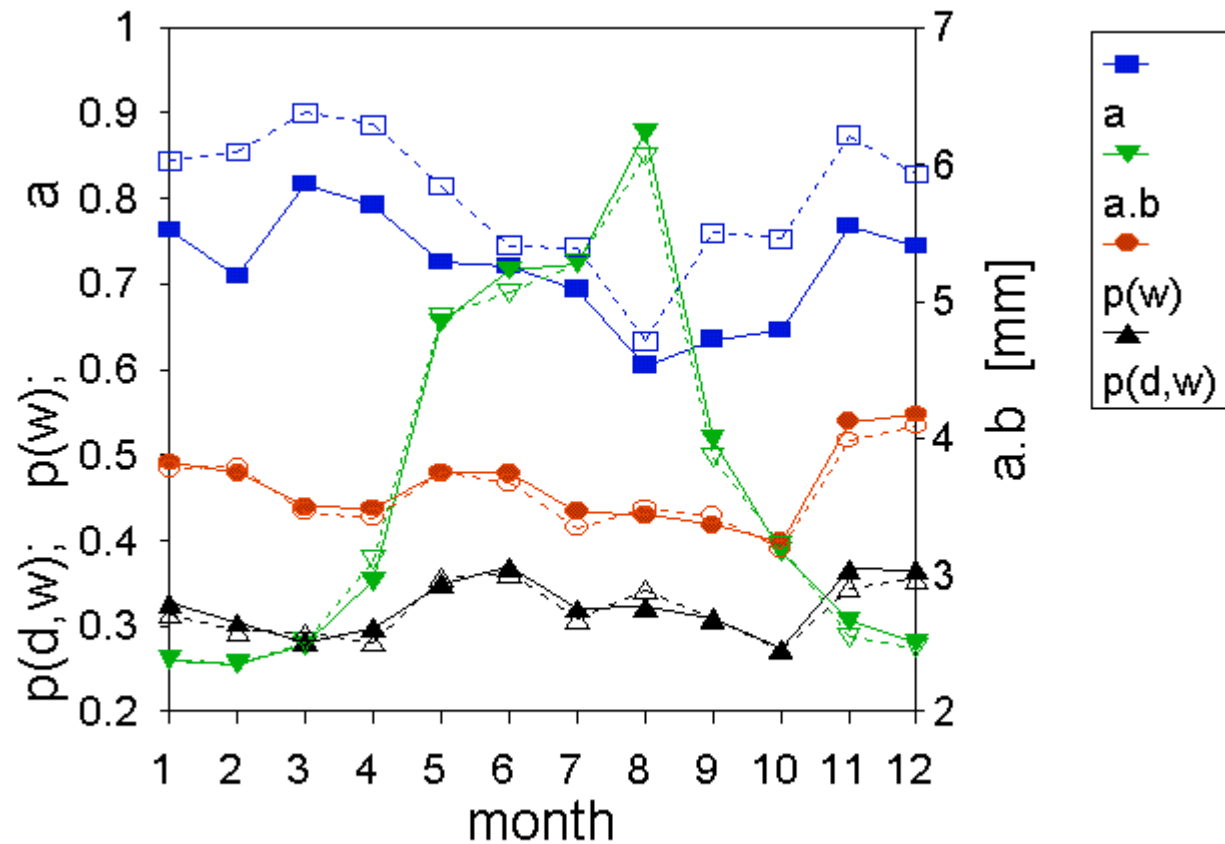
validation of WG was made in terms of:

- parameters of WG
- other characteristics
 - variability of monthly means
 - wet/dry/hot/cold spells

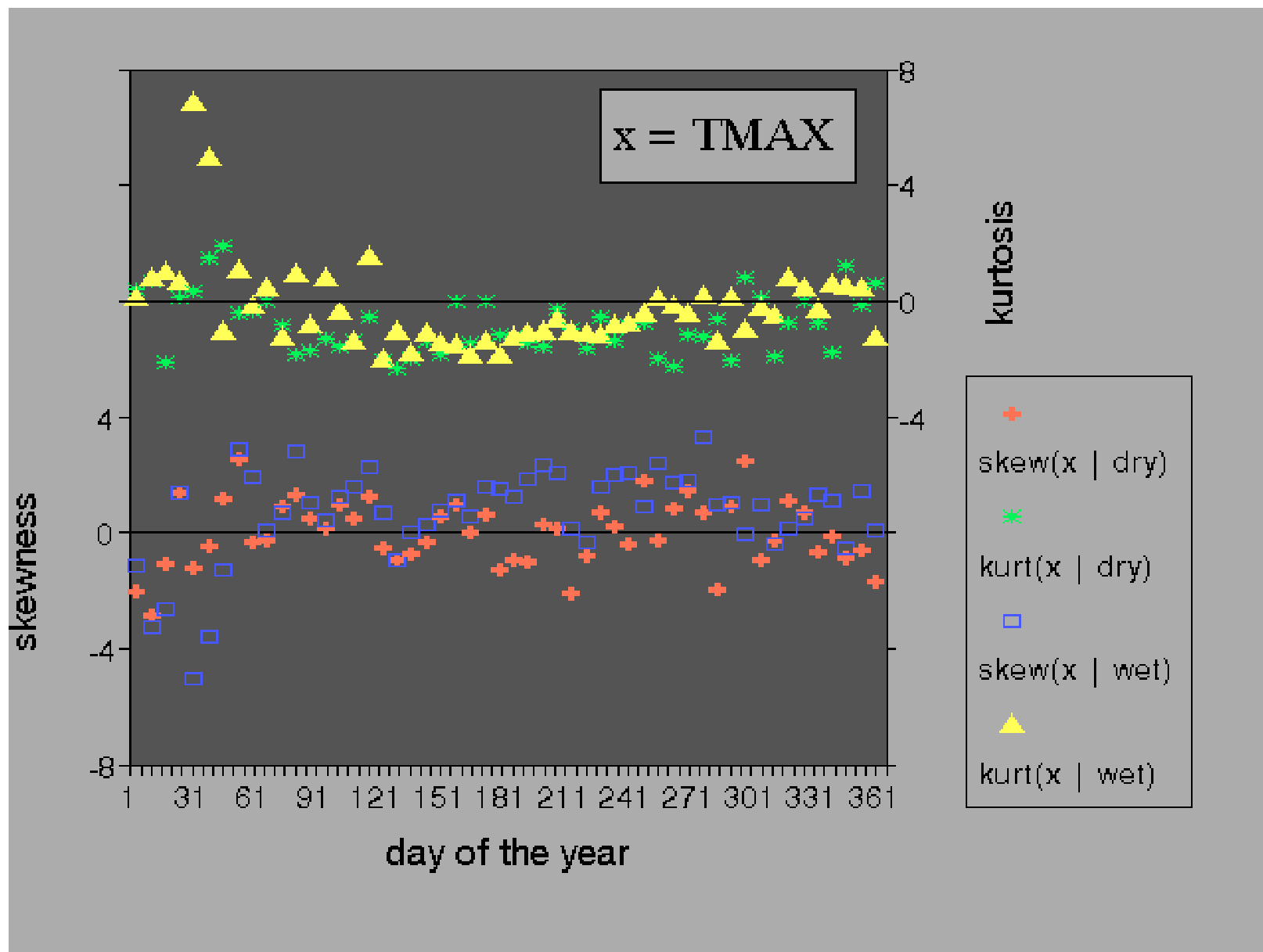
validation of Met&Roll: annual cycle of avg \pm std (TMAX)



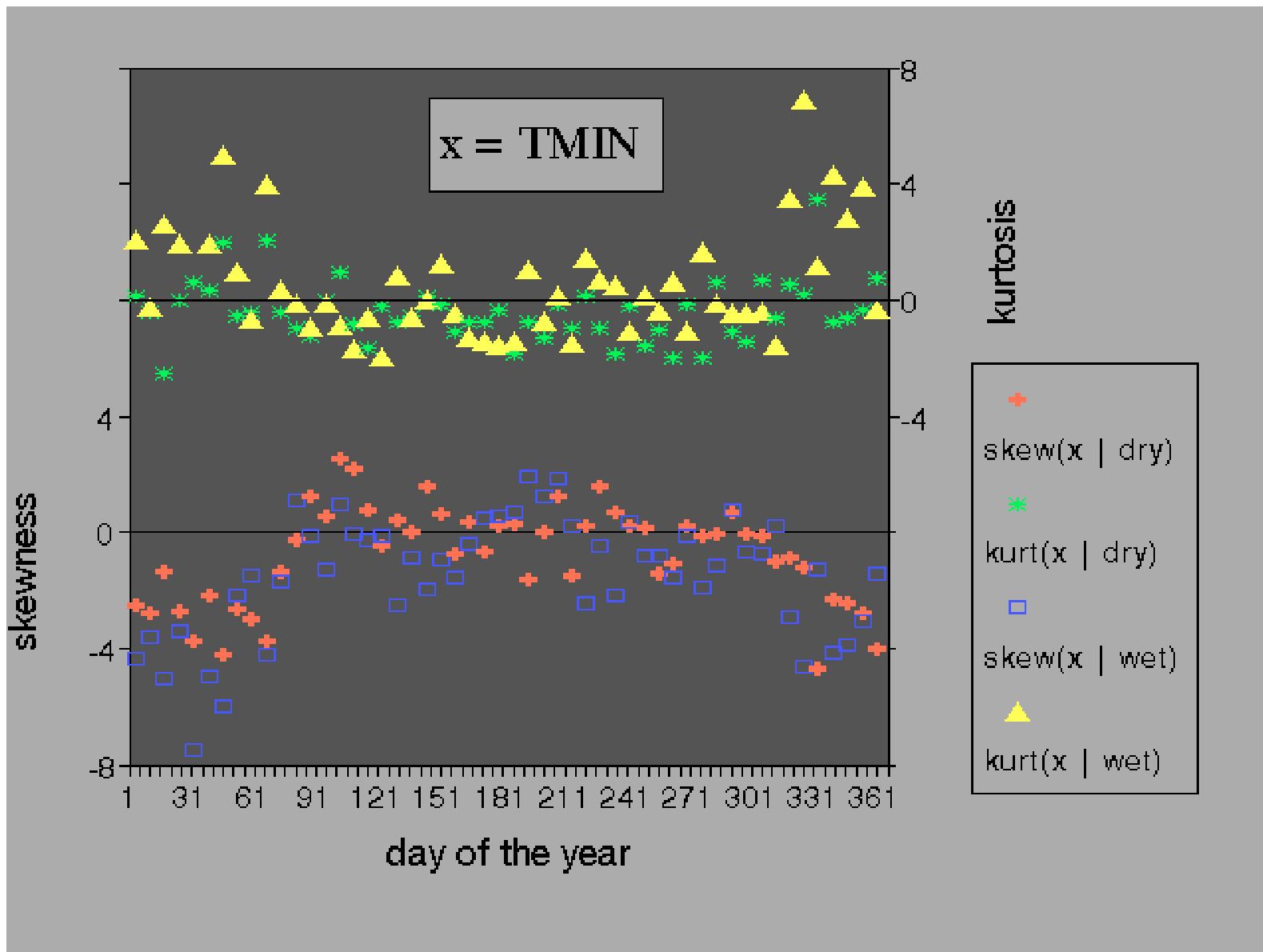
validation of Met&Roll: parameters of precipitation model



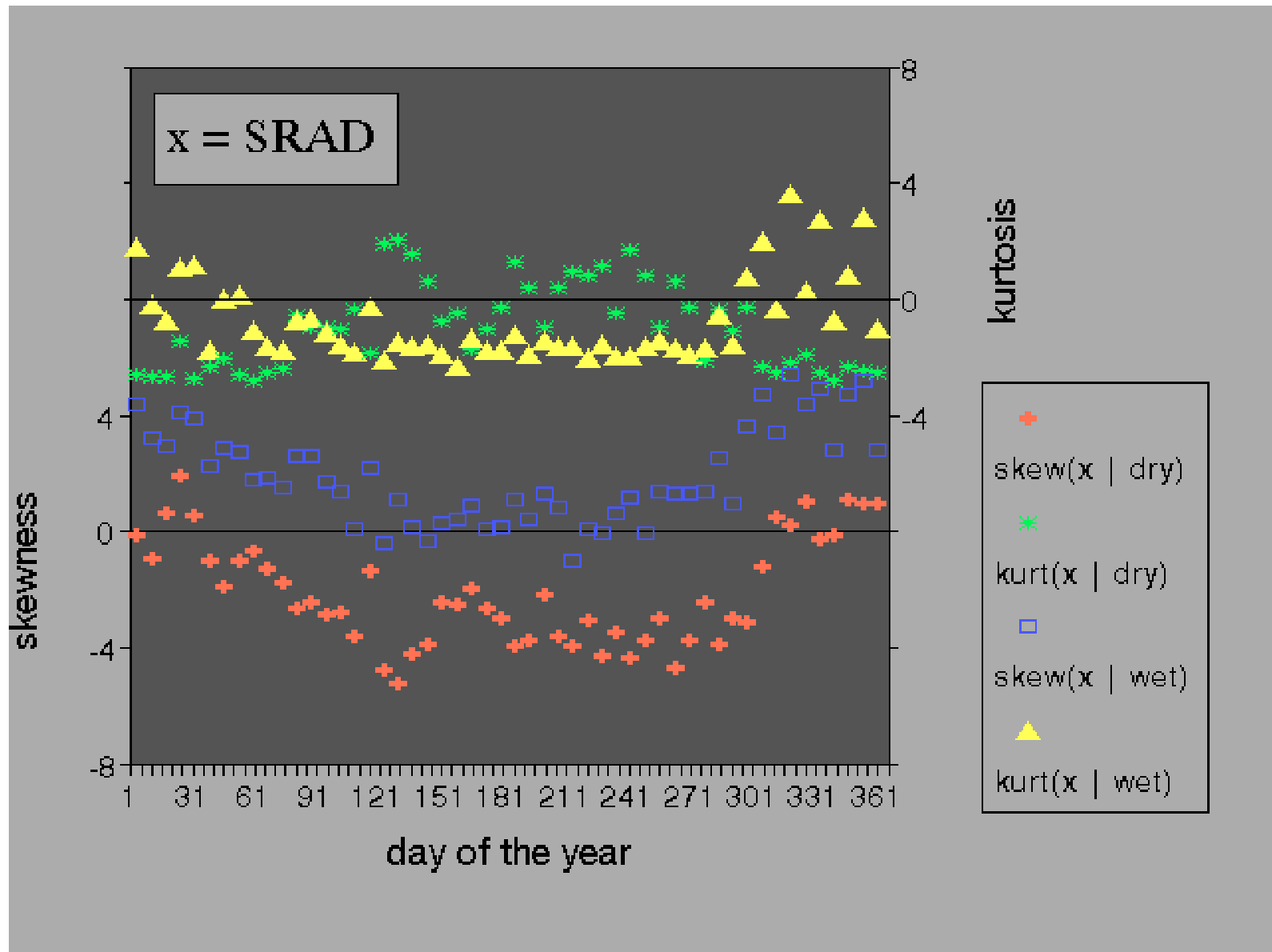
validation of Met&Roll: skewness and kurtosis of TMAX



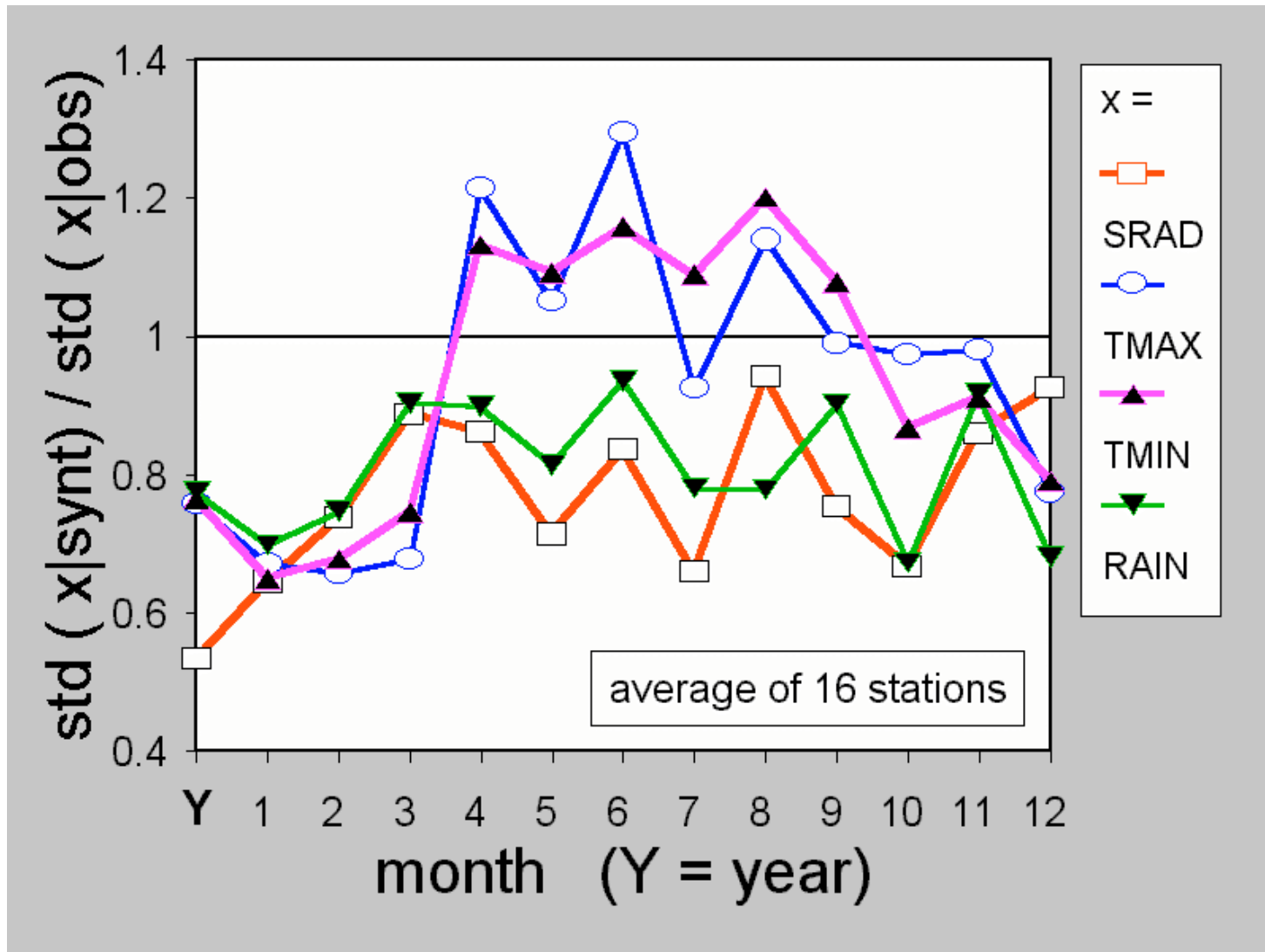
validation of Met&Roll: skewness and kurtosis of TMIN



