Met&Roll Weather Generator and its Use in Crop Growth Modelling

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***** Vienna, 23 November 2005 (Agridema) *****

outline

- **Introduction**
- **history of Met&Roll**
- **underlying model of Met&Roll**
  - first version (slightly modified WGEN)
  - focus on improvements
- **validation of Met&Roll**
  - direct validation
  - indirect validation
    - + crop modelling
    - + hydrological modelling
- **application of the weather generator (as implemented in PERUN system):**
  - climate change impact studies
  - probabilistic crop yield forecasting
- **present and near future activity:** **caliM&Ro project**
- **conclusion**

relevant papers and conference presentations may be found on web:
www.ufa.cas.cz/dub/dub.htm

Met&Roll: history

- **1995:** first version (based on WGEN)
- ... ... improvements of the model
- ... ... application of Met&Roll in crop modelling (with colleagues from Mendel University of Agriculture and Forestry) and hydrological modelling (various projects)
- **2001:** Met&Roll implemented in PERUN system (crop yield forecasting, climate change impacts)
- **2005:** caliM&Ro project starts (interpolation of WG, further improvements of the model, development of the user-friendly environment)

stochastic daily weather generator Met&Roll - model

basic version ~ WGEN (Richardson, 1981)

4 daily variables:

PREC: - occurrence ~ Markov chain (1st order; parameters: $P1, P01$)

$$P(RAIN > 0) = \begin{cases} P01 & \text{if } RAIN(t-1) = 0 \\ P11 & \text{if } RAIN(t-1) = 1 \end{cases}$$

- amount ~ Gamma distribution (parameters: $a, ß$ /~ shape, scale/)

SRAD, TMAX, TMIN: standardised deviations from their mean annual cycle are modelled using AR(1):

$$\mathbf{X}^*(t) = \mathbb{A}\mathbf{X}^*(t-1) + \mathbb{B}\mathbf{e}(t)$$

- parameters (P1, P01, a, ß, avg(X_i), std(X_i), A, B) are assumed to vary during the year

- avg(X_i) and std(X_i) are determined separately for wet and dry days

stochastic daily weather generator Met&Roll - validation

2 approaches to WG validation:

1) direct validation

2) indirect validation

direct validation of the weather generator

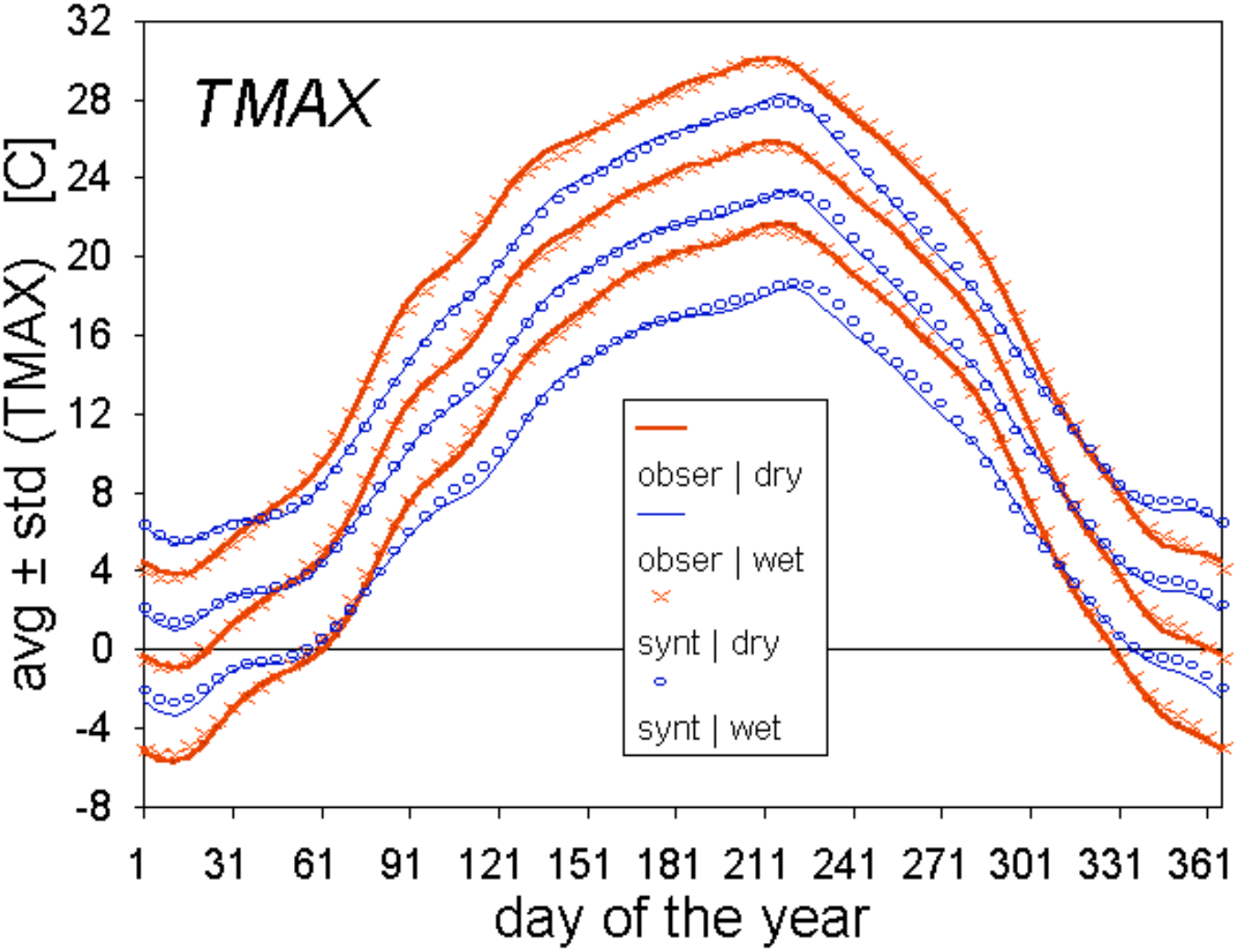
= synthetic weather series *vs.* **observed weather series**

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

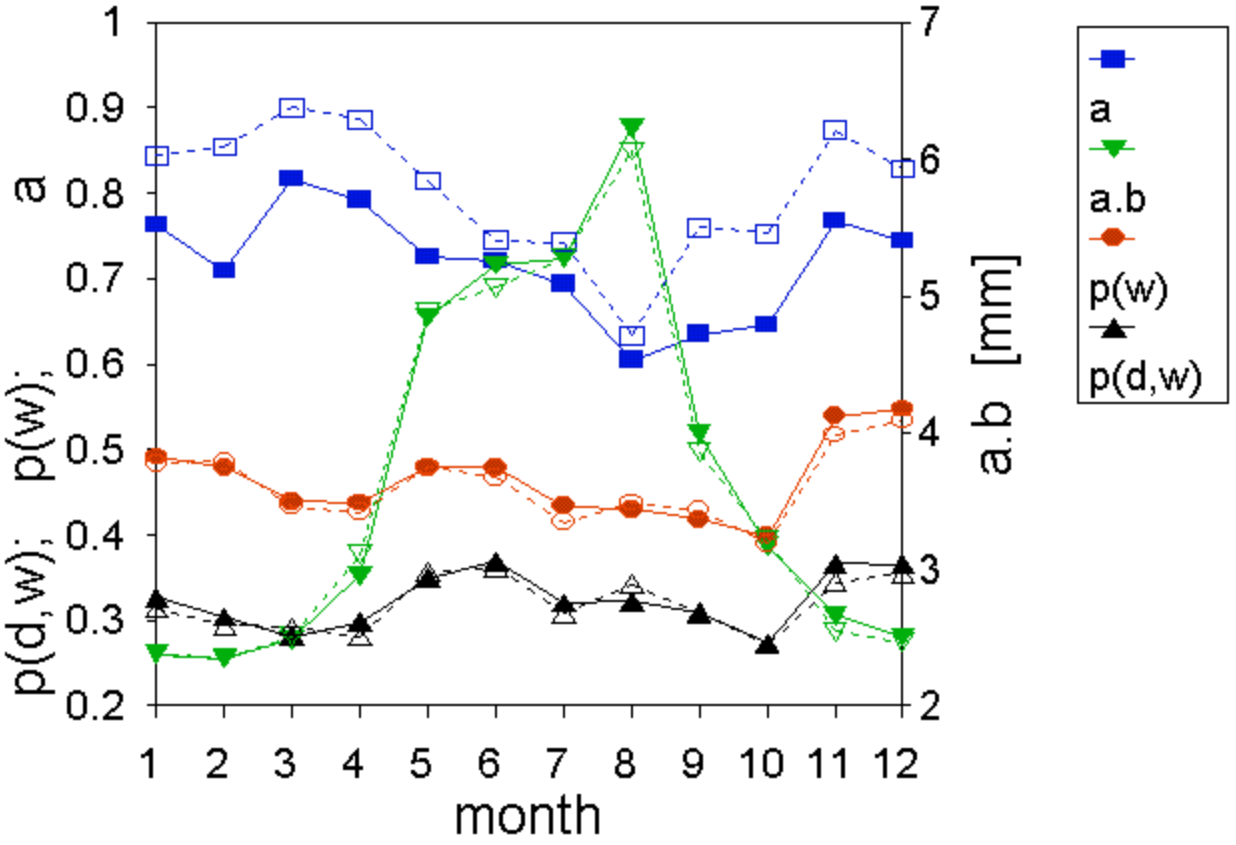
direct validation of WG was made in terms of:

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

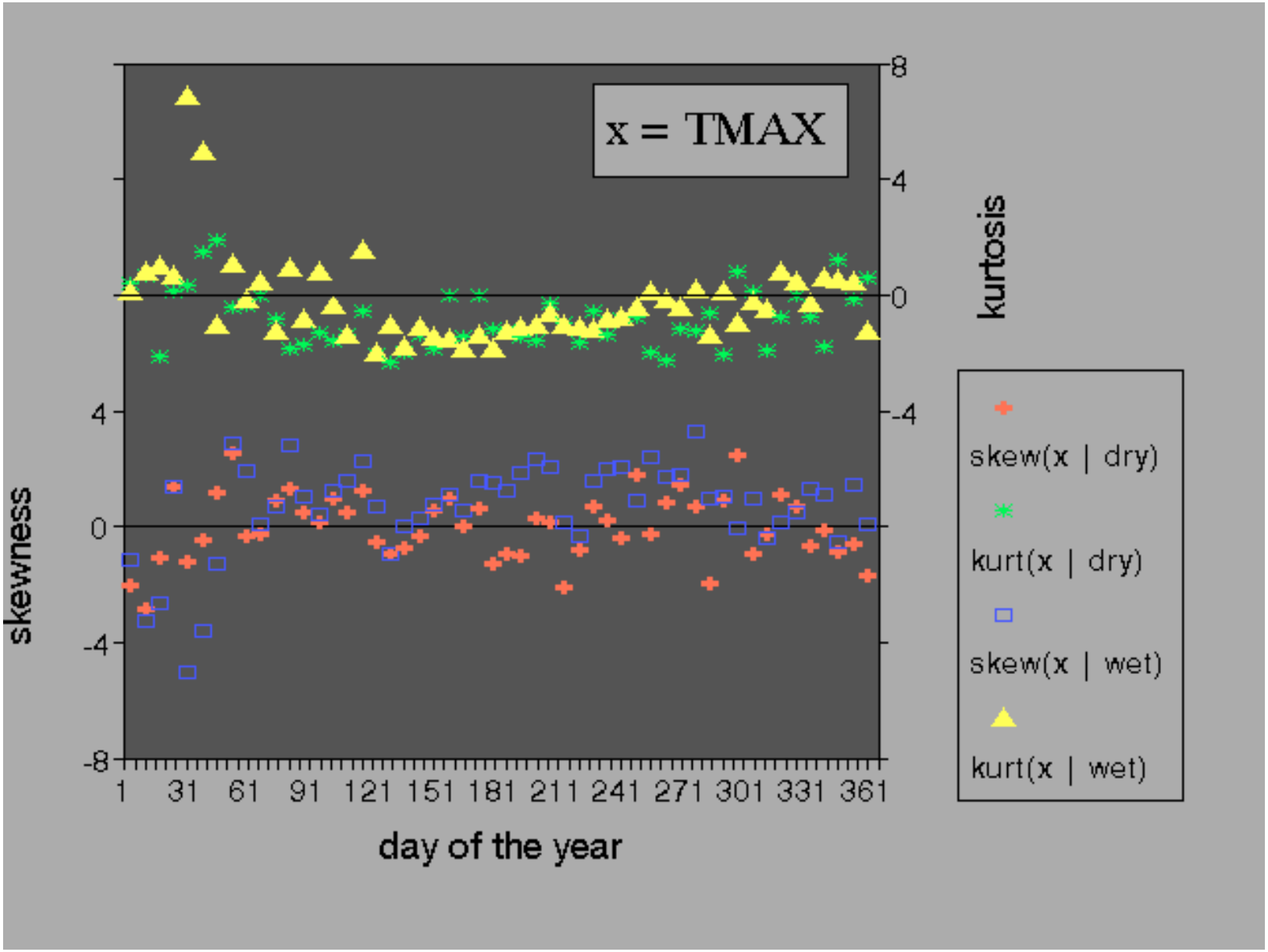
validation of Met&Roll: annual cycle of avg ± std (TMAX)



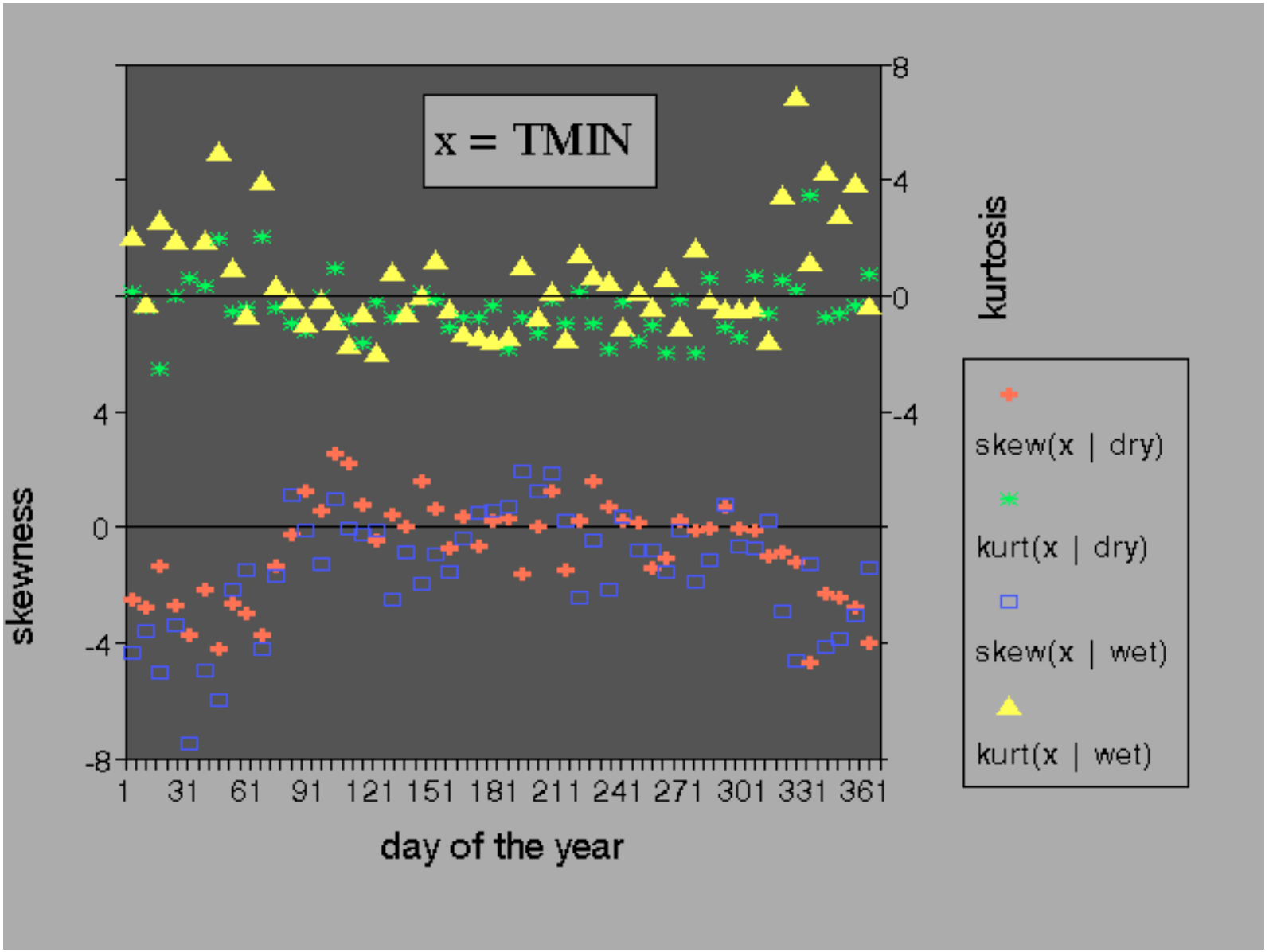
validation of Met&Roll: parameters of precipitation model



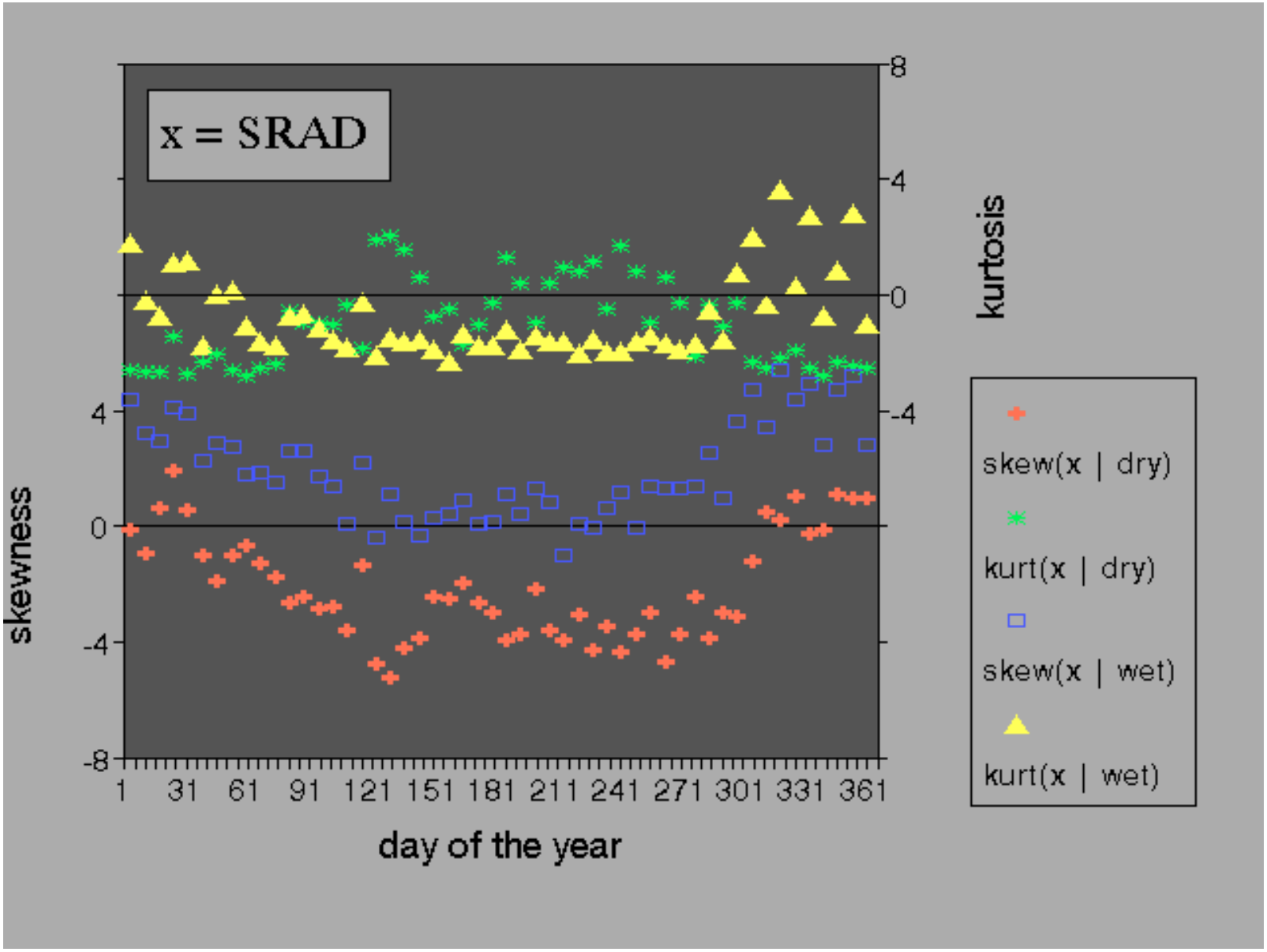
validation of Met&Roll: skewness and kurtosis of TMAX