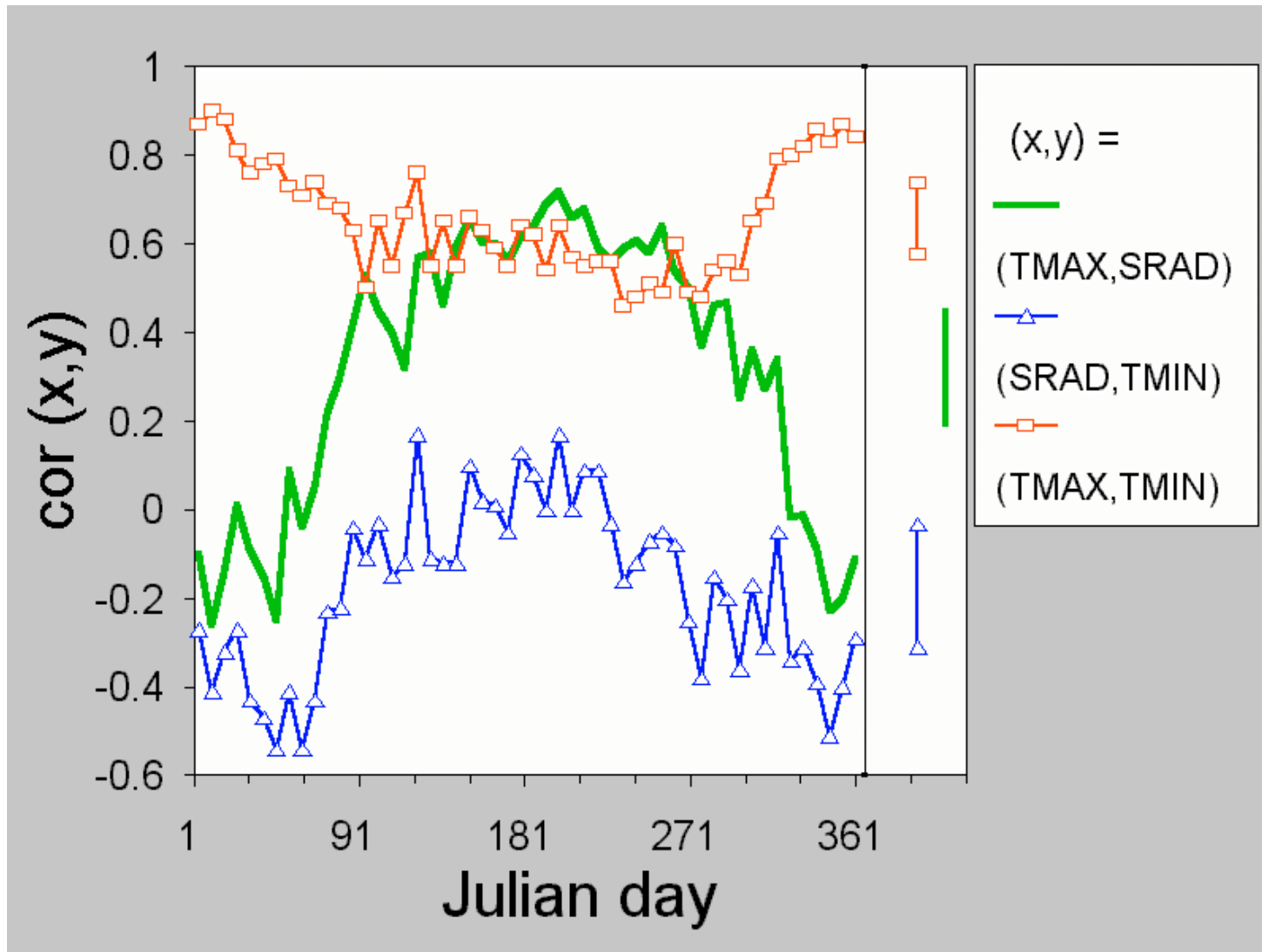
validation of Met&Roll: skewness and kurtosis of SRAD



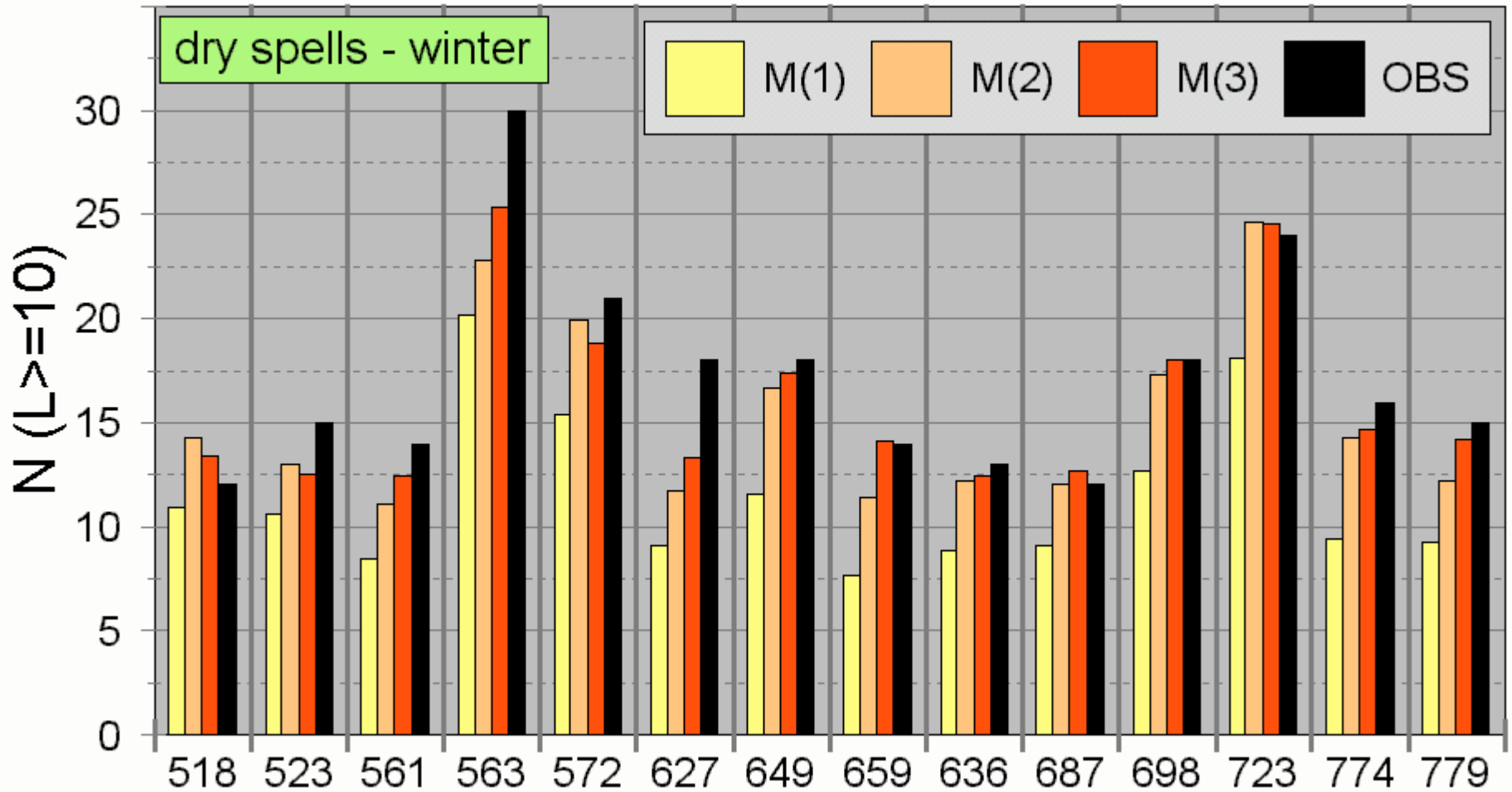
validation of Met&Roll: variability of monthly means



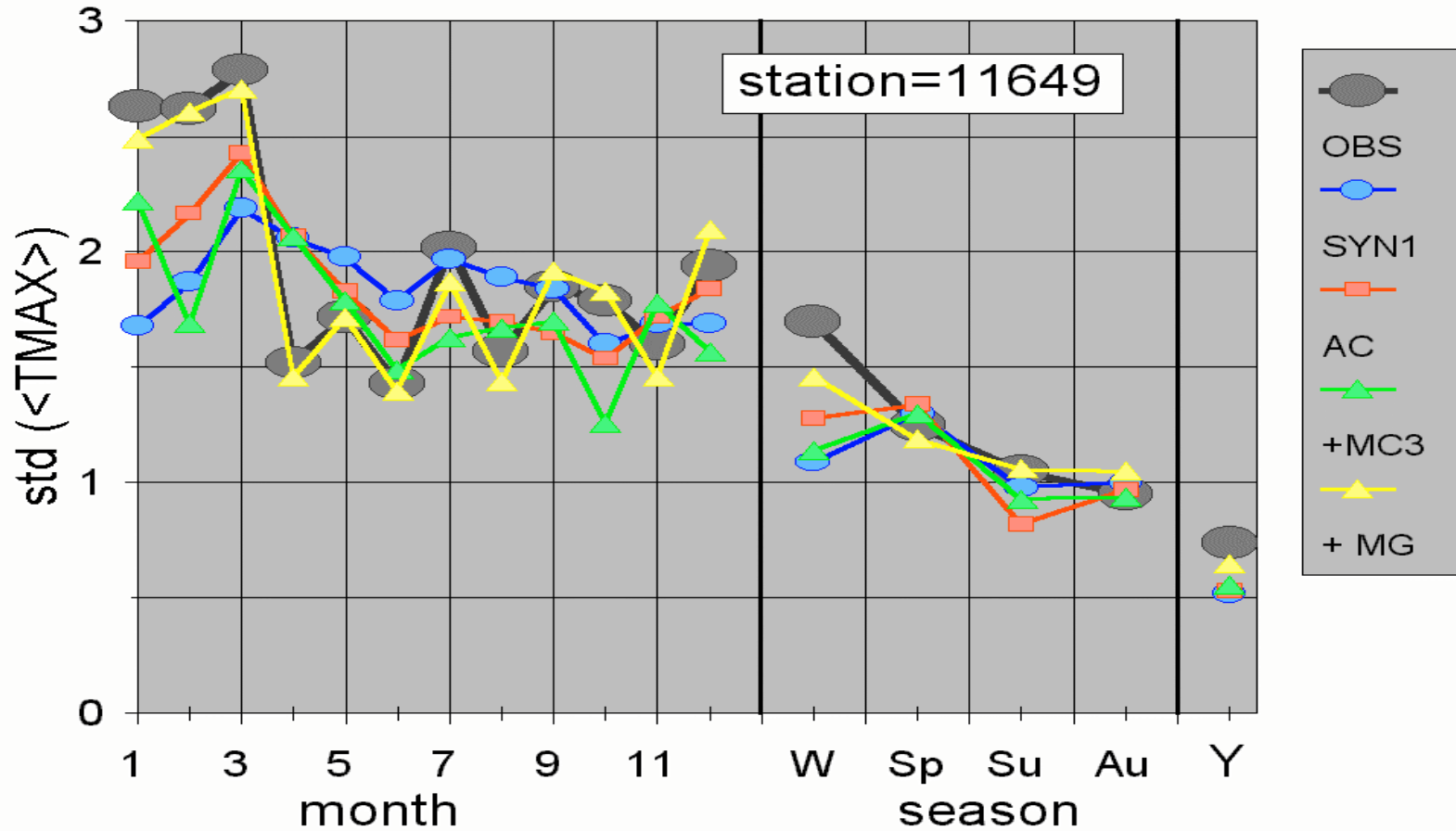
validation of Met&Roll: annual cycle of lag-0 correlations



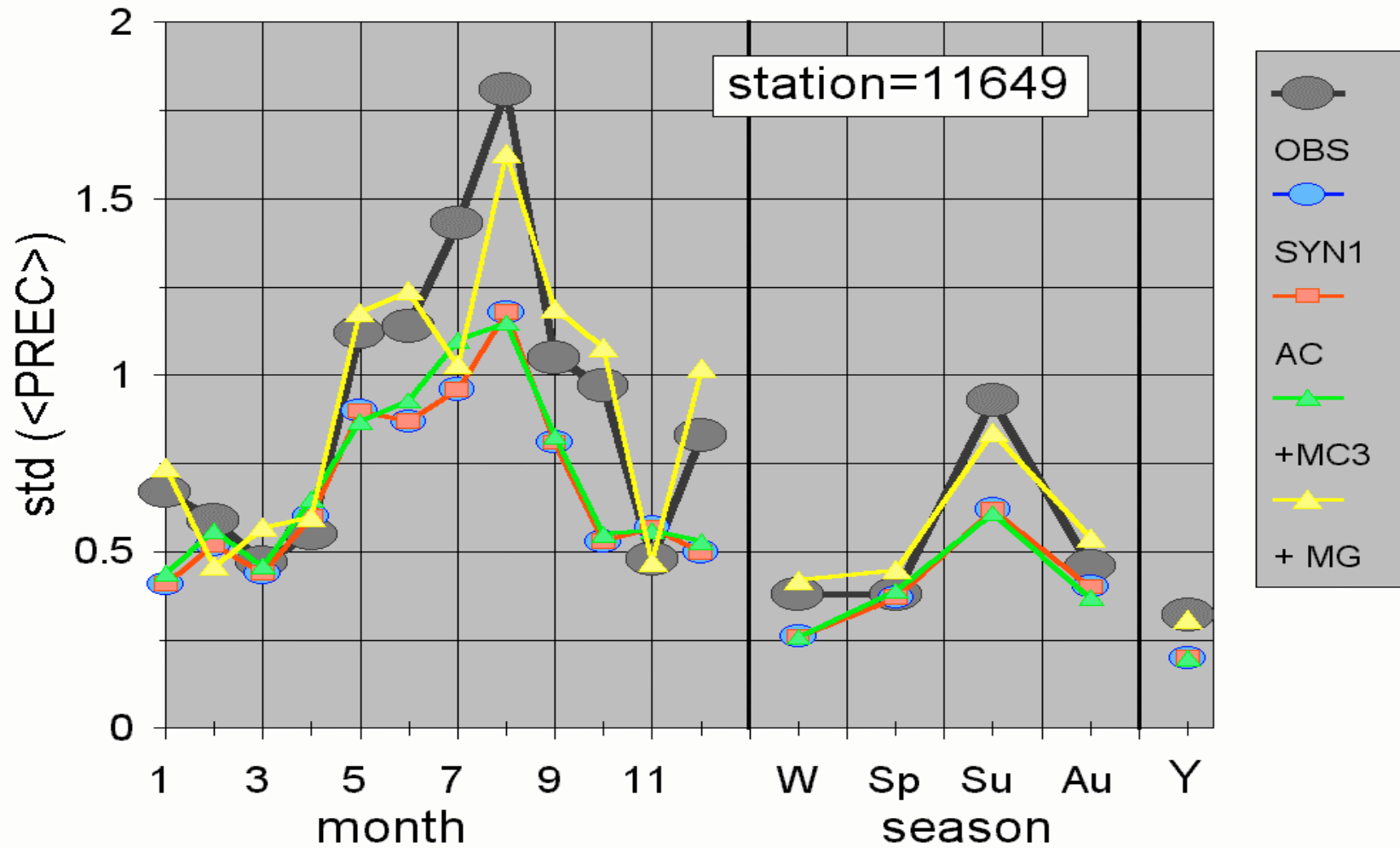
validation of Met&Roll: dry spells in winter (effect of Markov chain order)



validation of Met&Roll: variability of monthly means of TMAX



validation of Met&Roll: variability of monthly means of PREC



Met&Roll weather generator - indirect validation

motivation: direct validation shows the inaccuracies in reproducing the stochastic structure of weather series. (these may be reduced by improving the generator; /making it more complex and causing the estimate of WG parameters to be less accurate/). **The crucial question stands:** what is the effect of these inaccuracies on the output from the models fed by the weather series produced by WG?

(***requirement:*** probability distributions of outputs of models fed by observed and synthetic weather series do not differ)

indirect validation of Met&Roll

a) using crop model

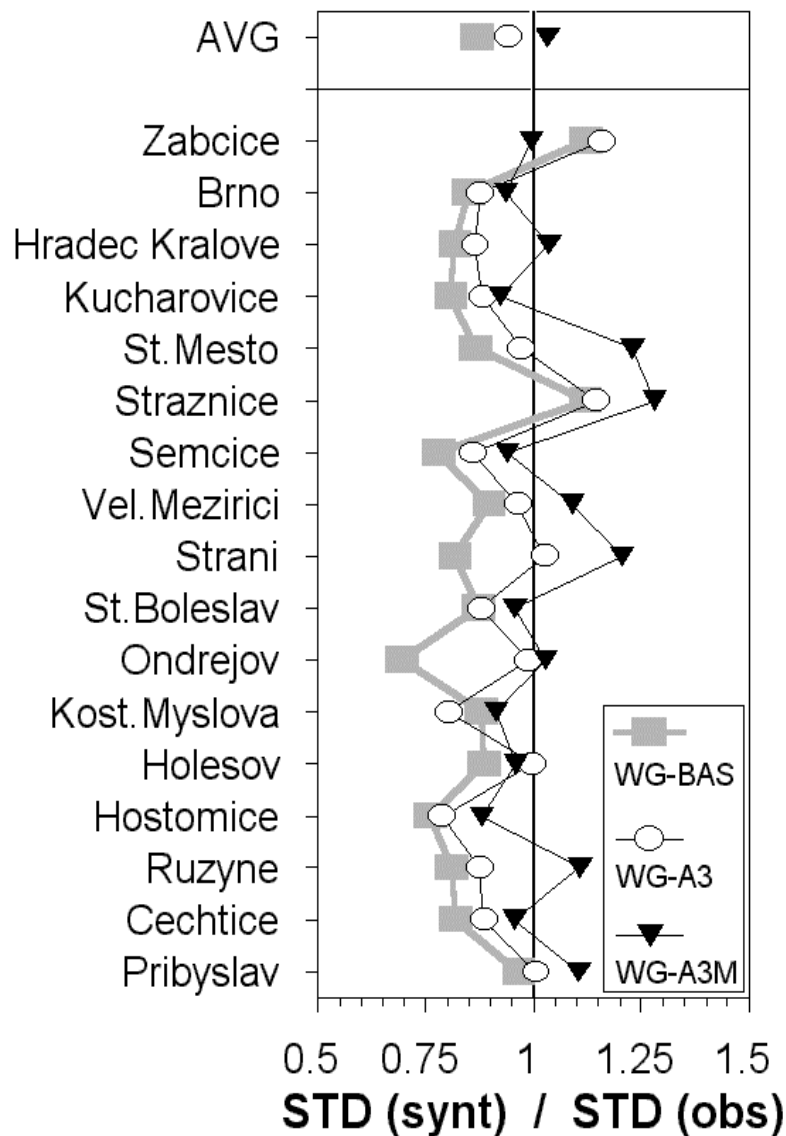
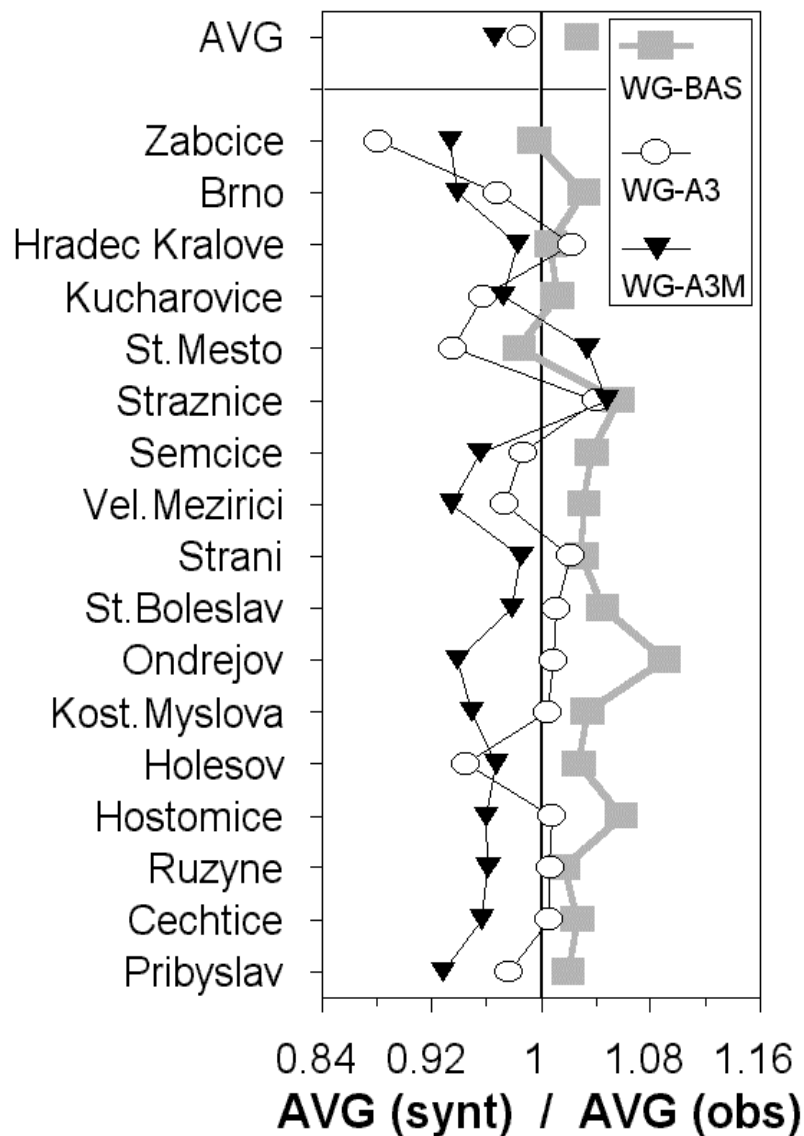
experiment:

- crop = winter wheat
- crop model = CERES-Wheat
- 30-year simulations for 17 Czech stations
- *input weather data:* PREC, SRAD, TMAX, TMIN (daily)
(30y observed vs. synthetic series)

validation: avg, std, quantiles of the 29 grain wheat yields
[>> Figure]

(+ Wilcoxon statistics, t-test, F-test were used to quantify the differences in PDFs, AVGs, STDs)

AVGs and STDs of wheat yields (for 17 stations and 3 versions of WG)



Met&Roll - indirect validation; b) via rainfall-runoff model

experiment:

model = SAC-SMA

(SACramento Soil Moisture Accounting model)

39-year simulations for river Malse

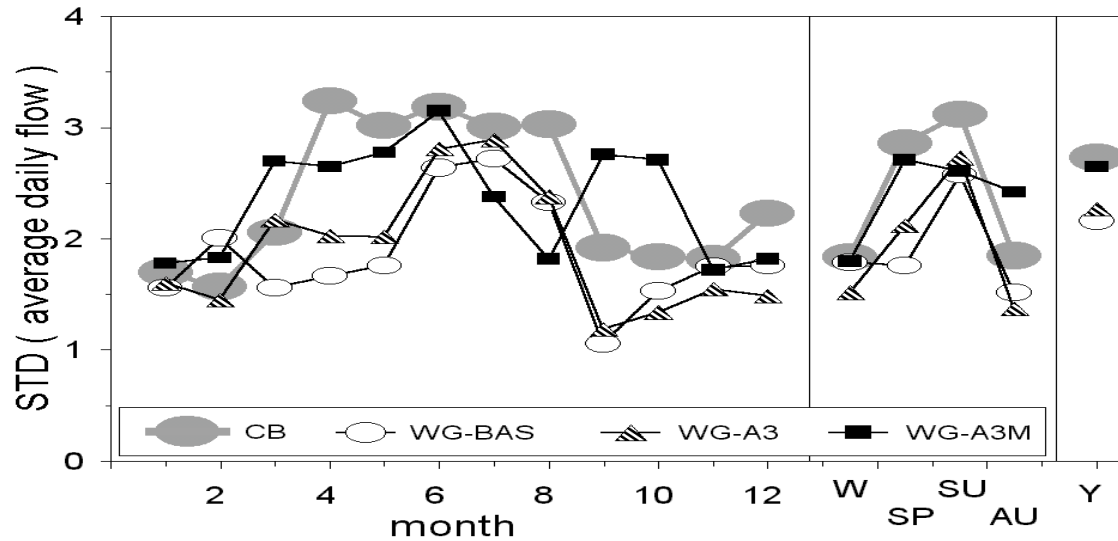
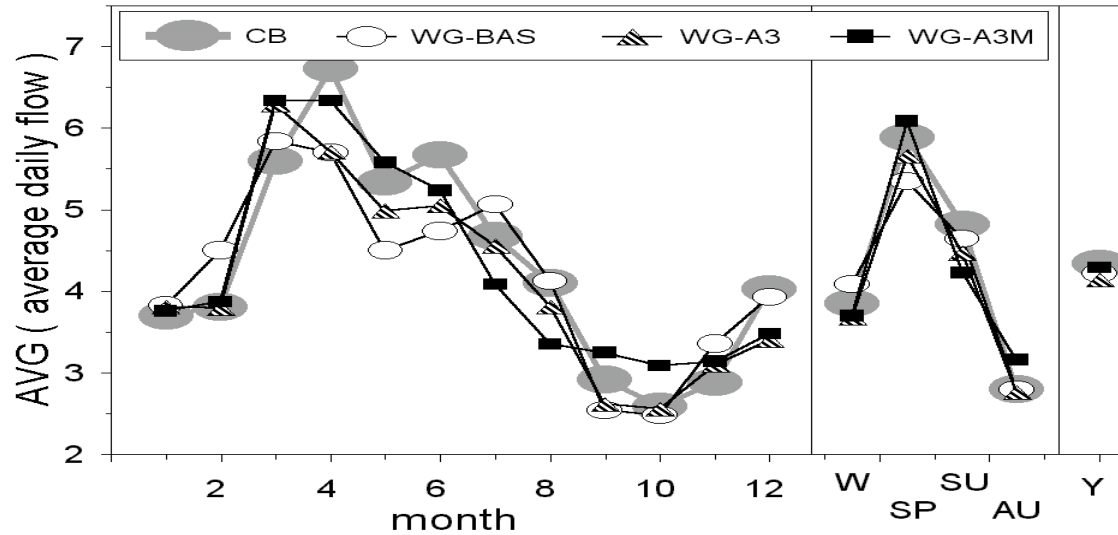
input weather: PREC and TAVG

(generated by 2-variate version of Met&Roll)

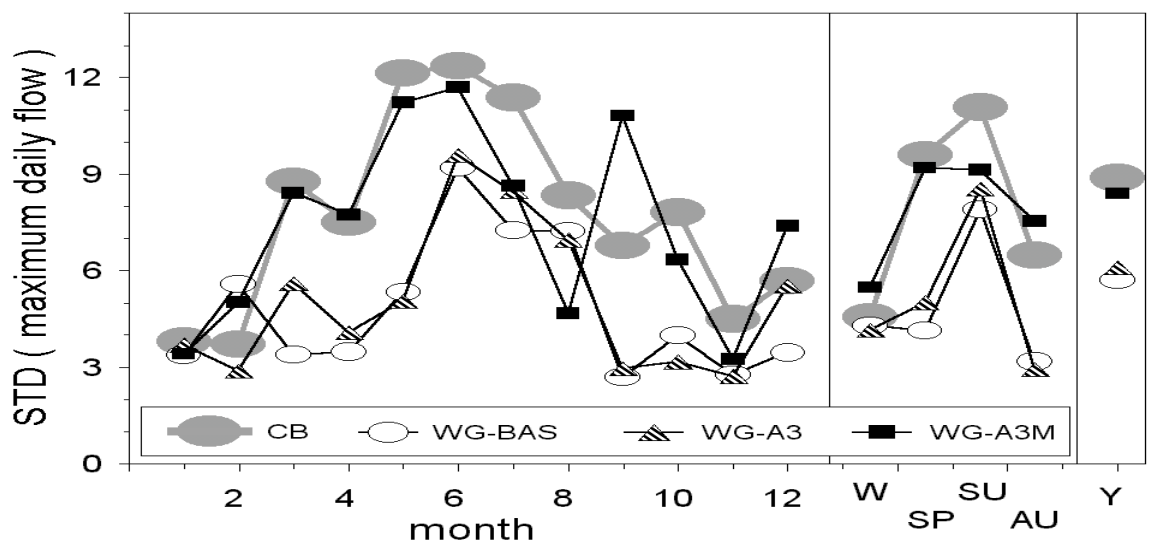
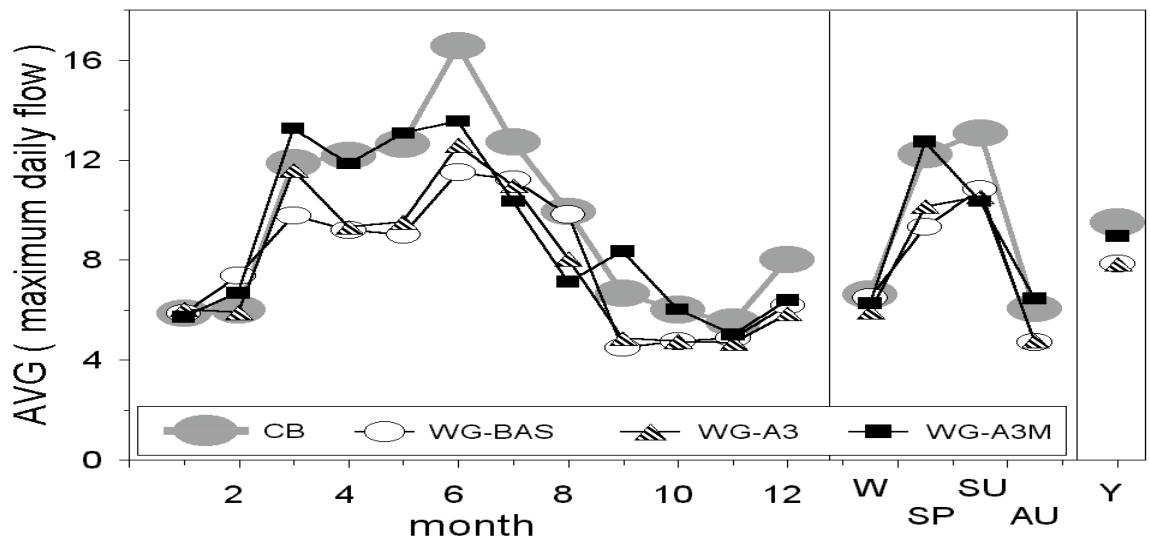
validation:

- AVGs and STDs of monthly MEAN and MAX streamflows
- PDFs of 5-day streamflows
- t-test, F-test

AVGs and STDs of average model daily streamflows



AVGs and STDs of monthly maxima of model daily streamflows



Indirect validation of Met&Roll using rainfall-runoff model

Table: The fit of the averages and standard deviations of monthly streamflow characteristics simulated using the synthetic weather series vs observed weather series.

	Version of the weather generator				
	WG-BAS	WG-A	WG-A3	WG-AM	WG-A3M
	<i>m/s/y</i>	<i>m/s/y</i>	<i>m/s/y</i>	<i>m/s/y</i>	<i>m/s/y</i>
<i>(a) Average monthly streamflow:</i>					
AVG; rejected by t-test	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
STD; rejected by F-test	3/3/1	4/3/1	4/3/1	4/1/0	3/1/0
<i>(b) Maximum monthly streamflow:</i>					
AVG; rejected by t-test	2/2/1	1/2/1	1/1/1	1/0/0	0/1/0
STD; rejected by F-test	9/3/1	8/3/1	6/3/1	5/2/0	2/2/0