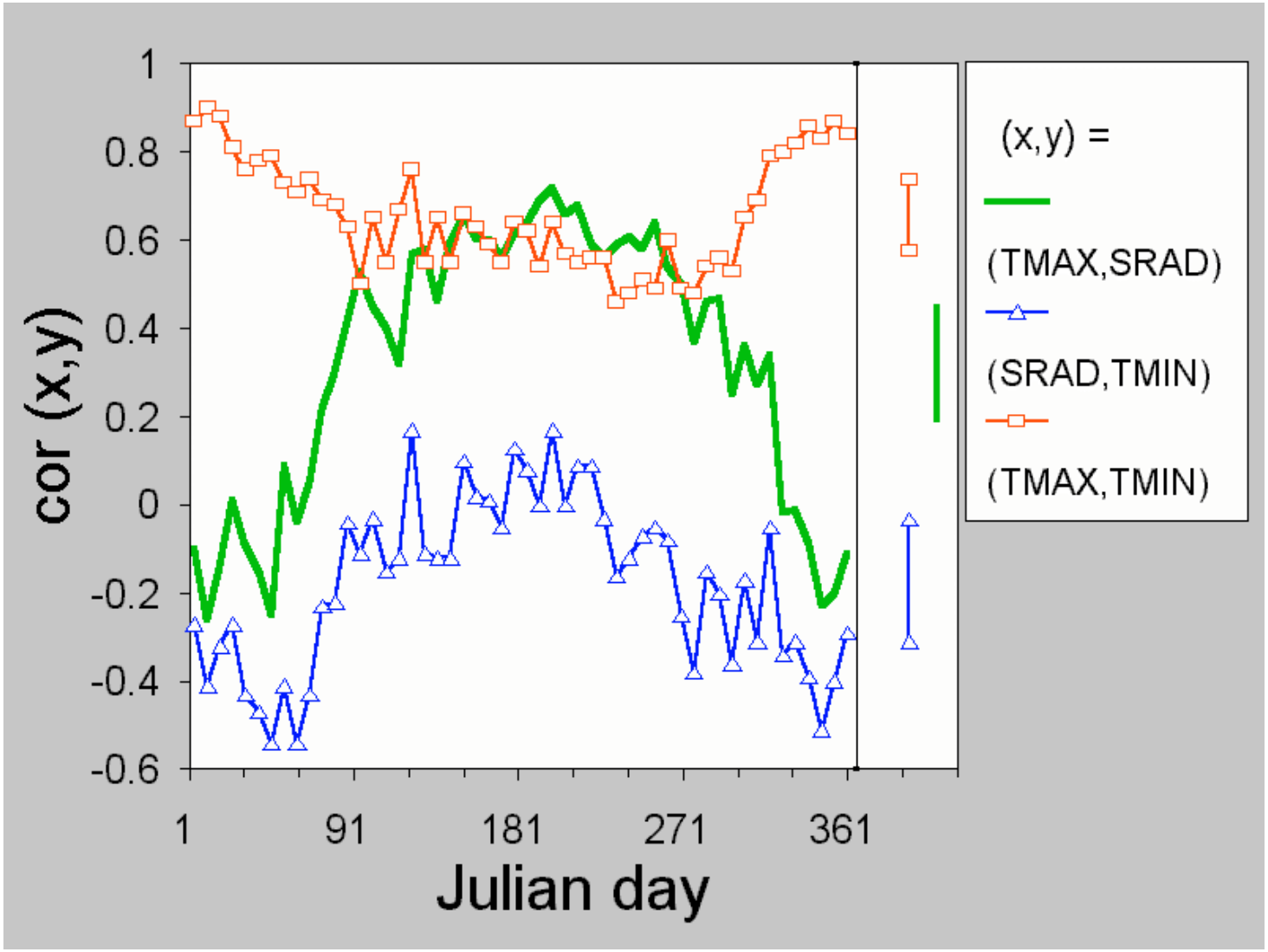
validation of Met&Roll: skewness and kurtosis of TMIN



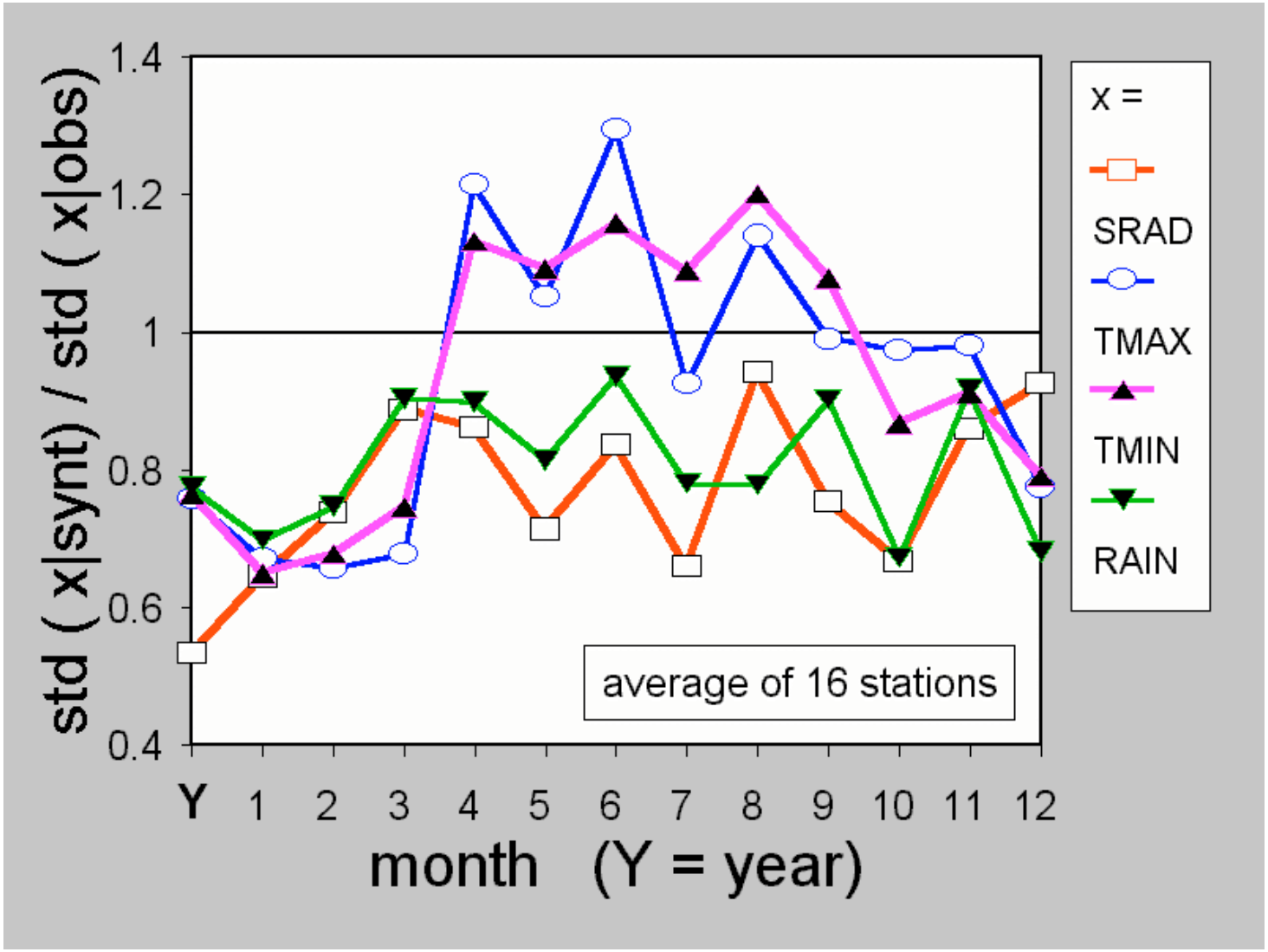
validation of Met&Roll: skewness and kurtosis of SRAD



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



validation of Met&Roll: variability of monthly means



direct validation of WG - results

- **Correlations and lag-1 correlations** among SRAD, TMAX and TMIN vary throughout the year
- **Variability of monthly means** is underestimated
- **Distribution of the length of dry periods** is not satisfactorily modelled by the first-order Markov chain
- **distributions** of SRAD, TMAX, TMIN differs **from normal**

® **improvements of Met&Roll suggested**

improvements of Met&Roll

1) **annual cycle of lag-0 and lag-1 correlations** in AR(1) implemented

2) **higher order Markov chain** (r = 1, 2, 3)

3) coupled with **monthly AR-1 generator** !!!

(improves reproduction of variability of monthly means)

+

+ **additional variables** may be added by nearest neighbours resampling

[DBZ, 2004]

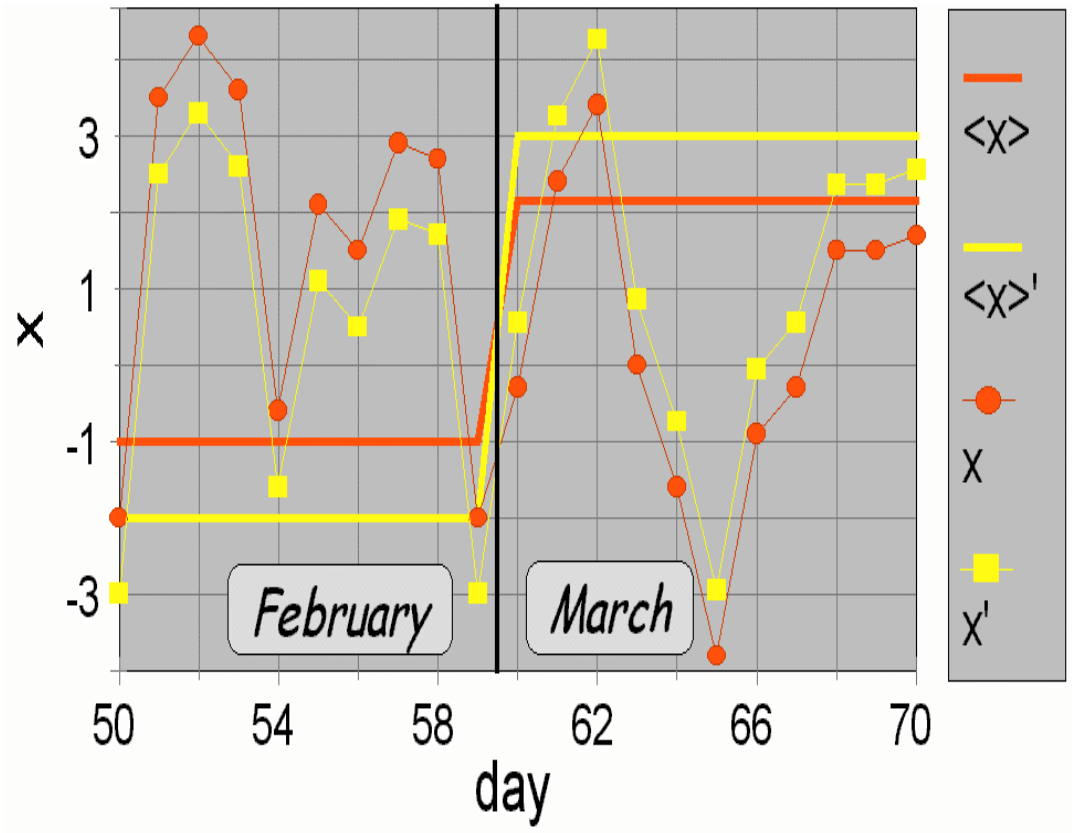
link with monthly generator

1. Daily series (DS) is generated

2. Monthly series (MS) is generated

3. Monthly means from DS are calculated and compared MS

4. Increments are applied to DS so that they fit MS



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:

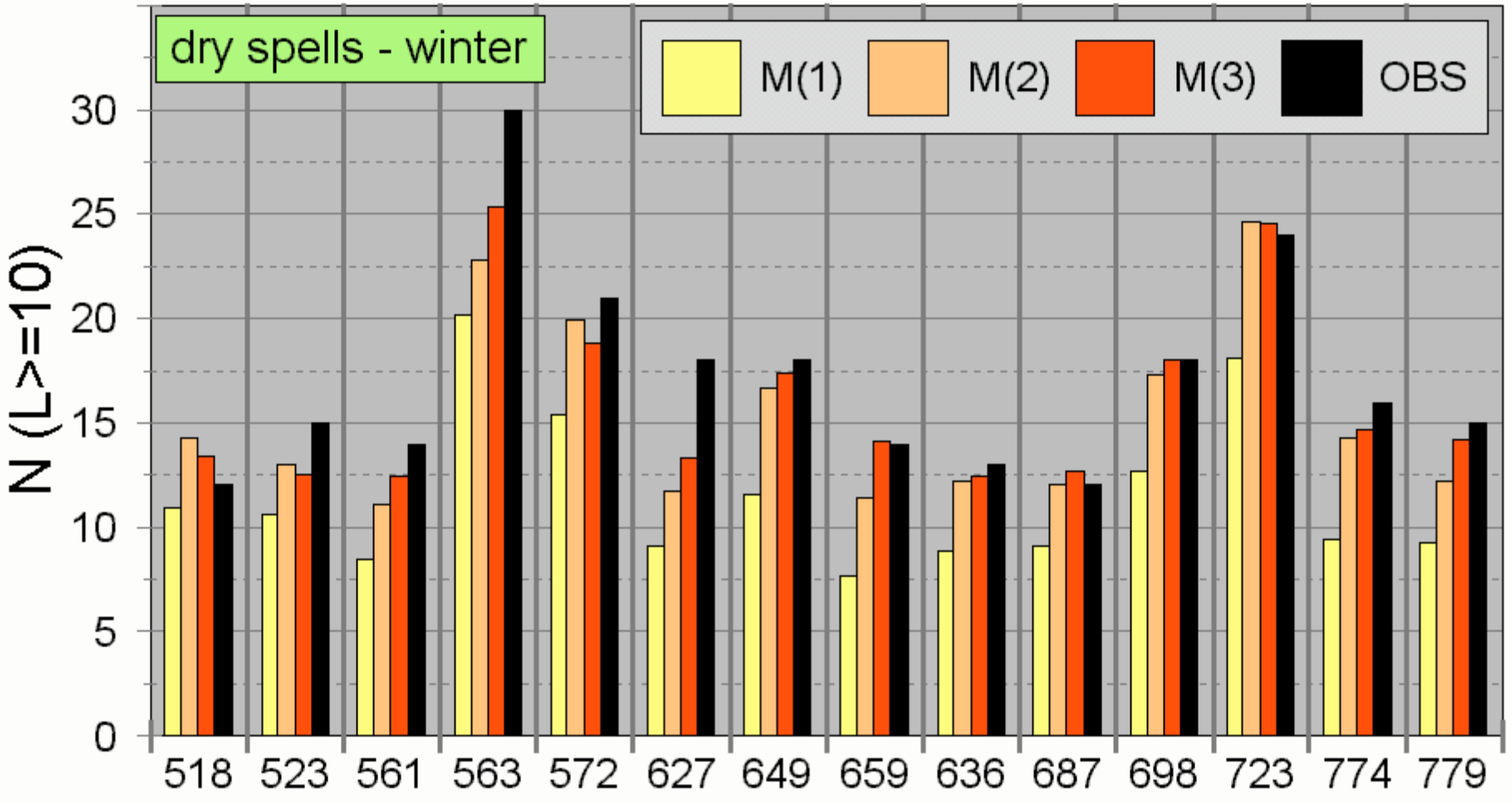
@DATE	SRAD	TMAX	TMIN	RAIN	VAPO	WIND
...						
xx001	1.6	1.3	-1.5	3.3	0.63	1.0
xx002	1.6	-0.8	-3.8	0.3	0.53	1.7
xx003	3.9	-2.3	-9.9	0.0	0.23	2.0
xx004	4.5	-2.3	-11.4	0.0	0.38	1.0
xx005	1.6	-6.1	-12.9	0.0	0.33	1.3
xx006	1.6	-1.8	-12.4	1.1	0.23	3.3
xx007	3.8	1.2	-2.3	0.0	0.52	4.7
xx008	1.7	-0.1	-4.3	0.0	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:

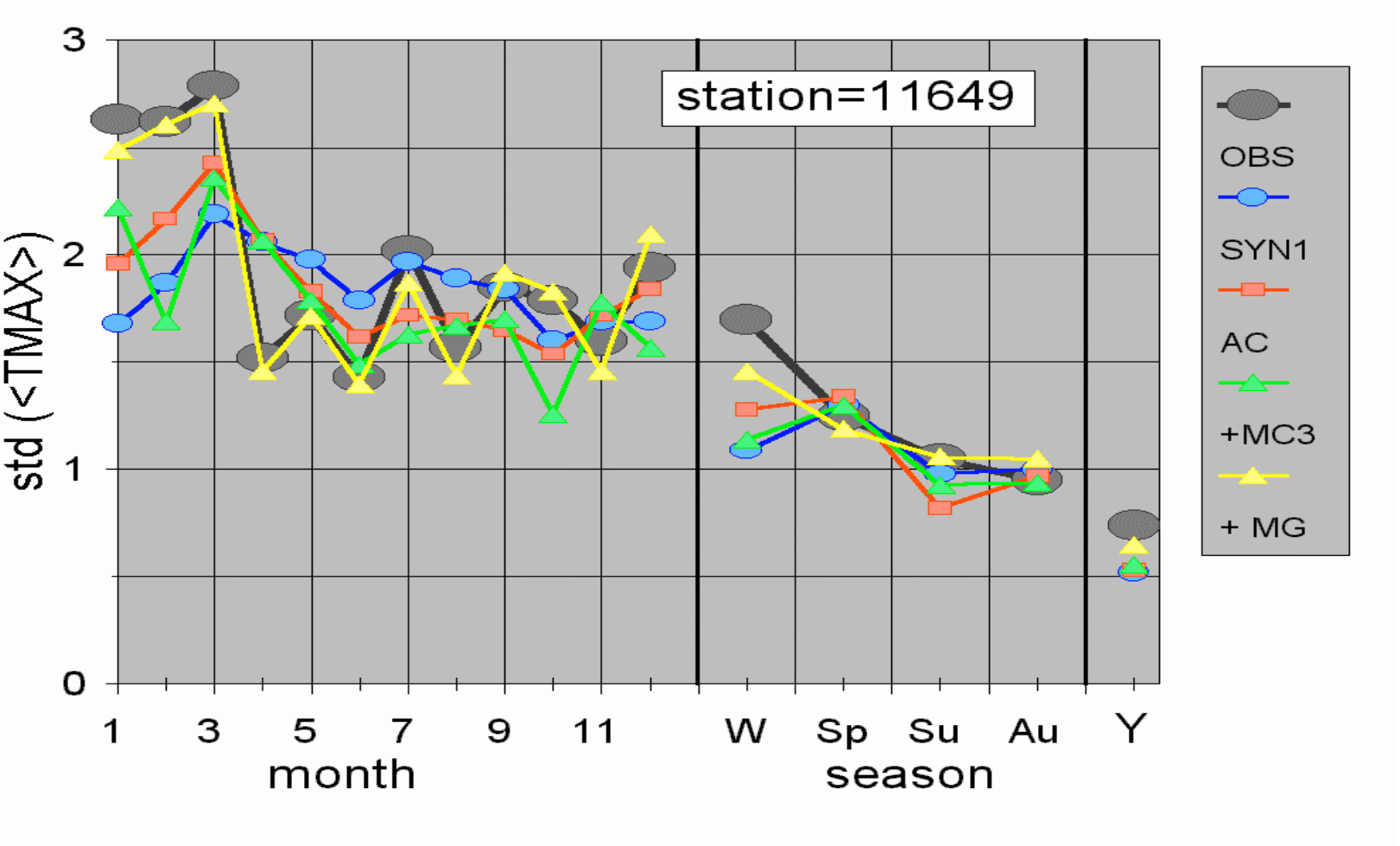
@DATE	SRAD	TMAX	TMIN	RAIN	VAPO	WIND
...						
99001	1.9	-2.7	-6.3	0.3	0.34	3.0
99002	2.1	-3.6	-3.7	0.7	0.28	3.0
99003	1.5	0.1	-1.3	2.4	0.61	3.0
99004	2.4	0.3	-2.7	0.6	0.57	3.0
99005	1.4	-1.4	-5.1	0.1	0.47	3.0
...						