Met&Roll - indirect validation; b) rainfall-runoff model

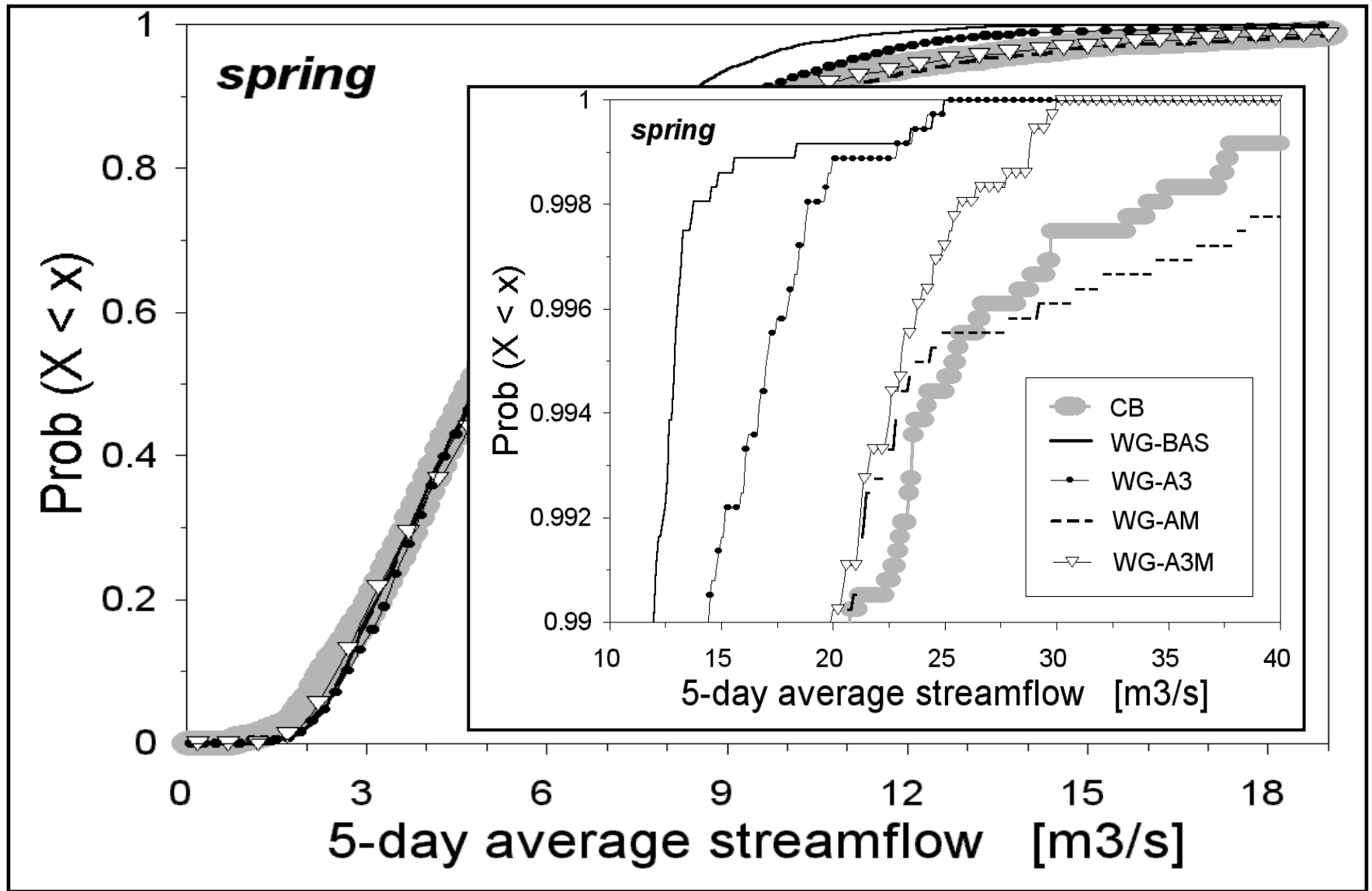


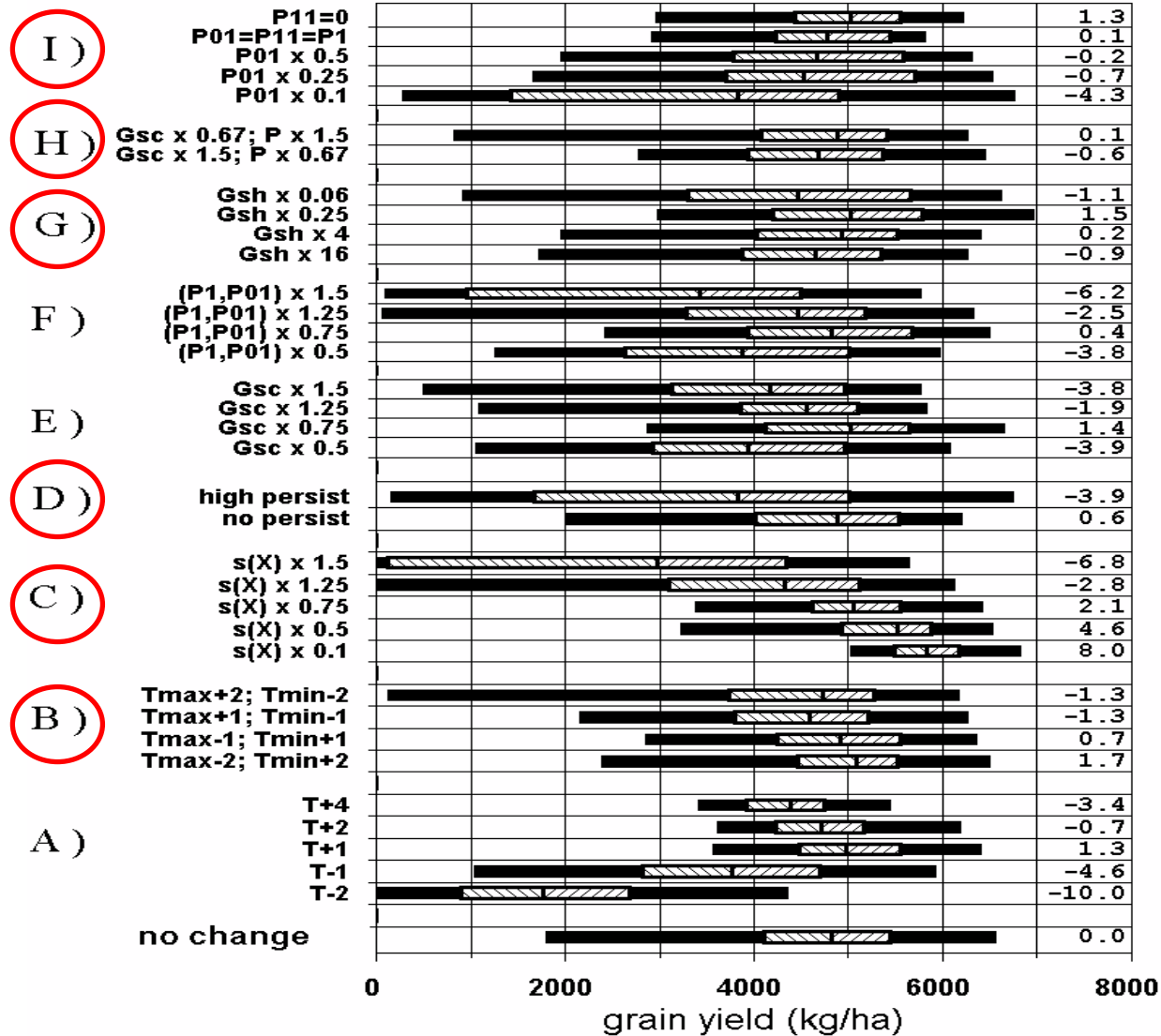
Fig. Probability distribution of 5-day average streamflow in spring simulated by SAC-SMA model with observed weather series (CB) and synthetic weather series [DBZ, 2004, CC]

Impacts of climate change on crop yields

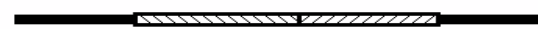
sensitivity of maize yields to stochastic structure of input weather series (*Dubrovsky et al., 2000*)

- **crop:** maize
- **crop model:** CERES-Maize
- **methodology:** WG approach (representative year + 99y synt. weather)
- **weather generator:** basic version
- **sensitivity analysis** (= sensitivity to changes in various climatic characteristics):
 - changes in the means
 - changes in variability
 - changes in persistence
 - changes in the shape of PDF of precipitation)

sensitivity of maize yields to stochastic structure of input weather series



Legend: 5th 25th median 75th 95th



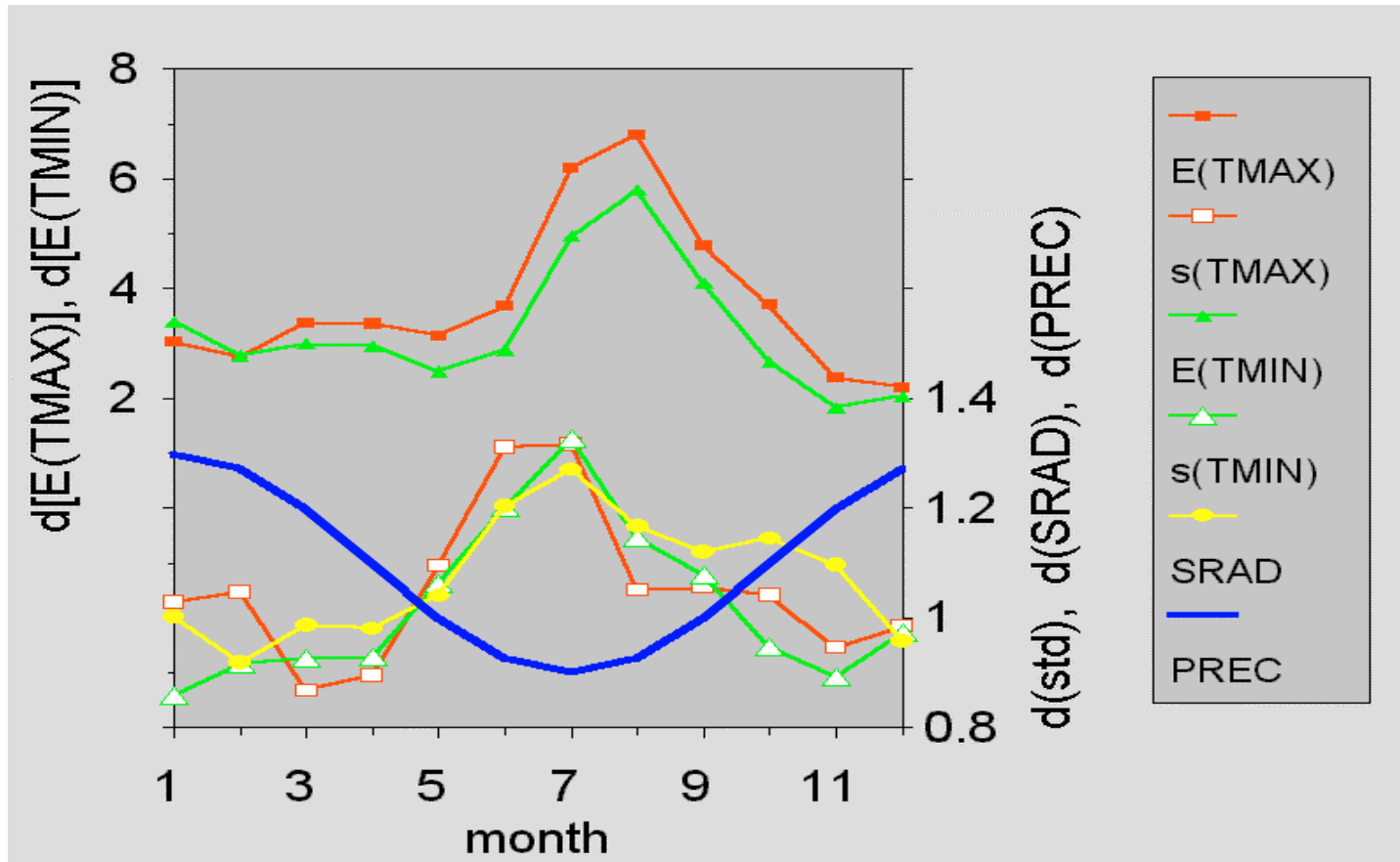
impact of climate change on maize yields

(Zalud & Dubrovsky, 2002, *Theor. and Appl. Climatol.*)

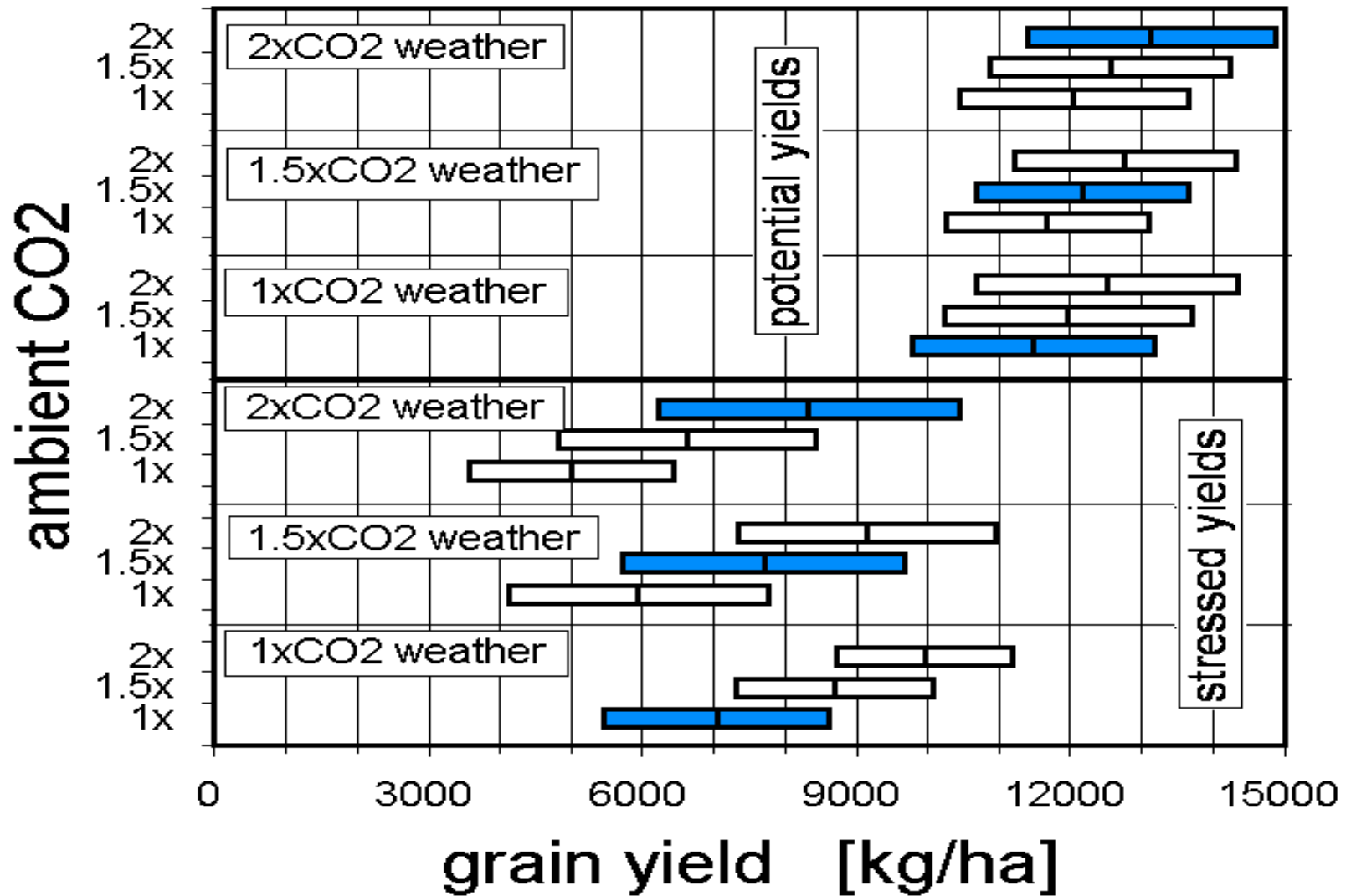
- crop = maize
- crop model = CERES-Maize
- climate change scenario: based on ECHAM3/T42 model
- weather generator = basic version
- experiments
 - **DM approach vs WG approach**
 - a) Direct Modification approach (observed 17y data, specific for each year)
 - b) WG approach (representative year + 99y weather series)
 - direct and indirect effects of CO₂ rise on **potential** and **stressed** yields
 - The magnitude of the direct effect of increased CO₂ is greater than the magnitude of the indirect effect, so that the superposition of both effects implies positive change in maize yields in increased CO₂ conditions.
 - direct effect is nearly linear, indirect effect non-linear
 - impacts on **other growth and development characteristics**
 - **adaptation analysis** (planting date)

climate change scenario

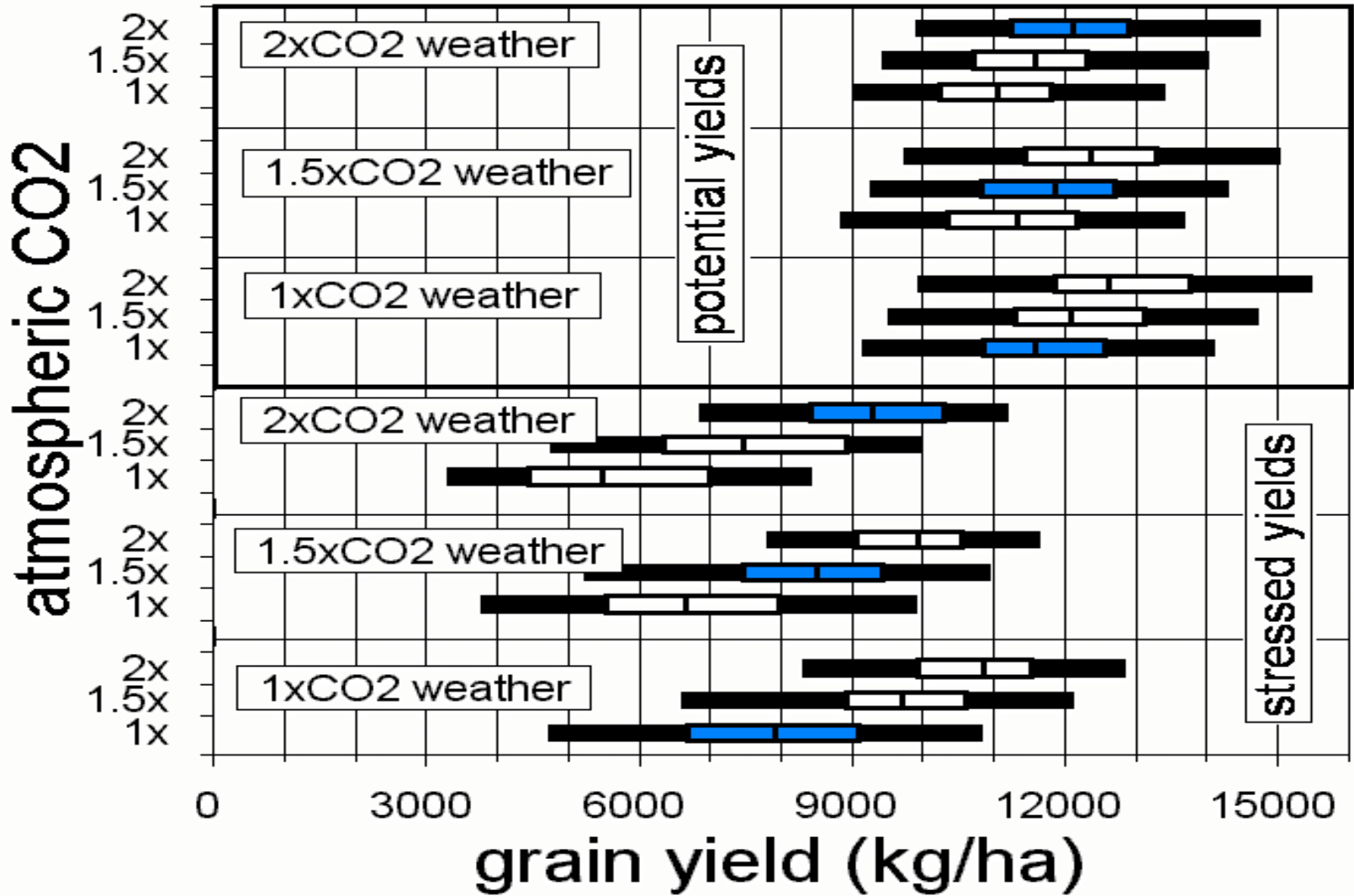
- temperature ~ ECHAM3 (equilibrium 2xCO₂ run vs. control period)
- SRAD ~ regression [= f(TMAX, TMIN)]
- PREC ~ expert judgement



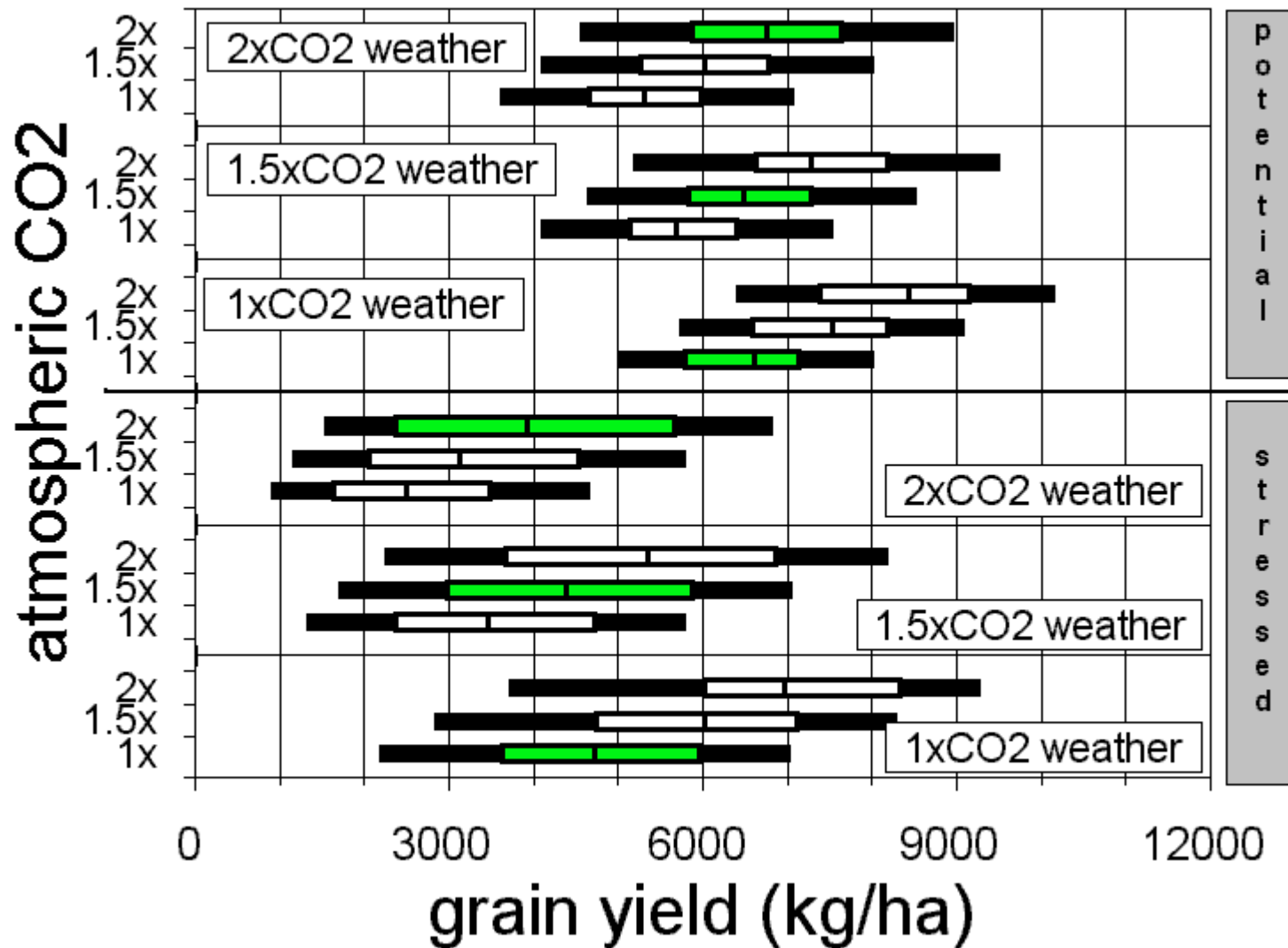
a) direct modification approach (17 years series)



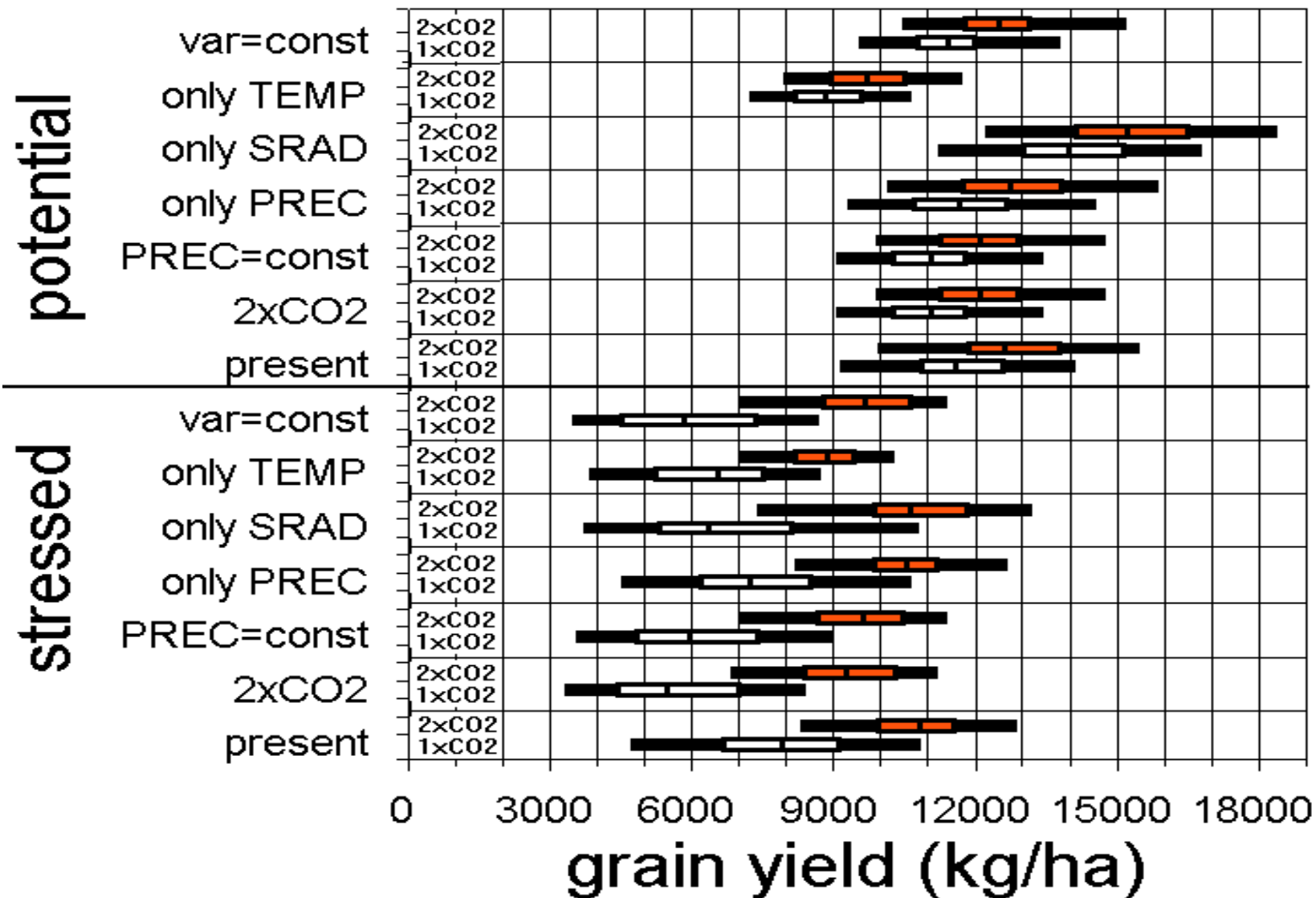
b) Weather Generator approach (99 years series)



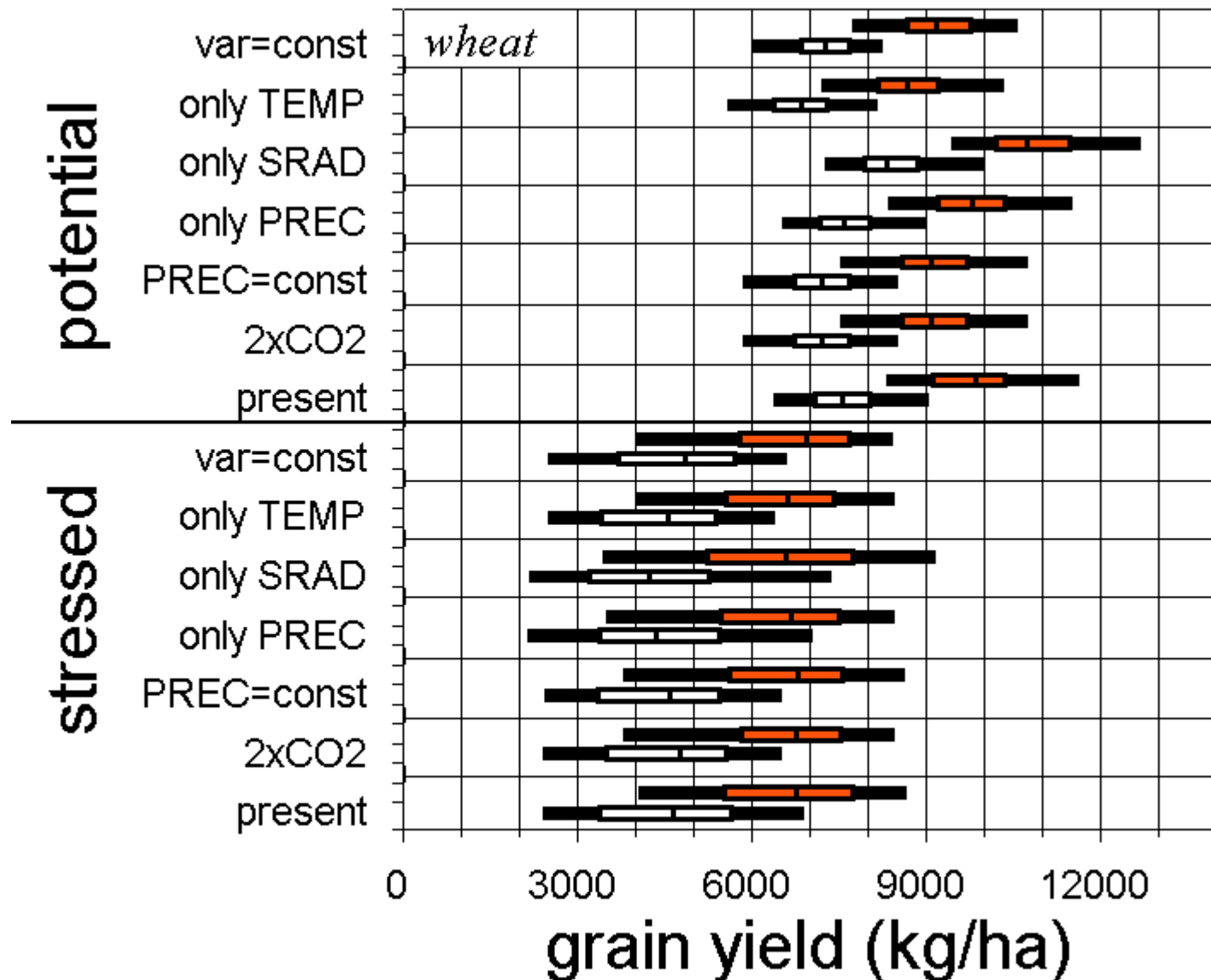
.... the same but for the barley



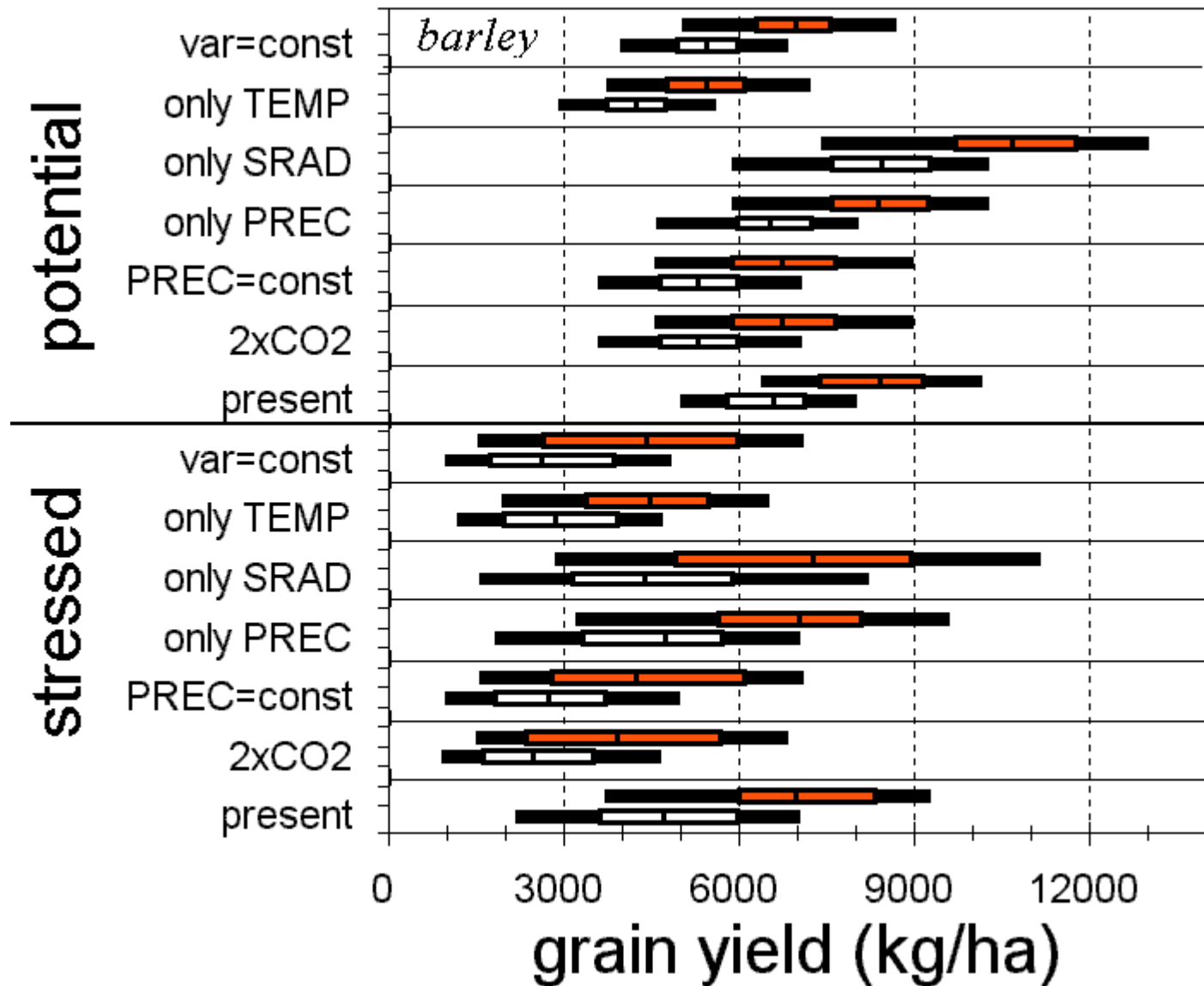
impact of climate change on maize



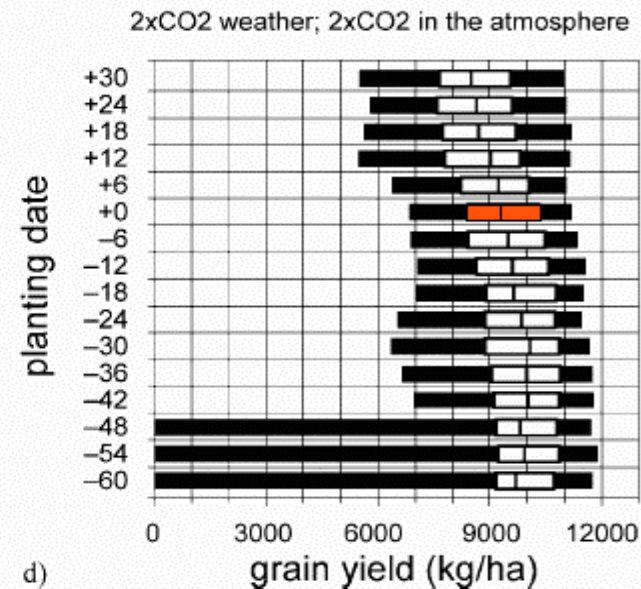
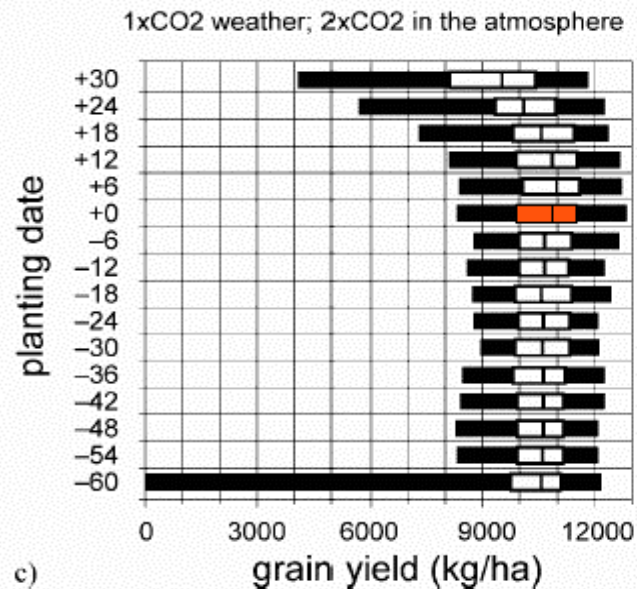
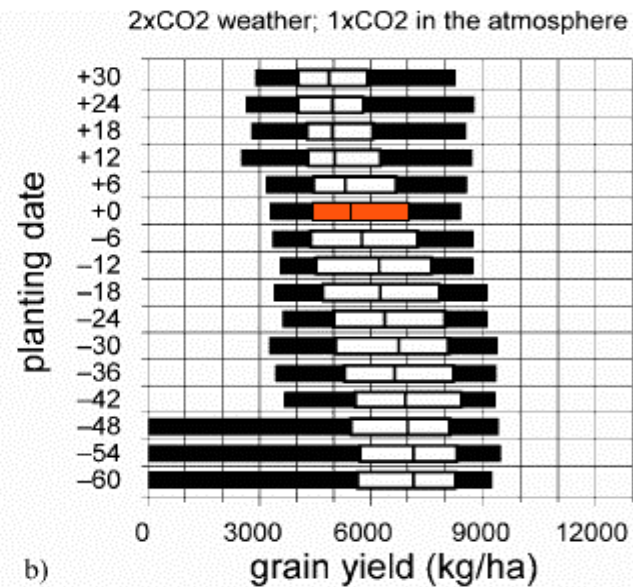
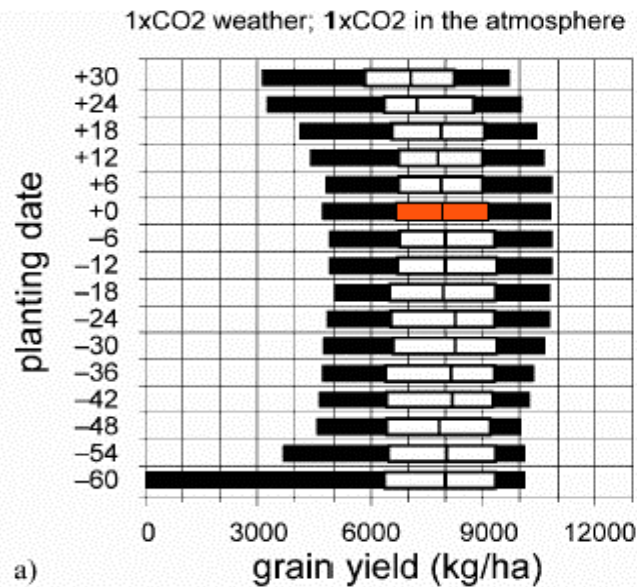
.... the same but for the wheat