nearest neighbours resampling

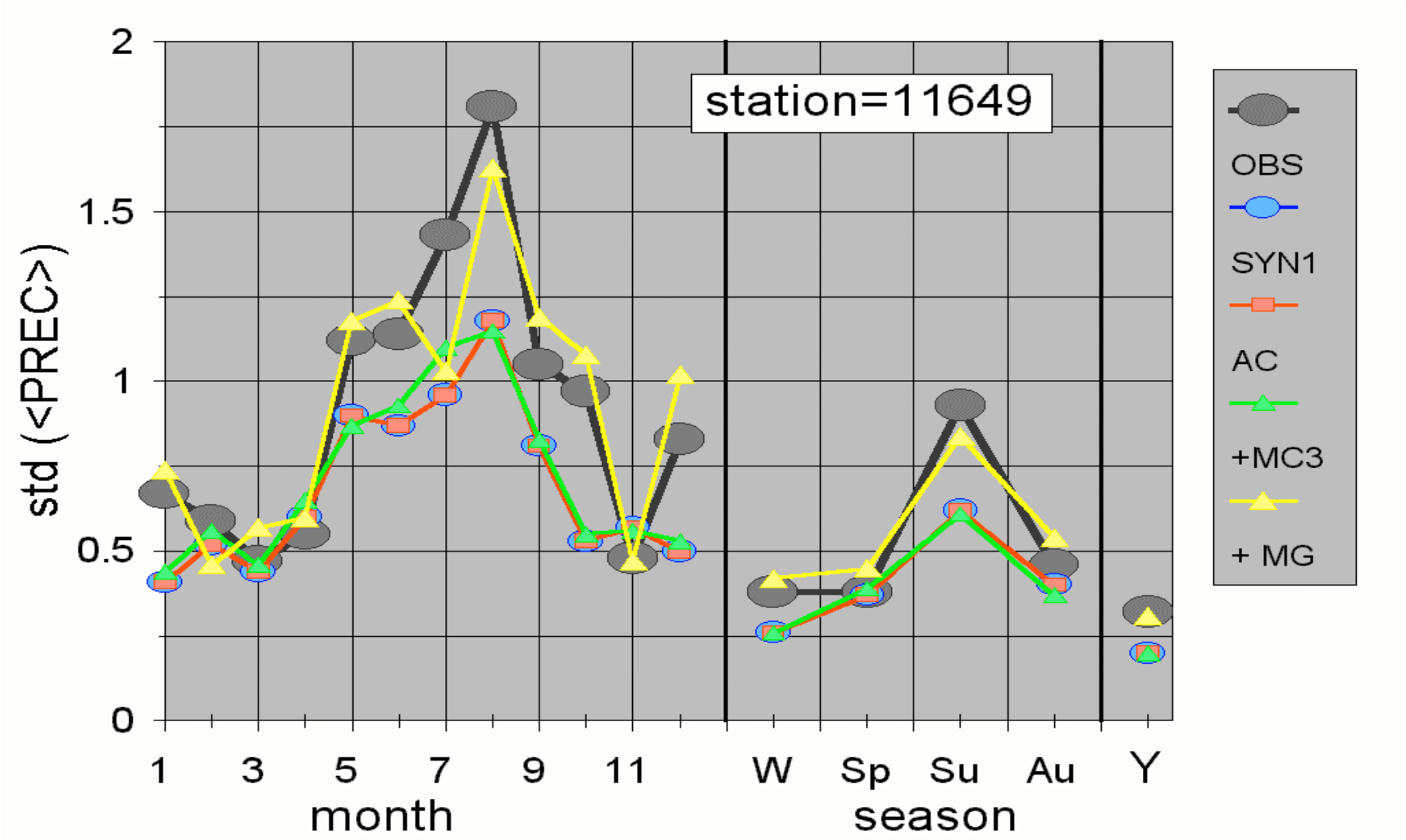
validation of Met&Roll: dry spells in winter (effect of Markov chain order)



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



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



indirect validation of the weather generator

= impact model fed by synthetic weather series

vs.

impact model fed by observed weather series

motivation: direct validation shows inaccuracies in reproducing stochastic structure of weather series.

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

[DBZ, 2004]

indirect validation of Met&Roll
a) using crop model

experiment:

- *crop / crop model:* winter wheat / CERES-Wheat
- 30-year simulations for 17 Czech stations

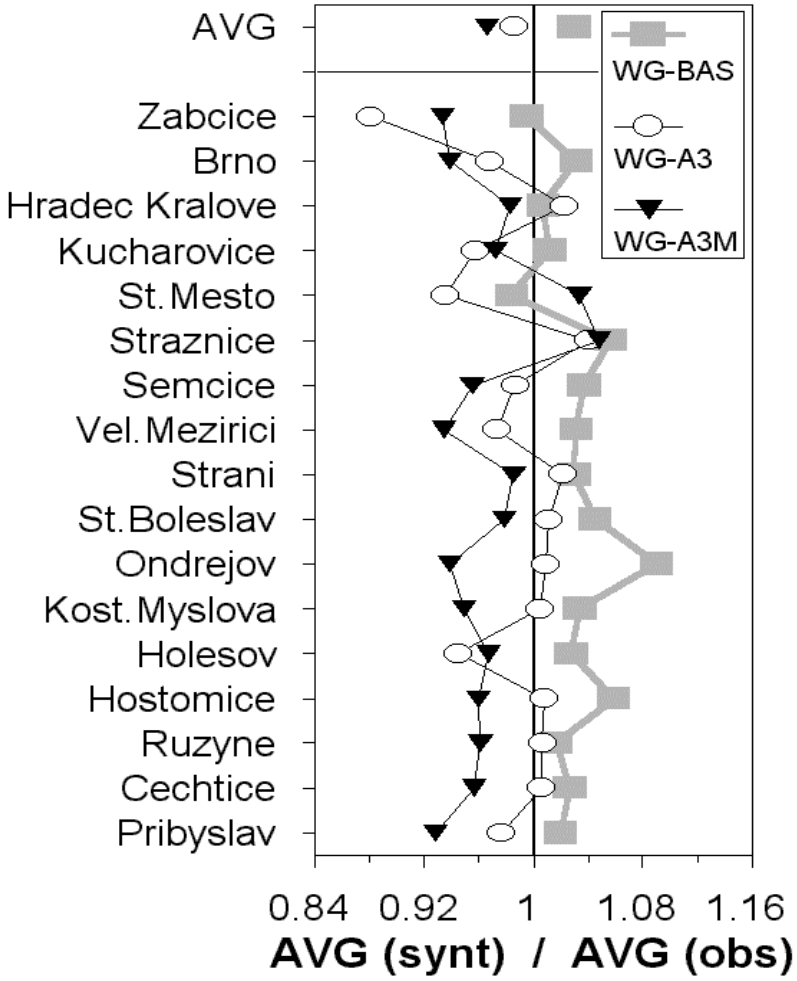
- *input weather data:* PREC, SRAD, TMAX, TMIN (daily)
  (30y observed vs. synthetic series)

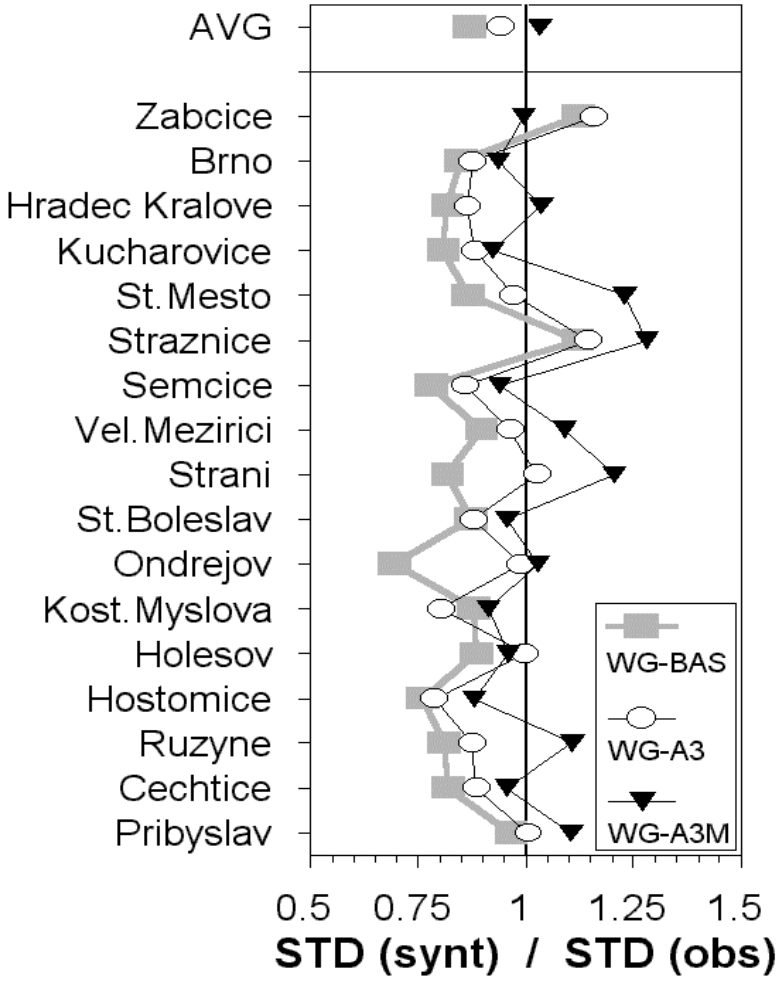
validation: avg, std, quantiles of the 29 grain wheat yields
[>> Figure]

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

indirect validation of Met&Roll using crop model

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





crop model = CERES-Wheat; 30-y simulations for 17 Czech stations;
WG-BAS: "basic" WG; **WG-A3:** improved WG; **WG-A3M:** "best" WG

[DBZ, 2004]

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

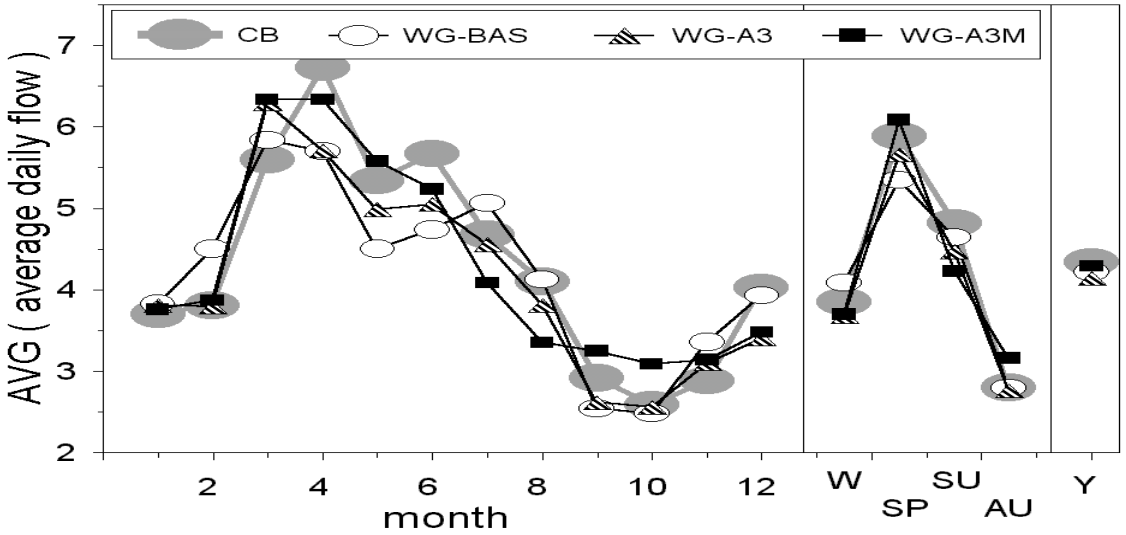
validation:

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

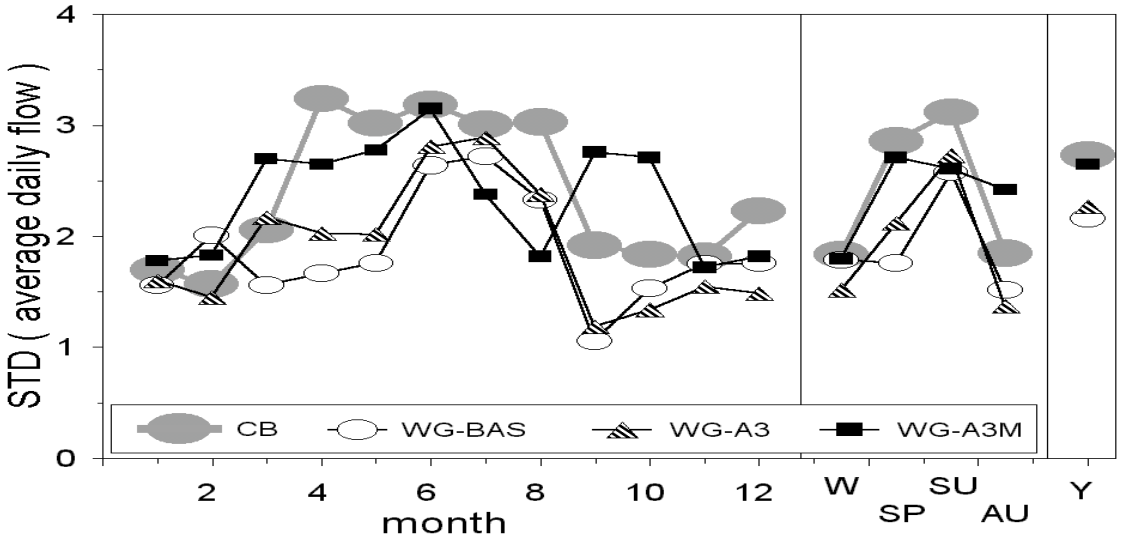
[DBZ, 2004, CC]

indirect validation of Met&Roll using rainfall-runoff model - average model daily streamflows

AVG



STD

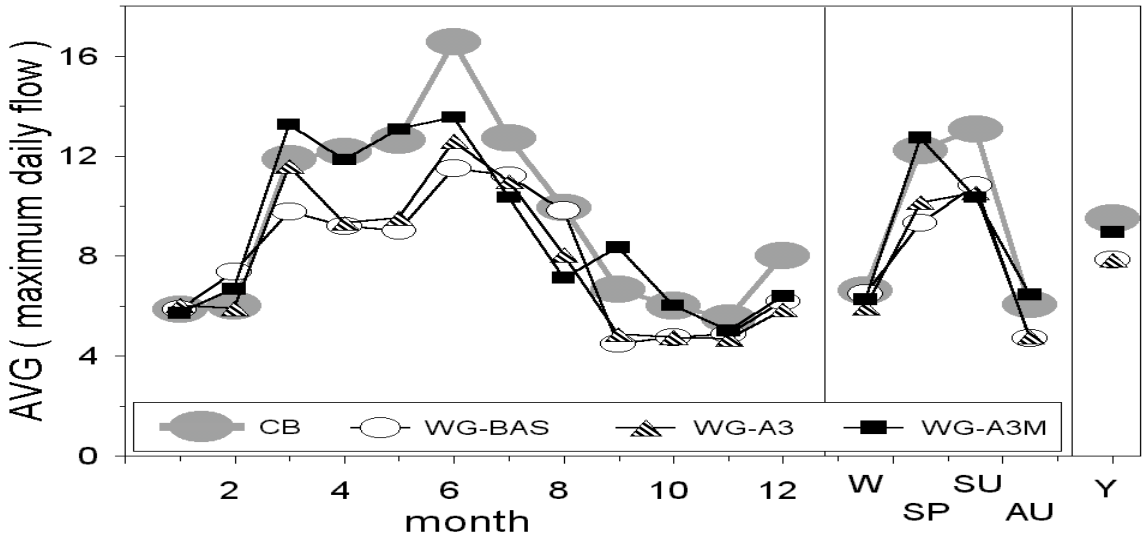


(model: SAC-SMA; 39-years)

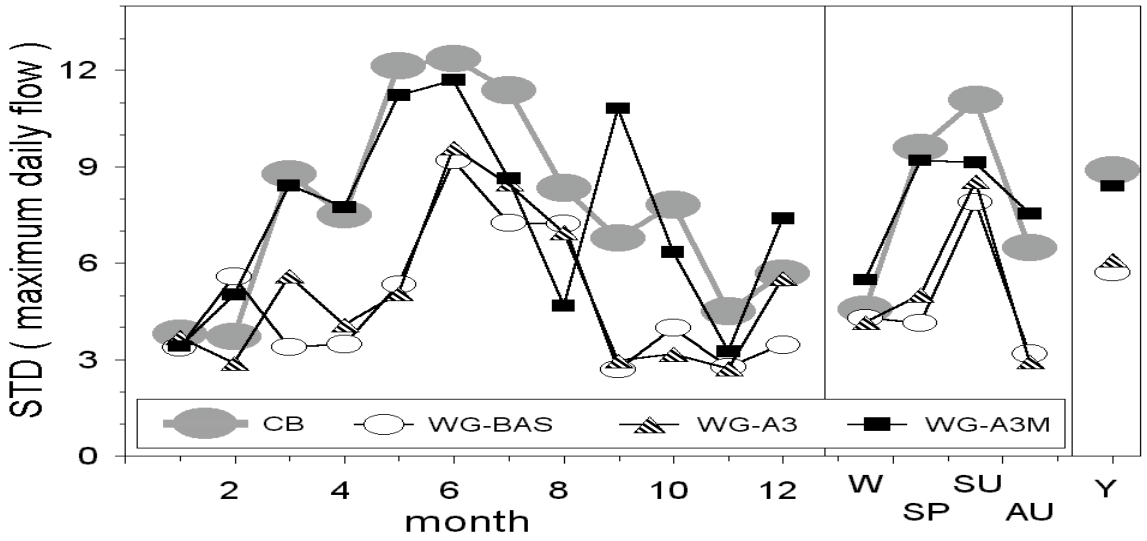
[DBZ, 2004, CC]

indirect validation of Met&Roll using rainfall-runoff model - monthly maxima of model daily streamflows

AVG



STD



(model: SAC-SMA; 39-years)

[DBZ, 2004, CC]

Indirect validation of Met&Roll using rainfall-runoff model

Table: The fit of the AVGs and STDs of monthly streamflow characteristics simulated using the synthetic weather series vs observed weather series.

WG-BAS: basic version

WG-A3M: A = annual cycle of AR matrices
3 = 3rd order Markov chain
M = linked with monthly generator

	Version of the weather generator				
	WG-BAS *m/s/y*	WG-A *m/s/y*	WG-A3 *m/s/y*	WG-AM *m/s/y*	WG-A3M *m/s/y*
(a) Average monthly streamflow:					
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
(b) Maximum monthly streamflow:					
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

[DBZ, 2004, *CC*]