.... the same but for the barley [Zalud et al, 2000 /in Czech/]



adaptation analysis (maize; shifting the planting date)



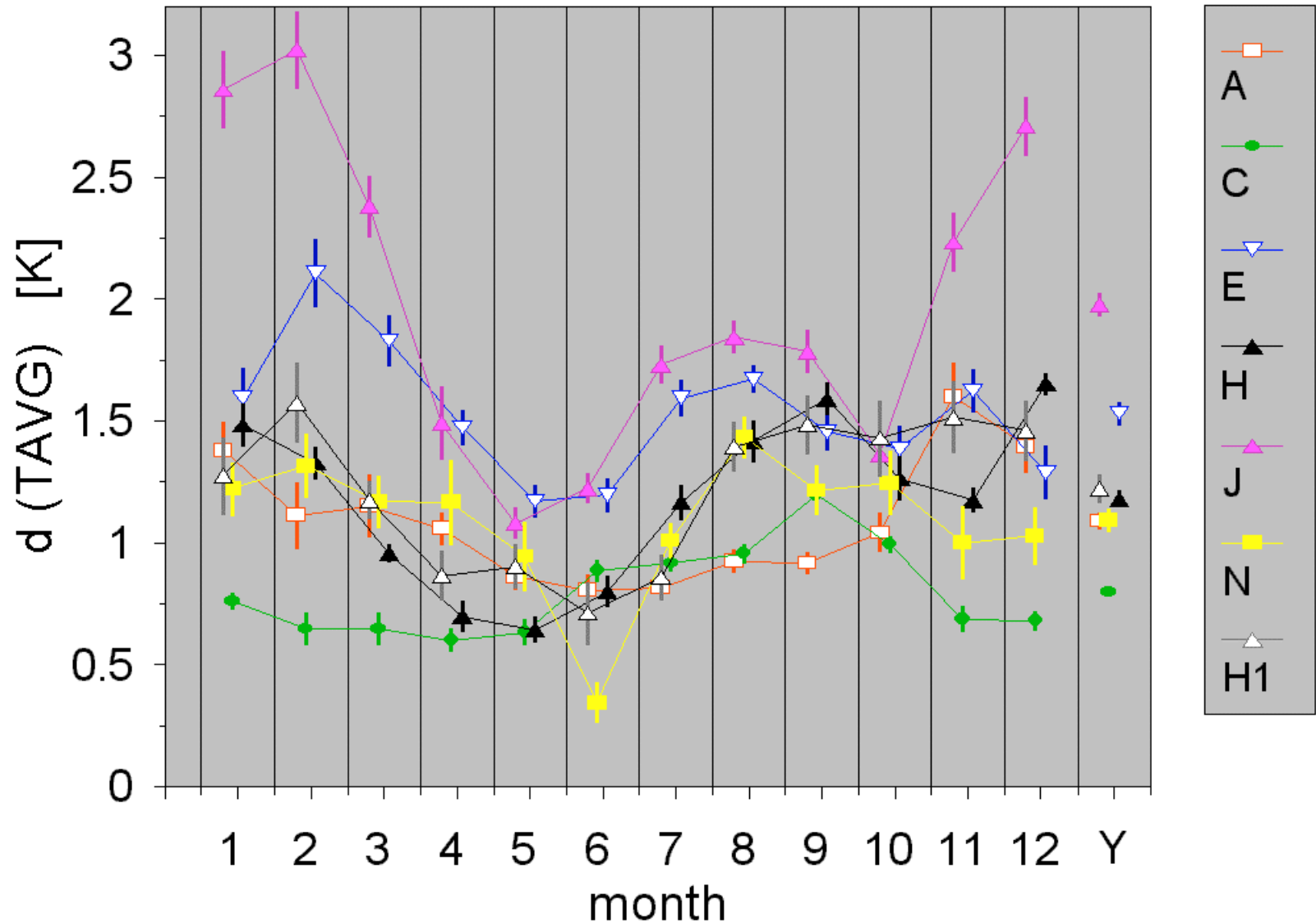
Projections of uncertainties in climate change scenarios into expected winter wheat yields (*Trnka et al., 2004, TAC*)

- **methodology:** WG approach (representative year + 99y synthetic series)
- **crop** = winter wheat
- **crop model:** CERES-Wheat
 - calibrated using observed data + validated using independent data
- **climate change scenario (pattern scaling method used):**
 - seven IS92a transient GCM simulations
 - lower scenario: low climate sensitivity + SRES-B1
 - high scenario: high climate sensitivity + SRES-A2
 - changes in means + incremental changes in temperature variability (Fig.6)
 - 3 time horizons: 2025, 2050, 2100
 - >>> 42 scenarios: 7GCMs x 3 time horizons x 2 emission scenarios
- **7 sites** in Czechia
- **experiments:**
 - impacts of climate change on stressed and potential yields of winter wheat
 - applicability of AVG scenario

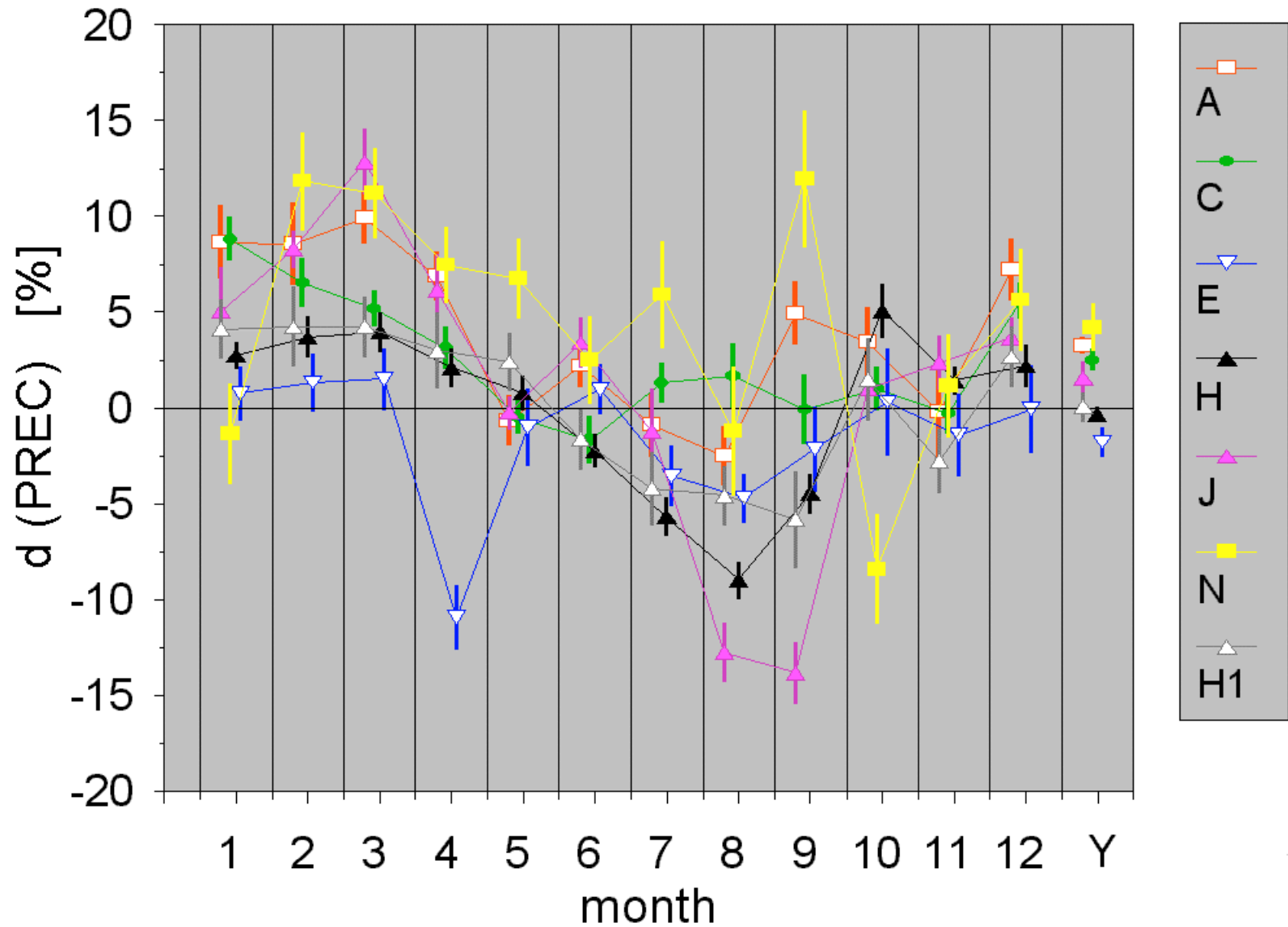
climate change scenario

- **data:** 7 GCMs run at IS92a (or similar) emission scenario (transient simulations; available from IPCC-DDC)
 - (GCMs were validated using Czech station data)
- **method:** pattern scaling
 - $dX = dX(\text{std}) * \Delta TG$
 - where $dX(\text{std})$ derived from 2010-2099 GCM
 - ΔTG estimated by MAGICC (provided by CRU)
- **changes in variability** were not included in the scenario, but the effect of variability was studied (sensitivity analysis)

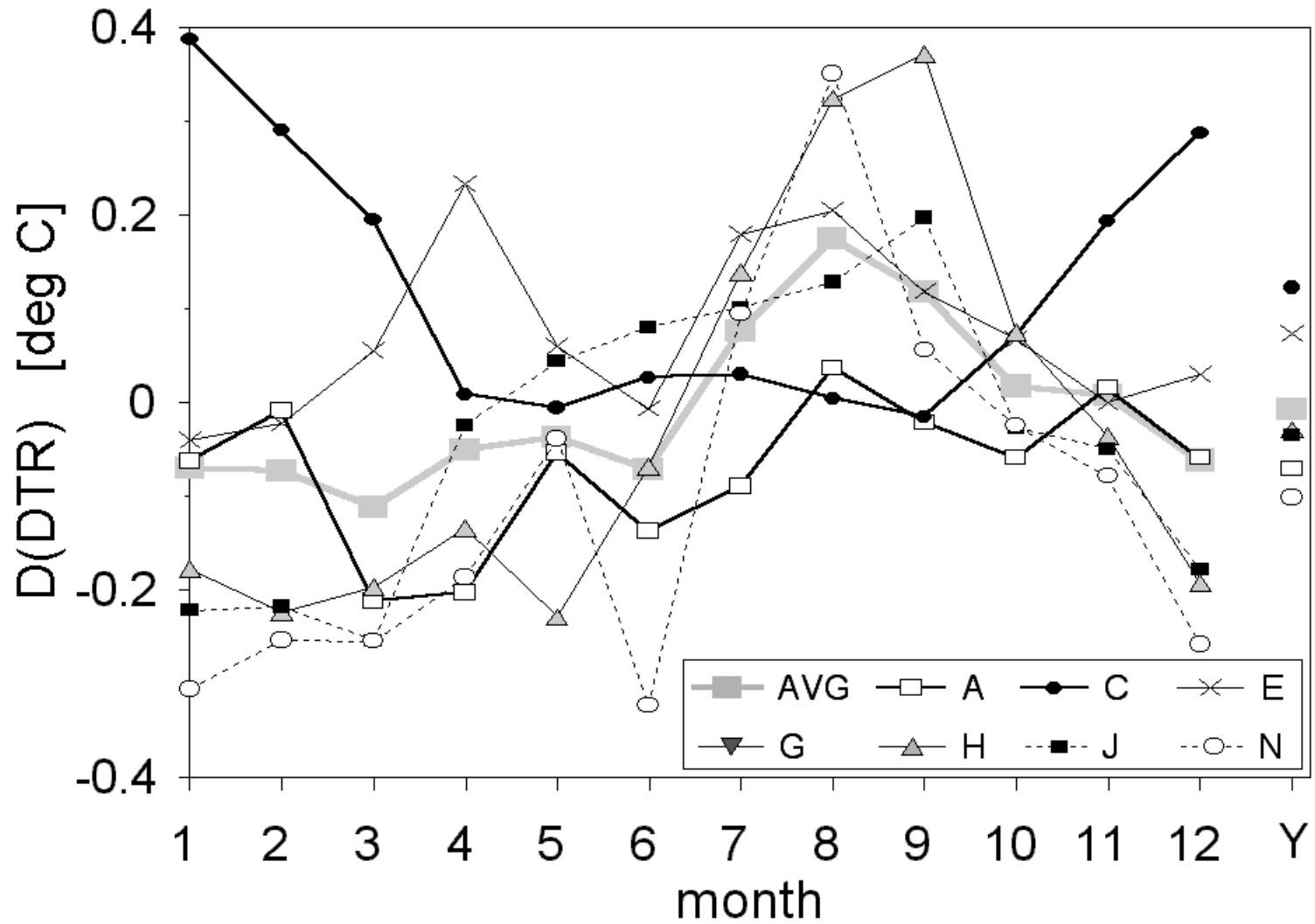
climate change scenario: TAVG



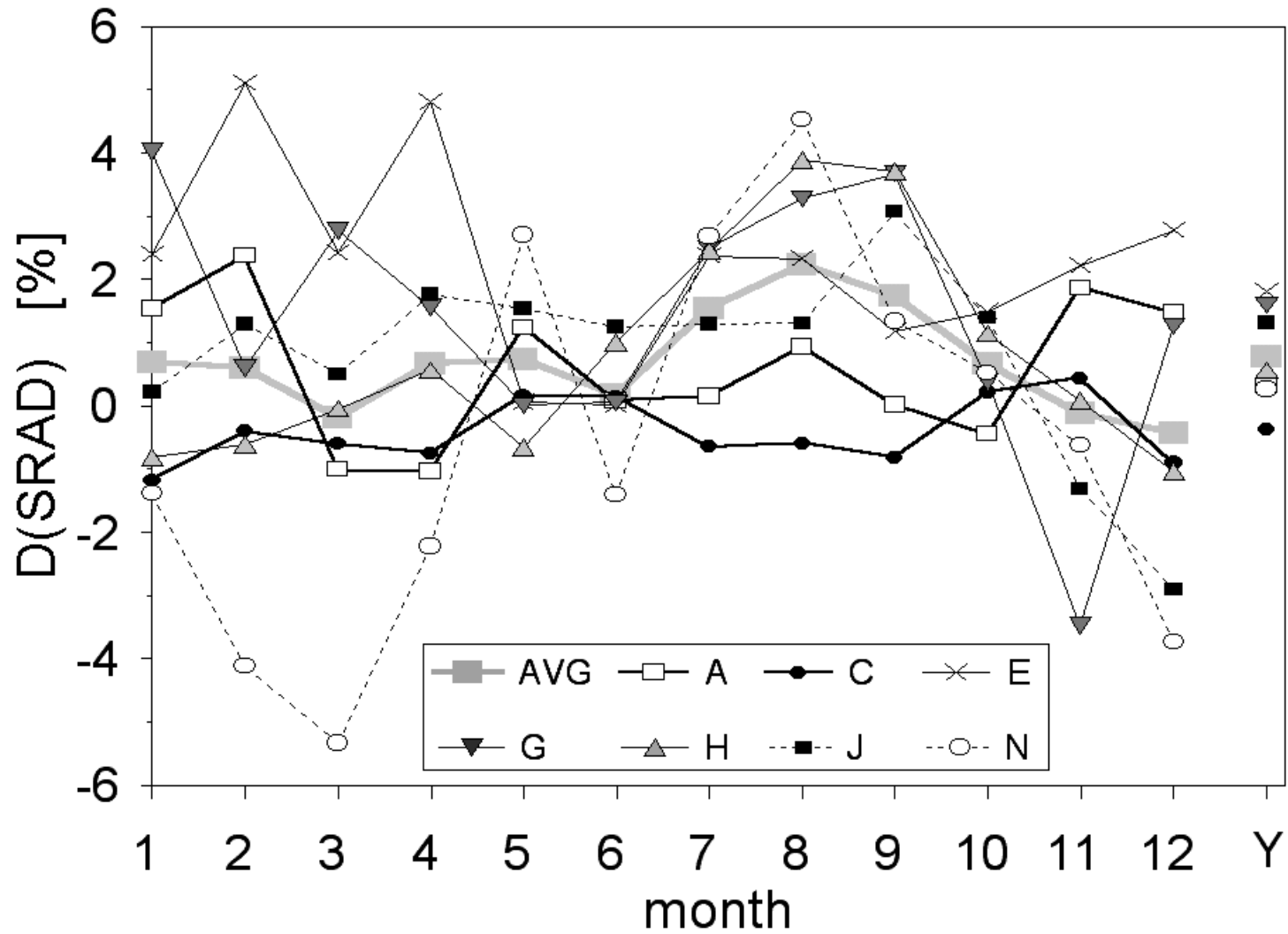
climate change scenario: *PREC*



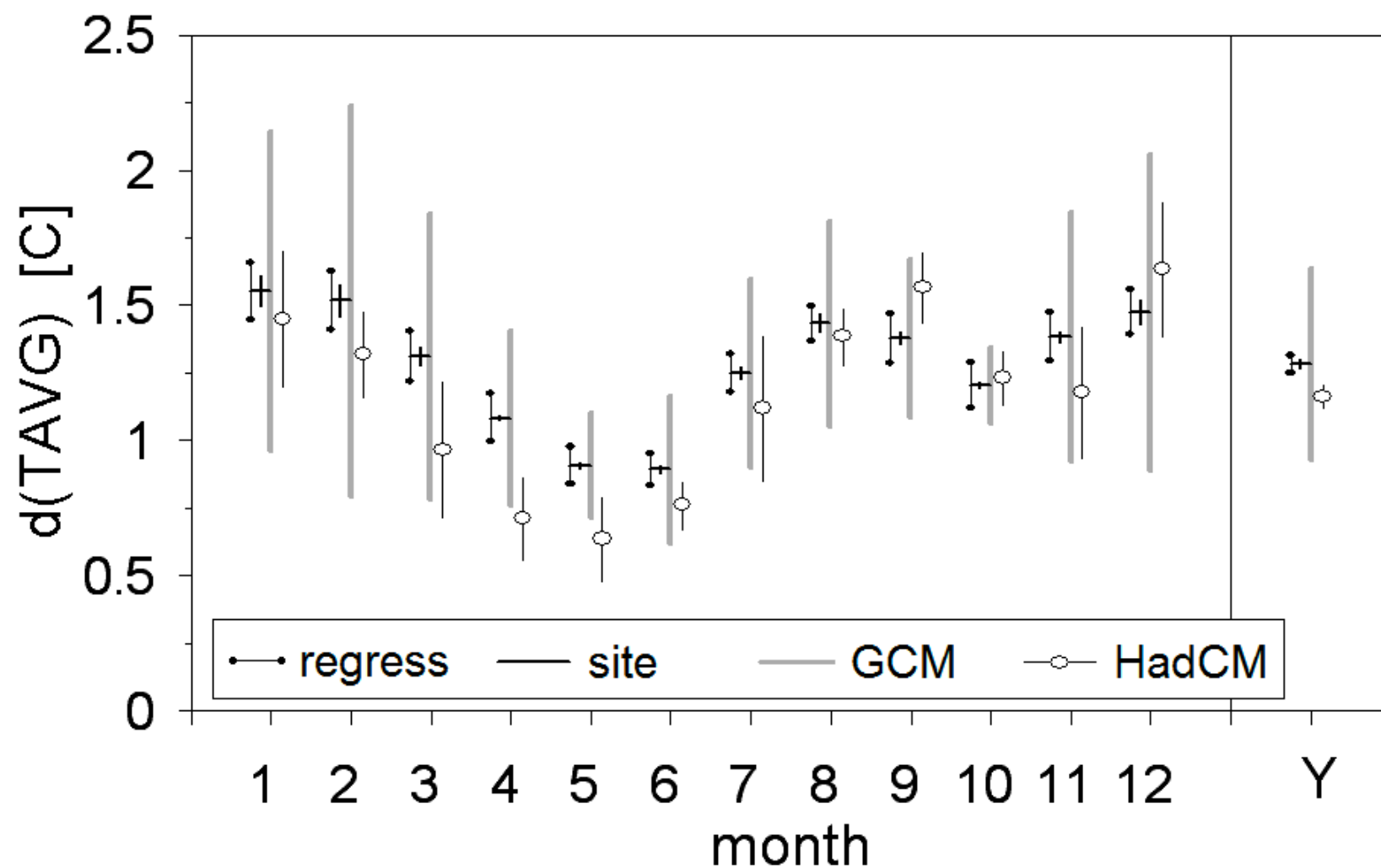
climate change scenario: *DTR*



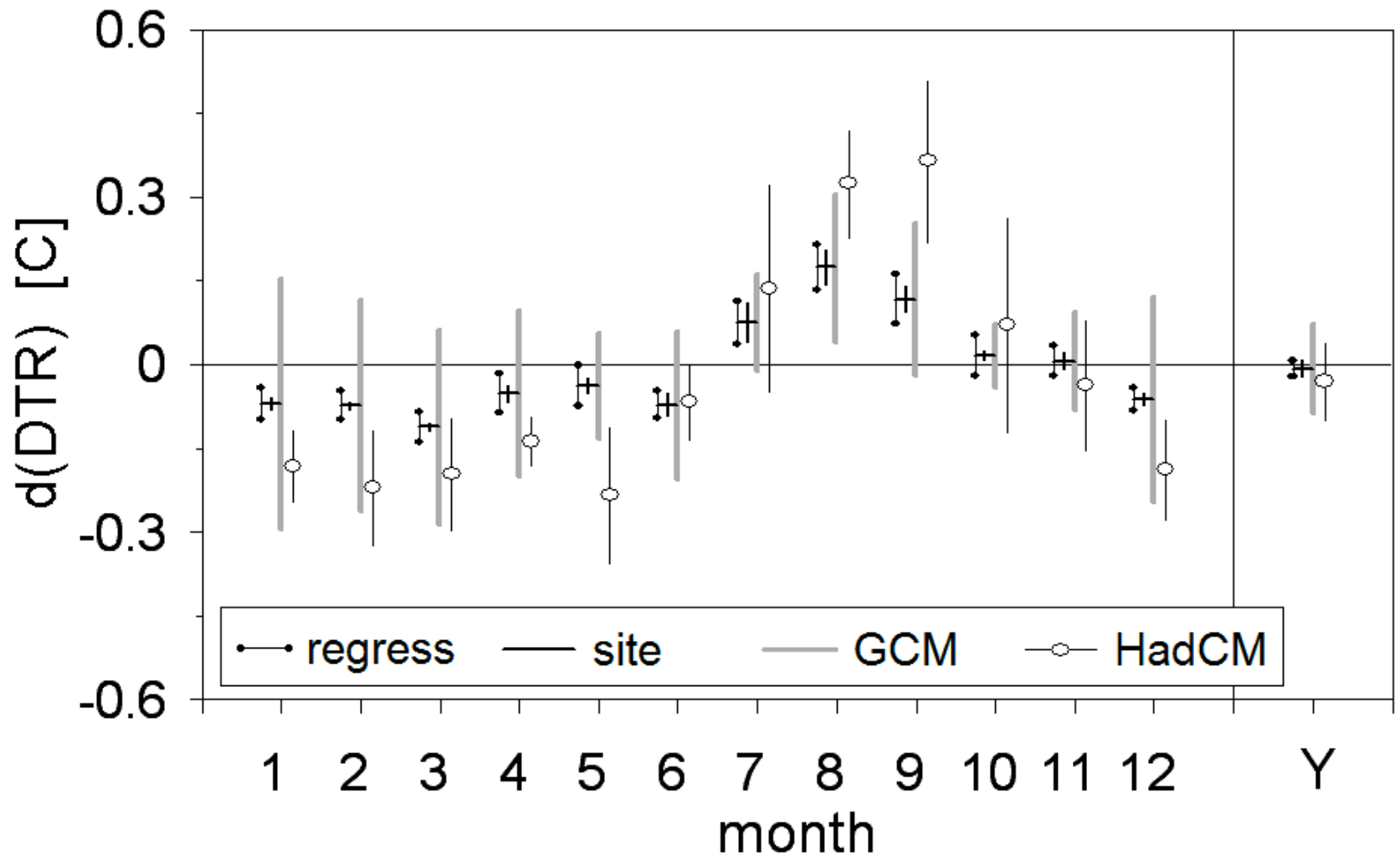
climate change scenario: *SRAD*



uncertainties in climate change scenario: **TAVG** (avg \pm std)

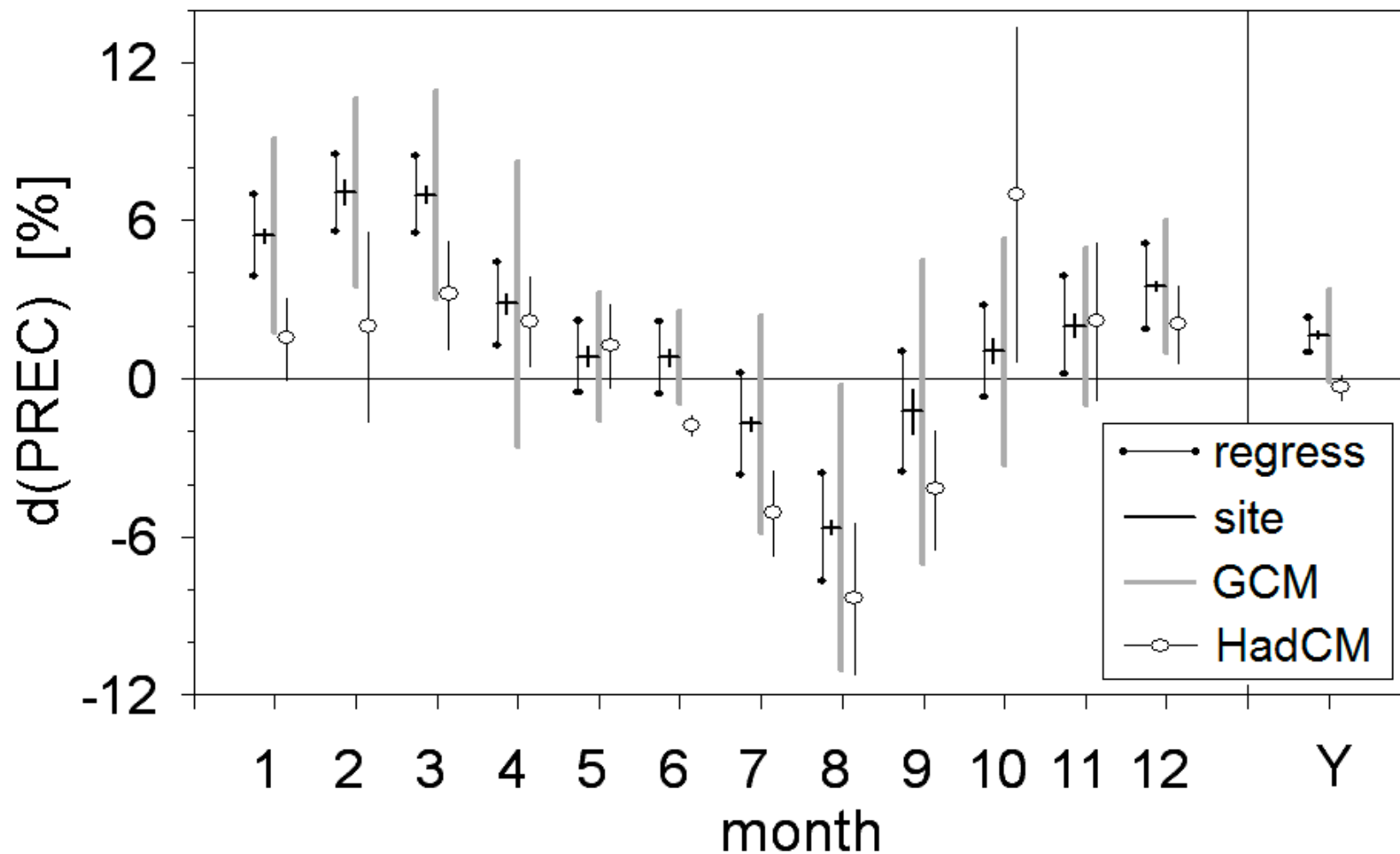


uncertainties in climate change scenario: **DTR** (avg \pm std)



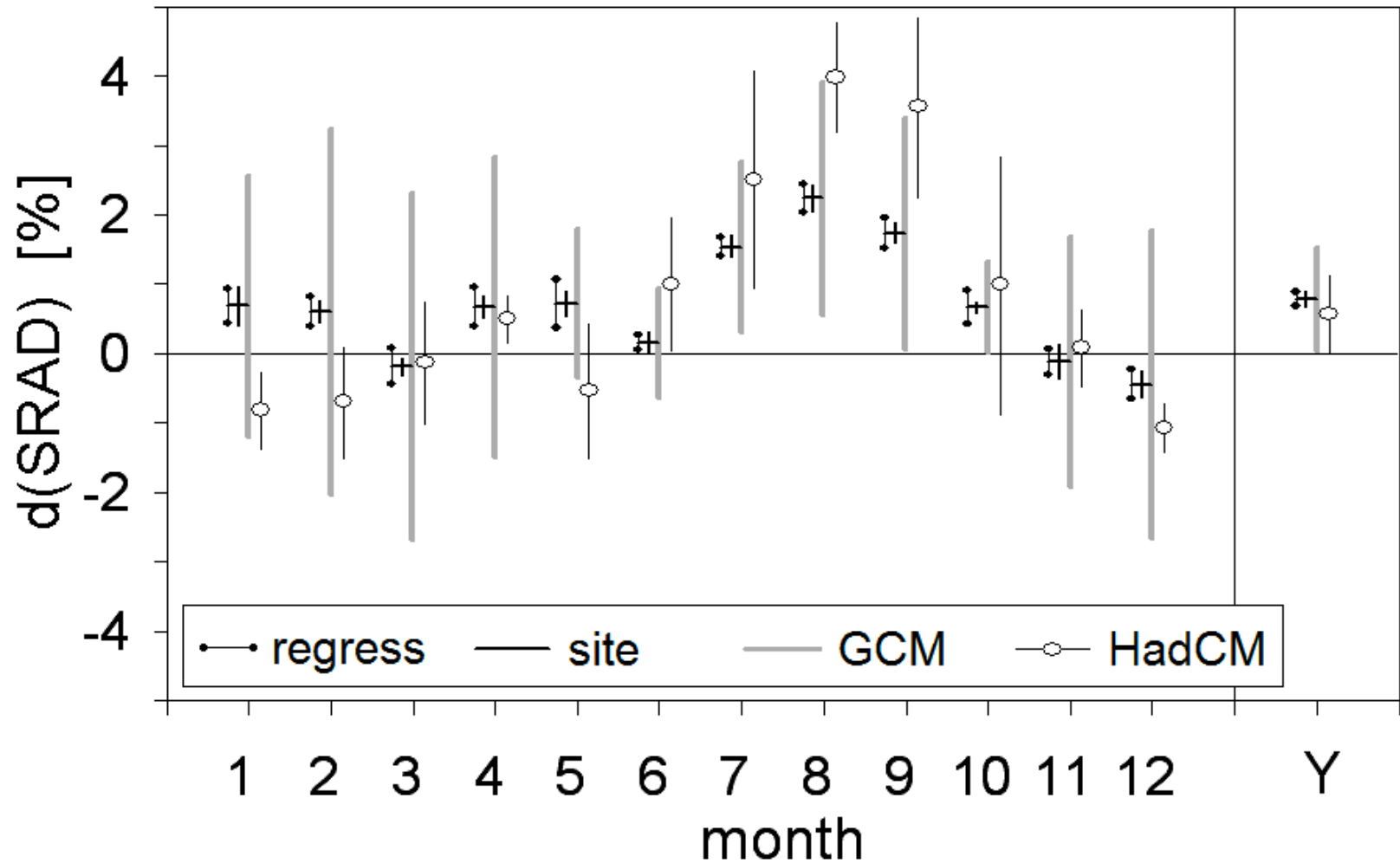
uncertainties in climate change scenario: **PREC**

(avg \pm std)

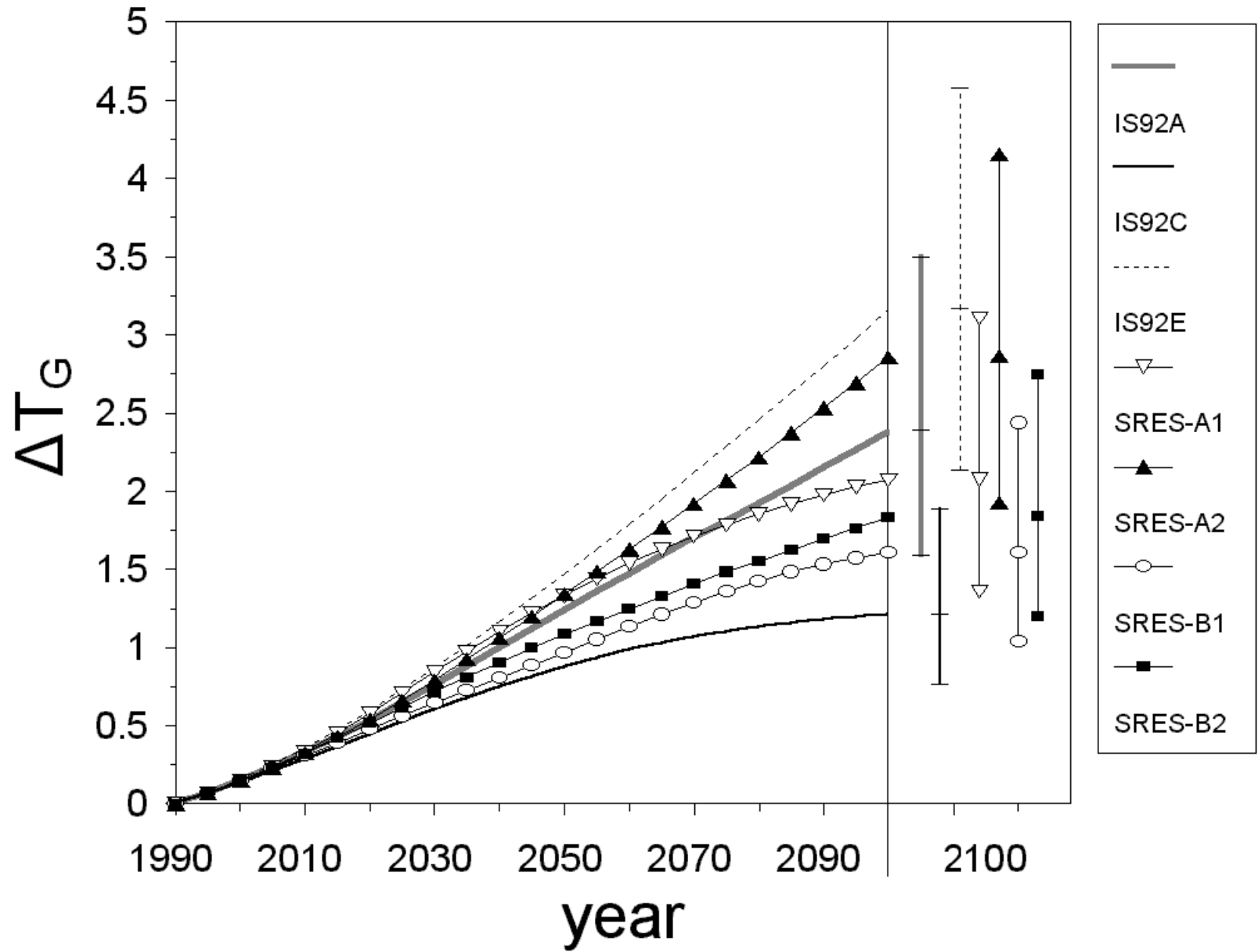


uncertainties in climate change scenario: **SRAD**

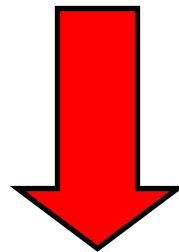
(avg \pm std)



global temperature change modelled by MAGICC



uncertainties in climate change scenario

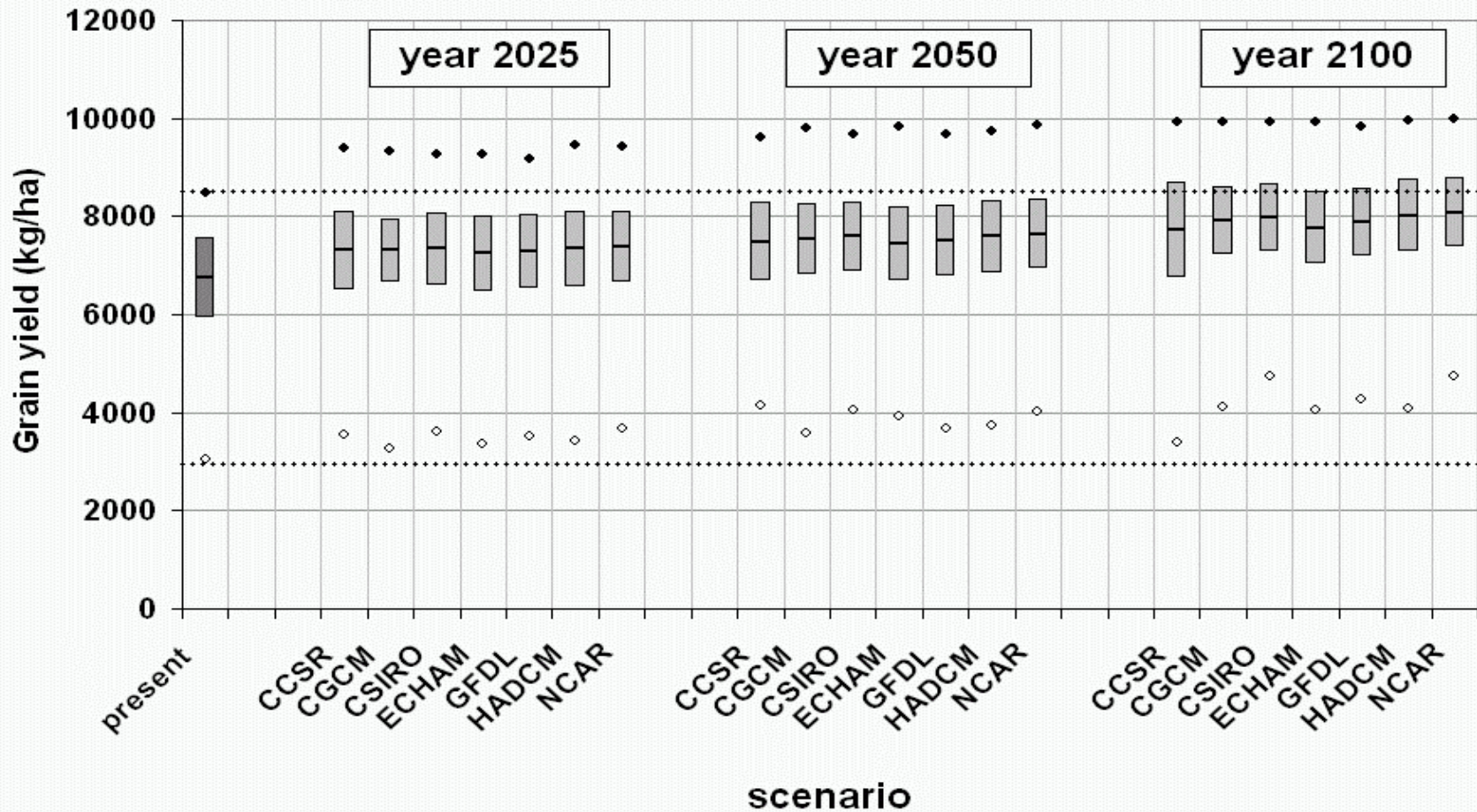


**multiple scenarios are required
in climate change impact studies!!!**

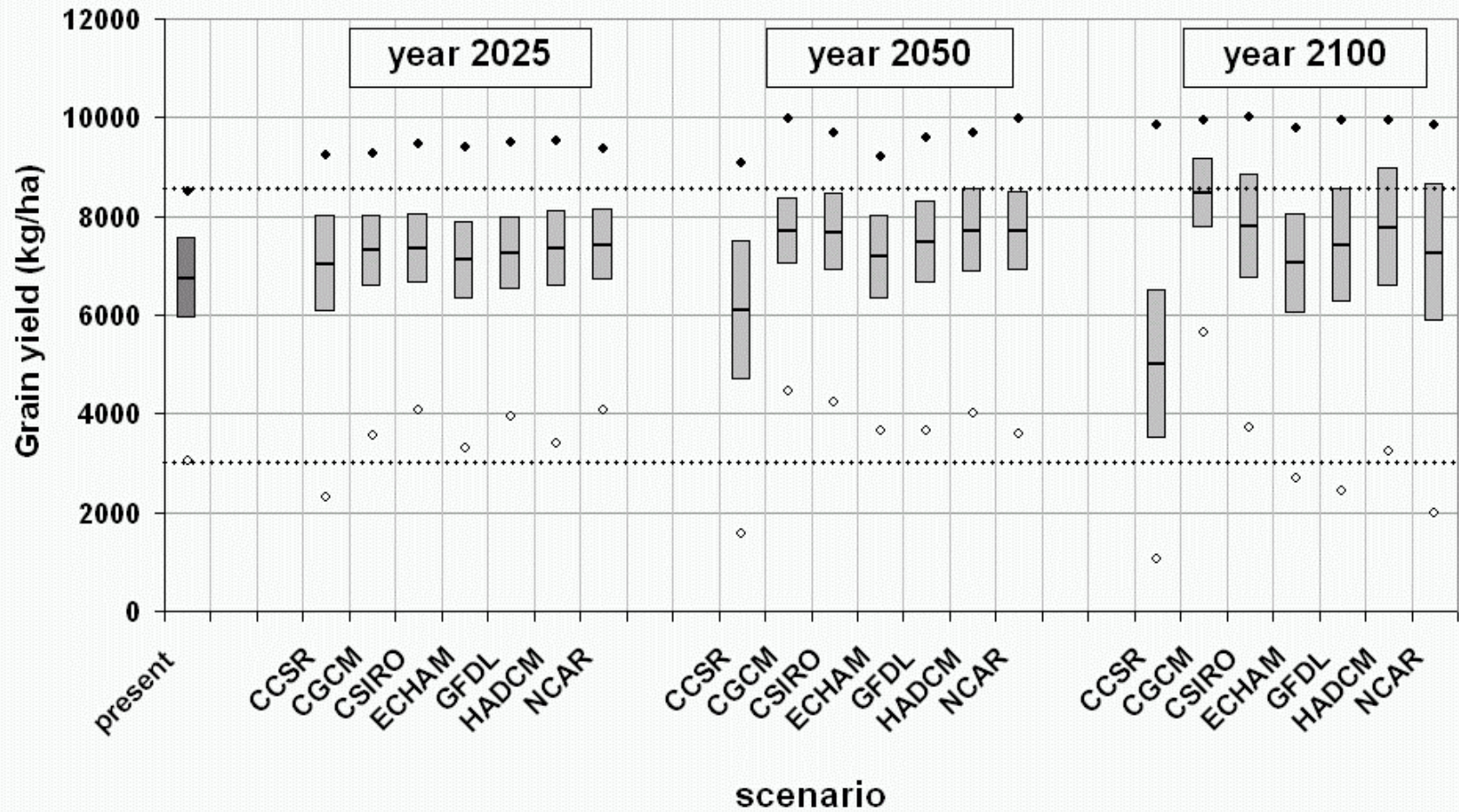
climate change scenarios developed for this study:

- 7 GCMs + AVG scenario
 - 2 values of ΔTG (estimated by MAGICC):
 - “low” estimate : SRES-B1 + low clim. sensitivity (1.5 K)
 - “high” scenario: SRES-A2 + high clim.sensitivity (4.5 K)
- + 3 time horizons (2025, 2050, 2100)

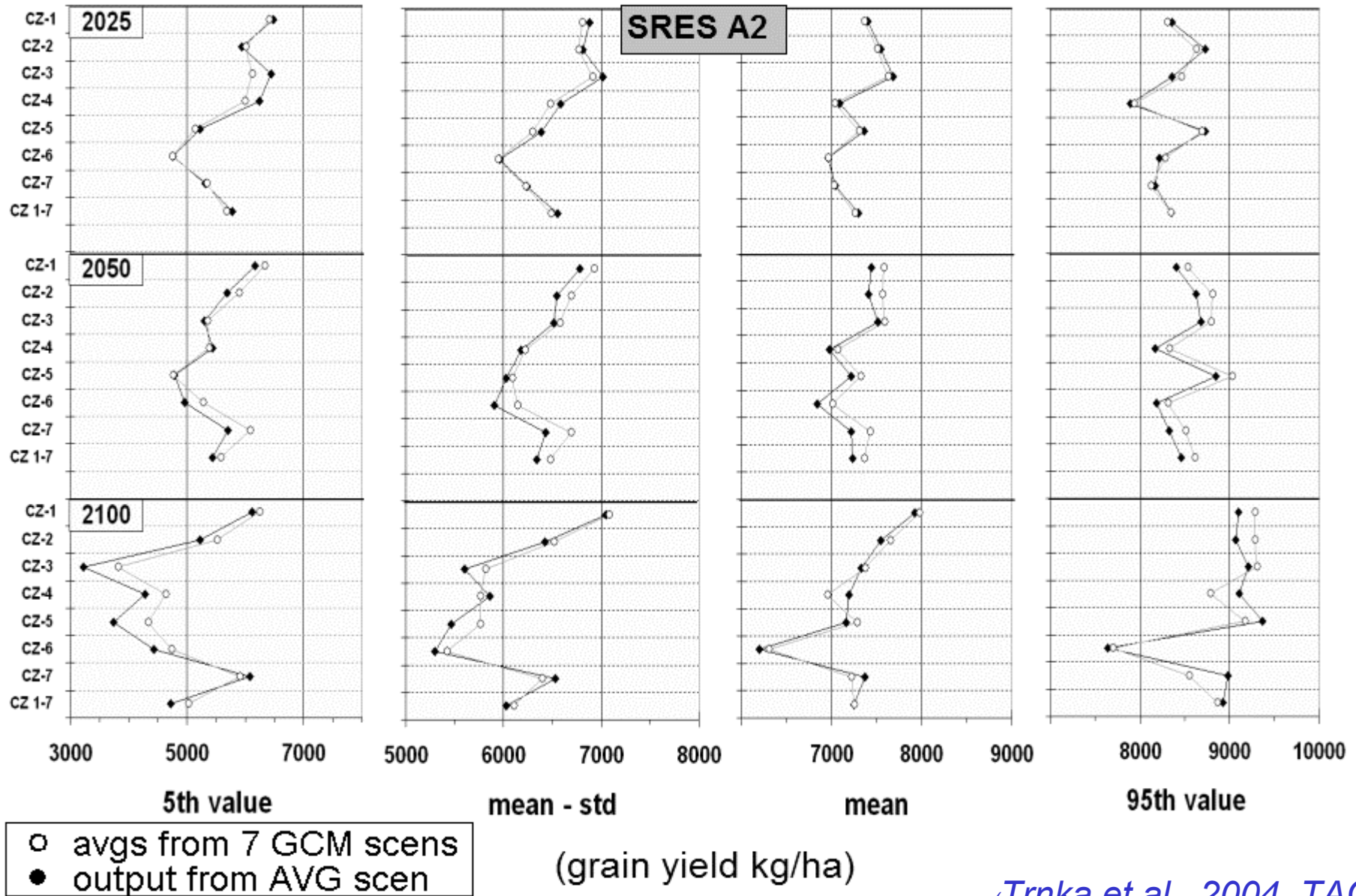
impact of climate change on winter wheat yields (SRES-B1) (stressed yields; combined effect of increased CO₂)



impact of climate change on winter wheat yields (SRES-A2) (stressed yields; combined effect of increased CO₂)



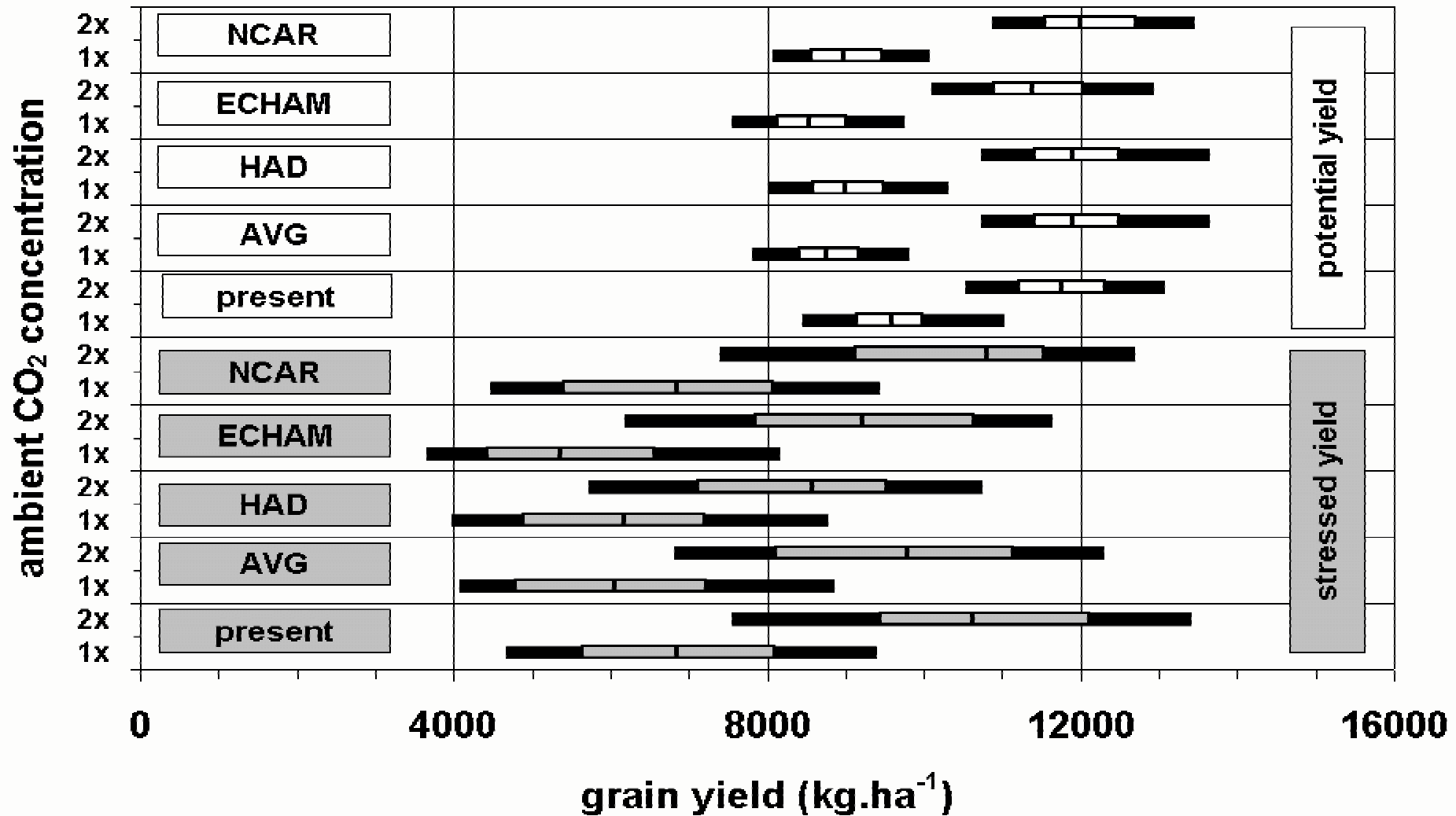
results from AVG(7GCMs) scenario vs. average results from 7 scenarios



Climate Change Impacts and Adaptation Strategies in **Spring Barley** Production in the Czech Republic (*Trnka et al., 2004, Clim. Change*)

- methodology: representative year + 99y synthetic series; CERES-Barley (calibrated and validated using site specific data!); stressed + potential yields simulated
- 3 experimental regions (in Czechia)
- 4 climate change scenarios: ECHAM4, HadCM2, NCAR-DOE, AVG
 - (standardised scenarios shown earlier were multiplied by $\Delta TG = 2.33$ K (2xCO₂ climate, IS92a scenario))
- experiments:
 - impacts of climate change on crop yields (direct / indirect /combined effects of CO₂ rise on stressed and potential yields)
 - adaptation options: planting date, cultivar with different length of vegetation
 - sensitivity analysis (initial soil water content)

Climate Change Impacts on Spring Barley Yields



!!! Positive direct effect of doubled CO₂ dominates over negative effect of changed weather. The stressed yields would increase by 13–52% under 2 × CO₂ conditions!!!

Conclusions + plans (wishes) for future

- **methodology provides nice results, but many uncertainties**
 - climate change scenario
 - reliability of crop models in changed climate conditions
 - adaptation options
- **weather generator**
 - might be further improved, but even the present version shows good applicability (see results of the indirect validation)
 - free for your use! (*.... although very unfriendly*)
- **further tasks:**
 - further improvements
 - make the generator more user-friendly
 - new climate change scenarios
 - crop modelling:
 - other crop models,
 - spatial analysis,
 - more intensive application in hydrology
 - conditioned by developing multi-site generator

www.ufa.cas.cz/crop/crop.htm

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