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

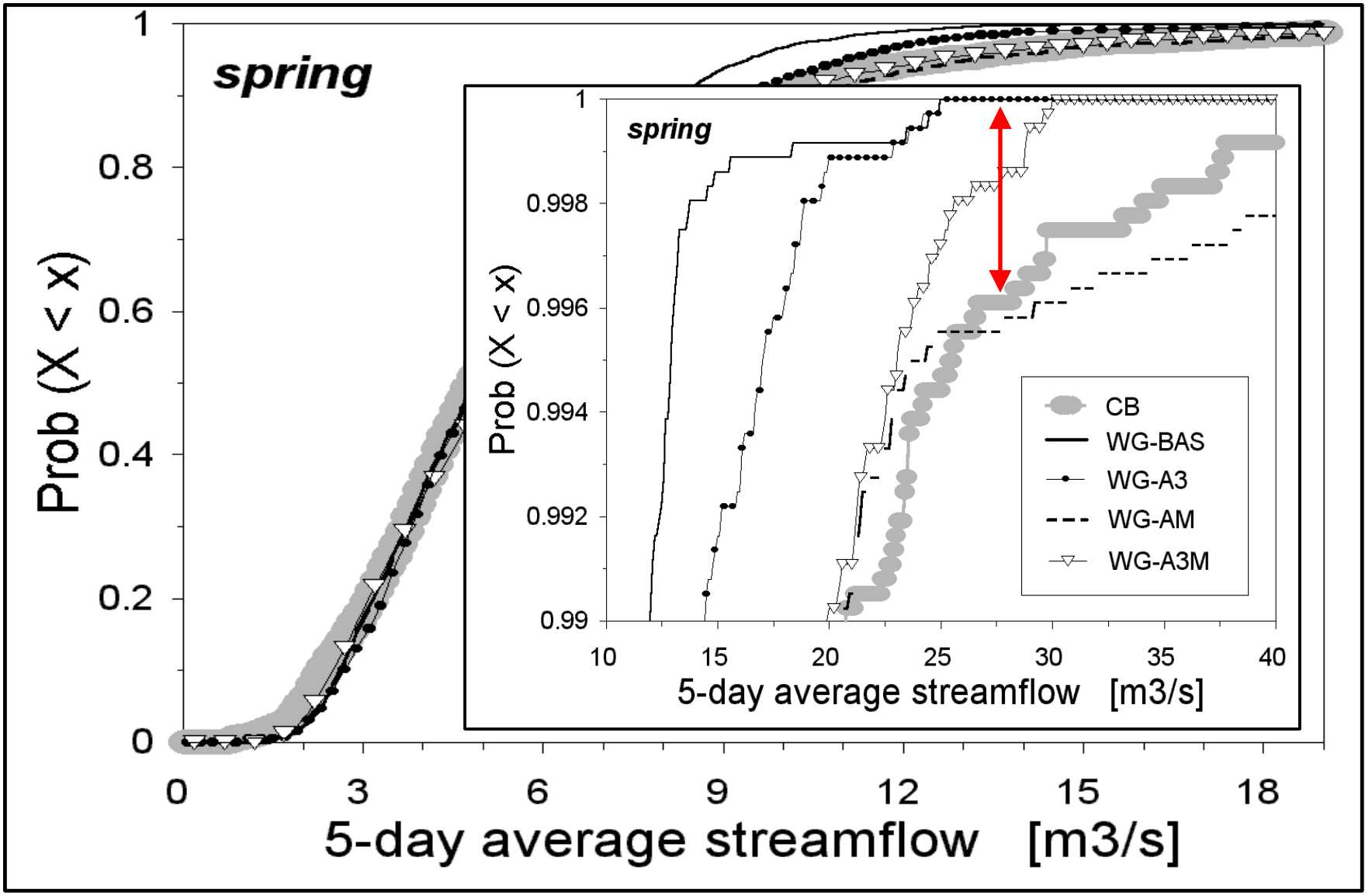


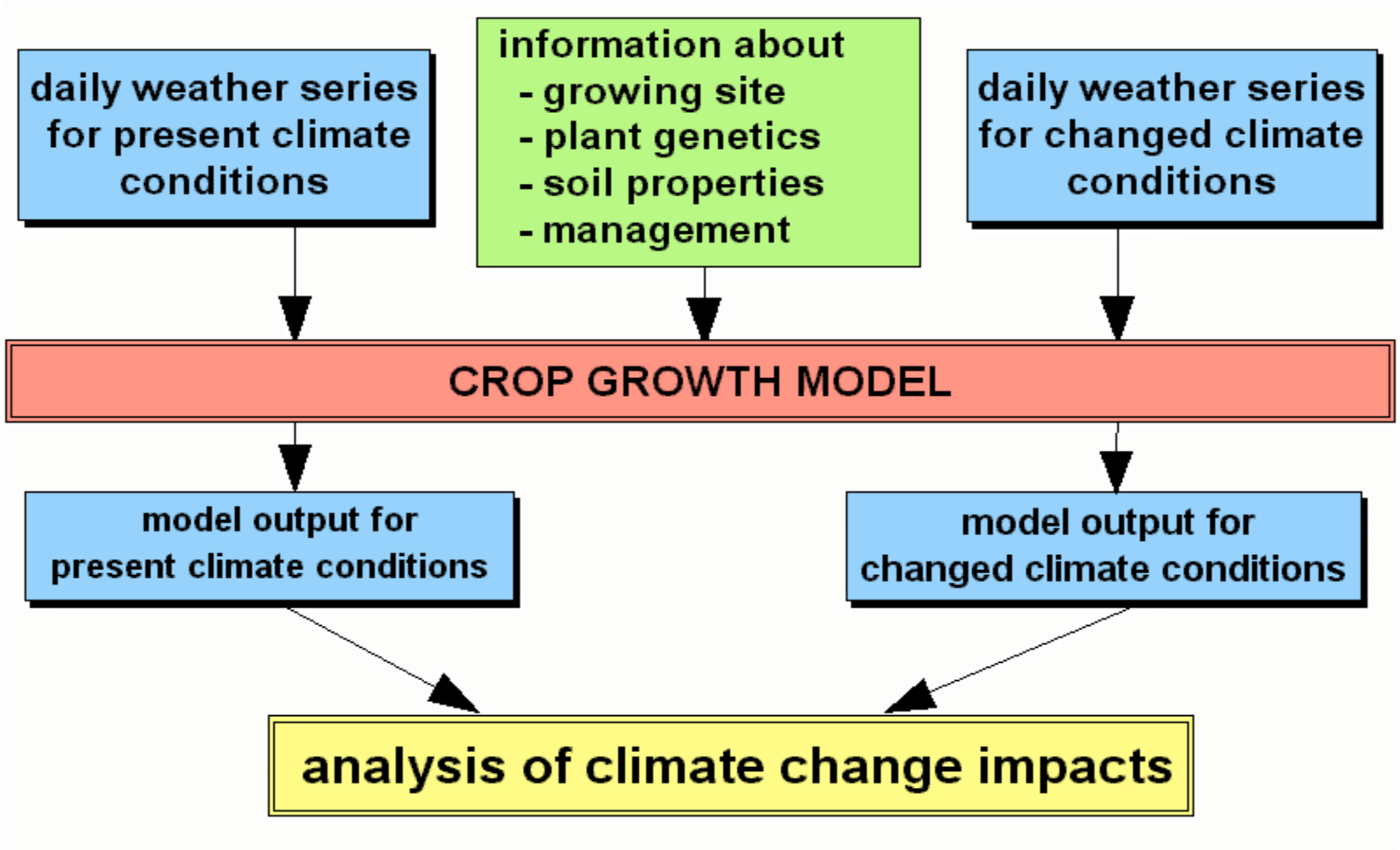
Fig. Probability distribution of 5-day average streamflow in spring simulated by SAC-SMA model with observed weather series (CB) and synthetic weather series [DBZ, 2004, *CC*]

Application of Met&Roll in assessing impacts of climate change on crop yields

(implemented in PERUN system)

climate change impacts - methodology

to PERUN



- multi-year simulation is made to assess mean and variability

PERUN

Two approaches to multi-year simulations (both implemented in PERUN !)

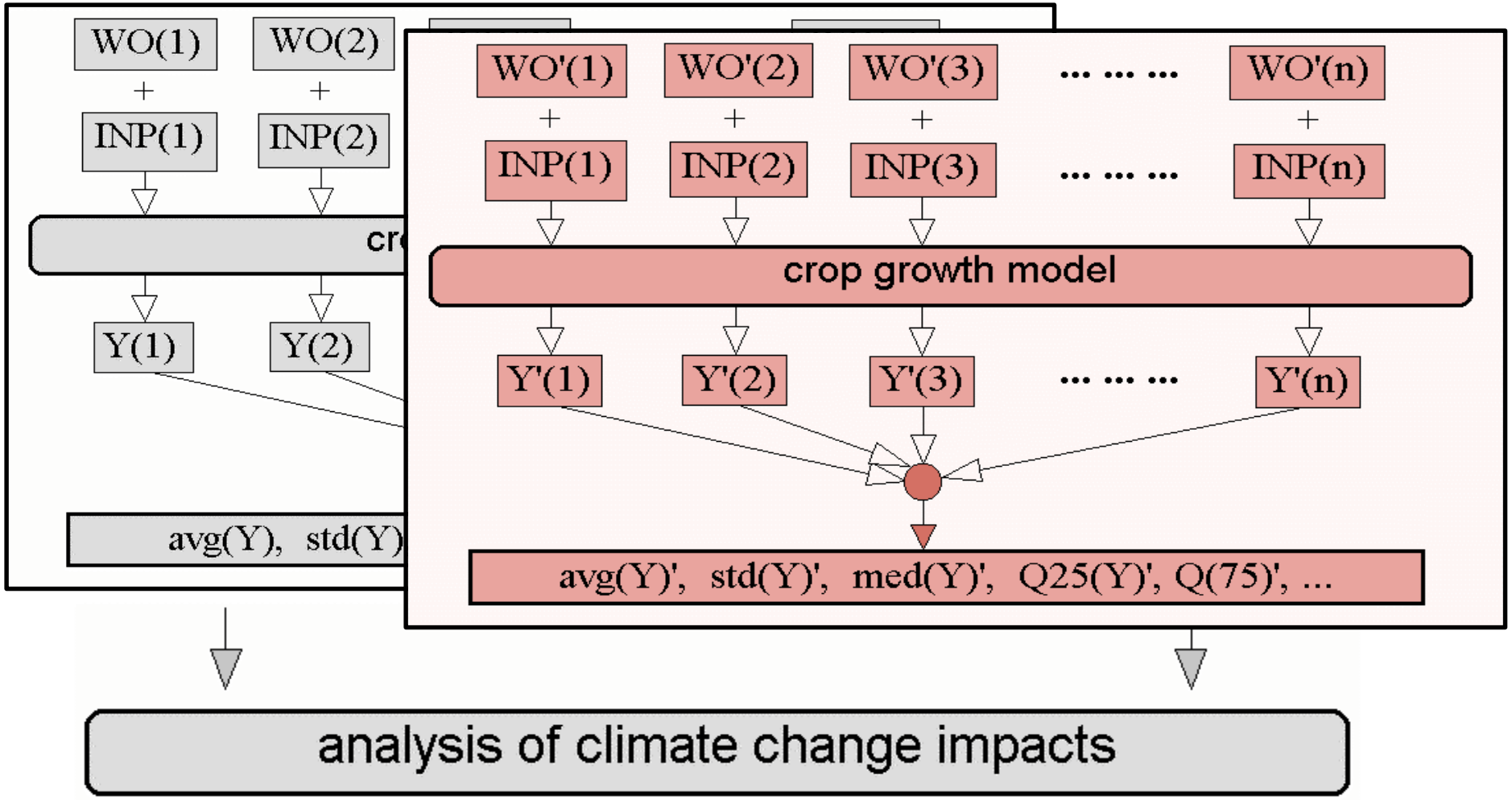
1) Direct Modification approach:

- **non-meteo input**: 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

a) *Direct Modification* (DM) approach



Legend:

WO´(i) = modified observed weather

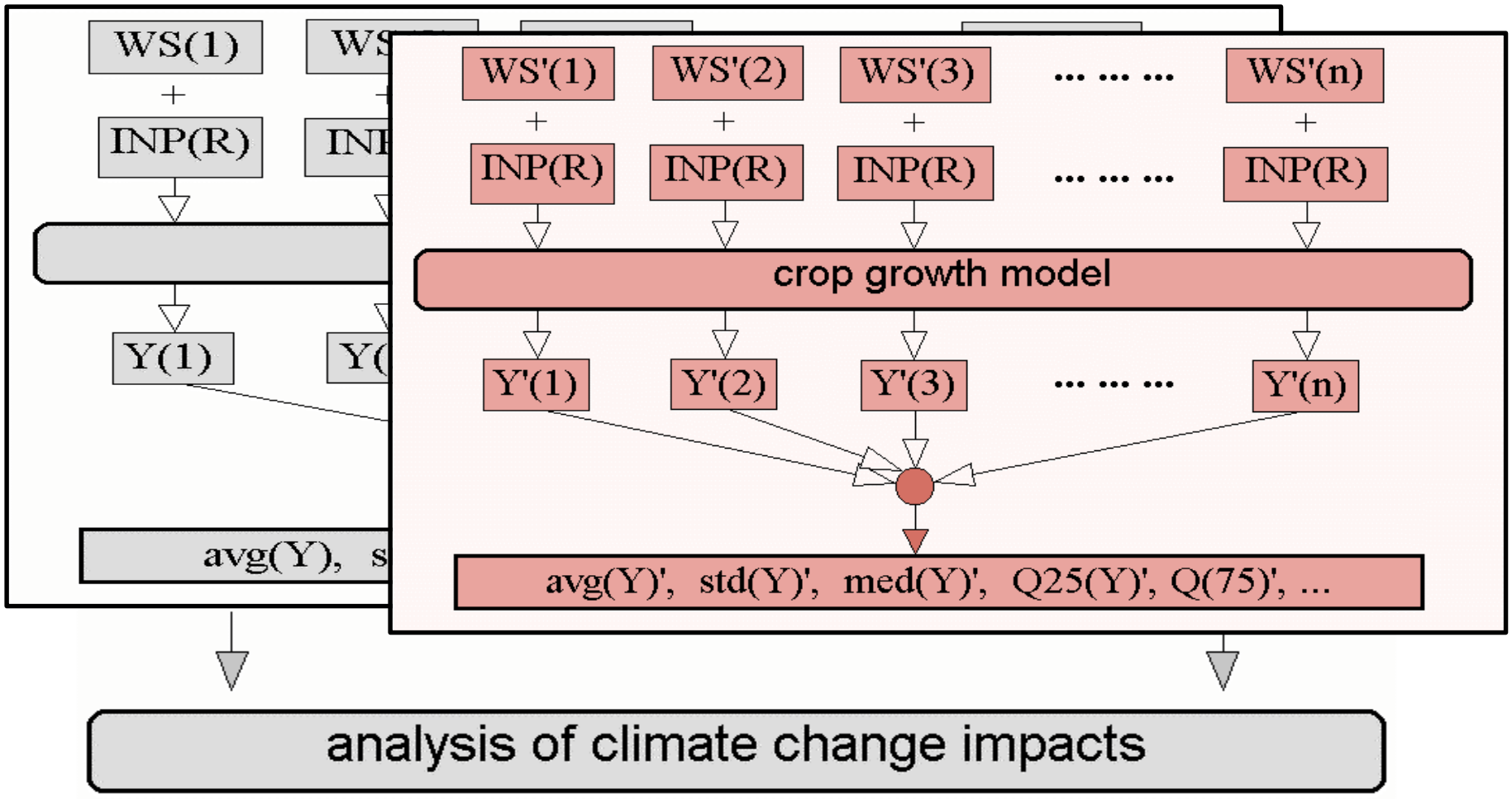
Y, Y´ (i) = crop yield

WO(i) = observed weather (present)

INP(i) = non-meteo input to crop model

i = index of the year

b) *Weather Generator* (WG) approach



Legend:

Y(i), Y´ (i) = crop yield

i = index of the year

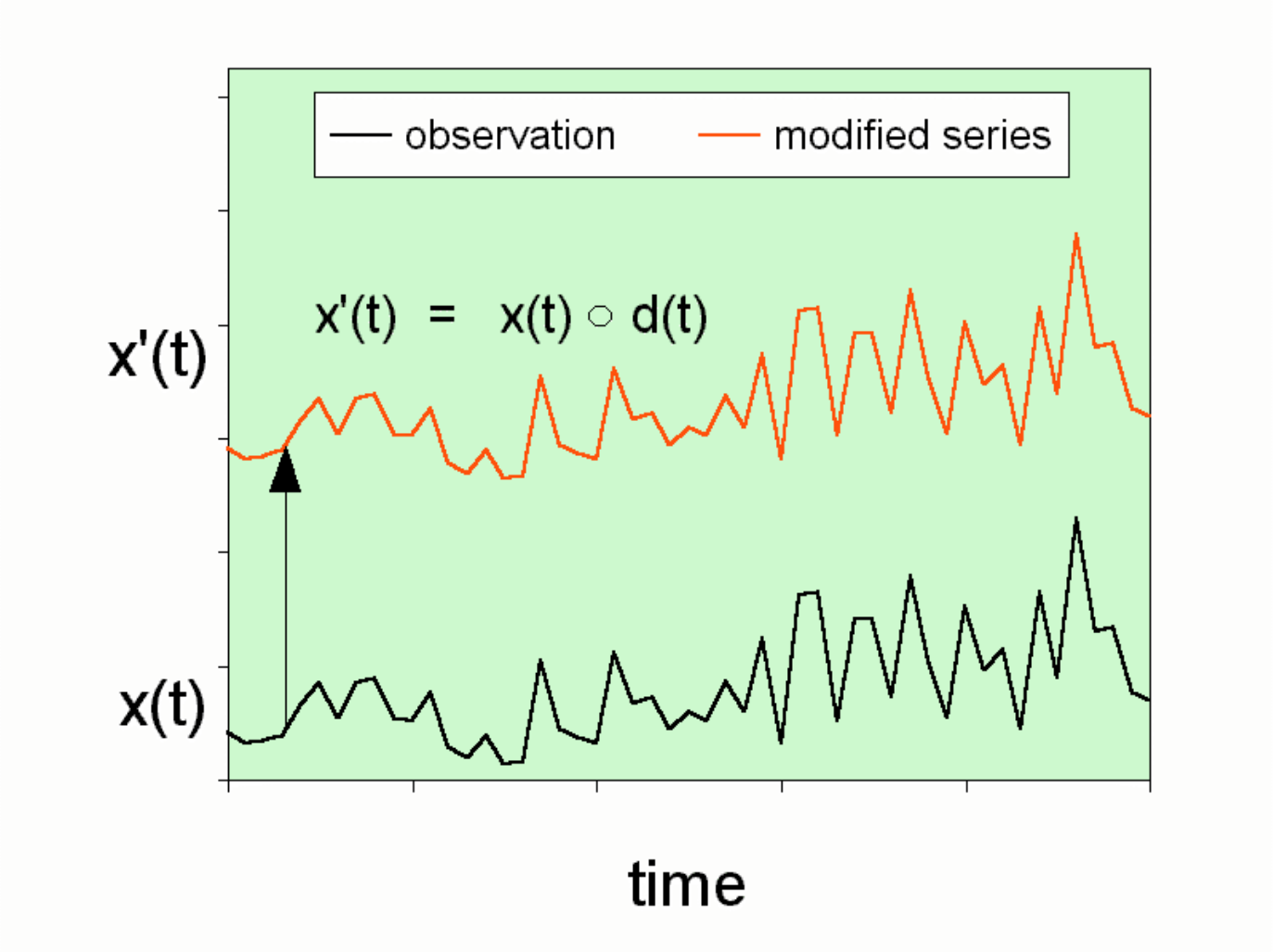
WS(i) = synthetic weather (present)

WS´(i) = synthetic weather (future)

INP(R) = non-meteo input based on a representative year

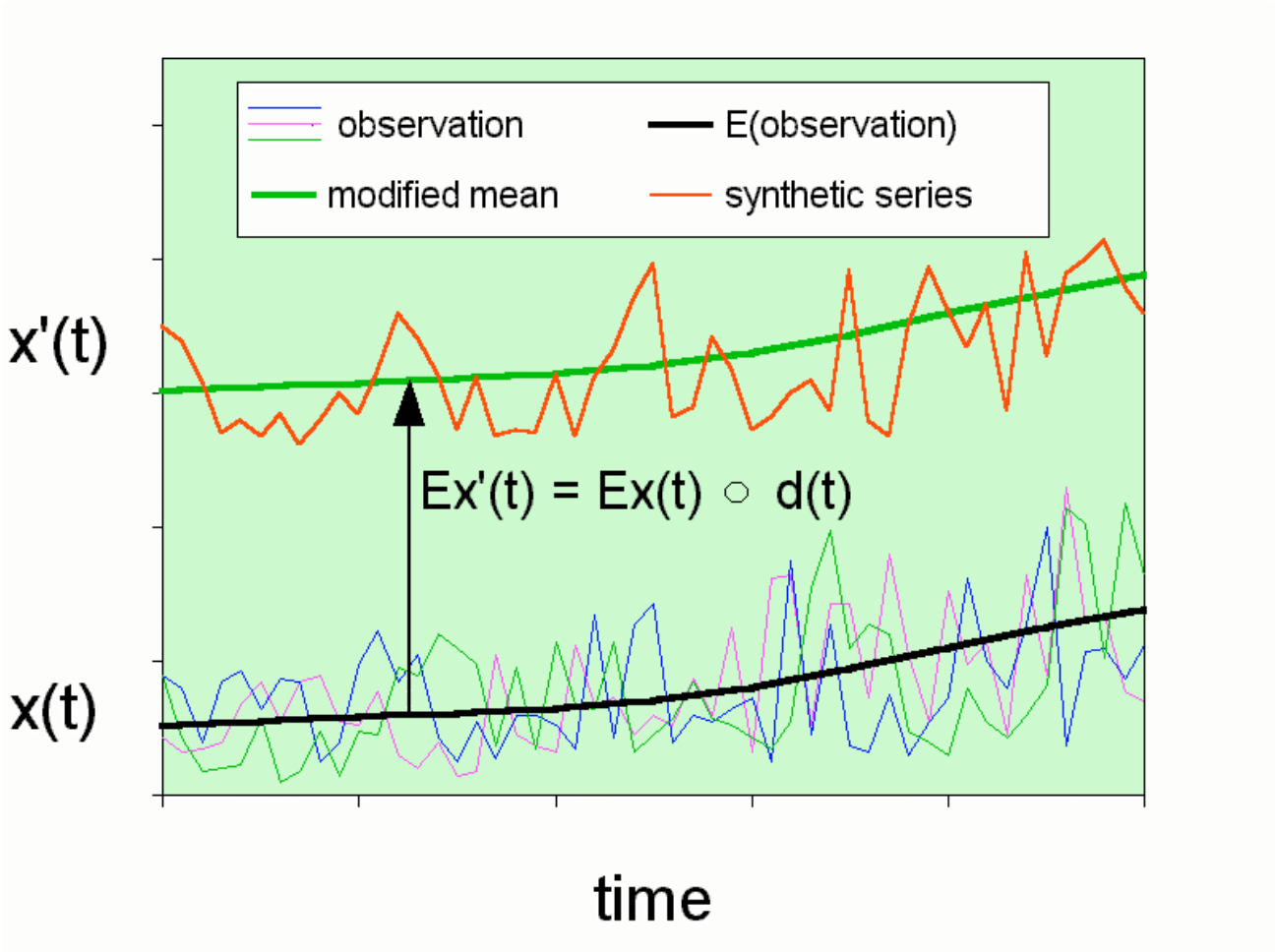
preparing daily weather series for changed climate

a) direct modification of observed series:



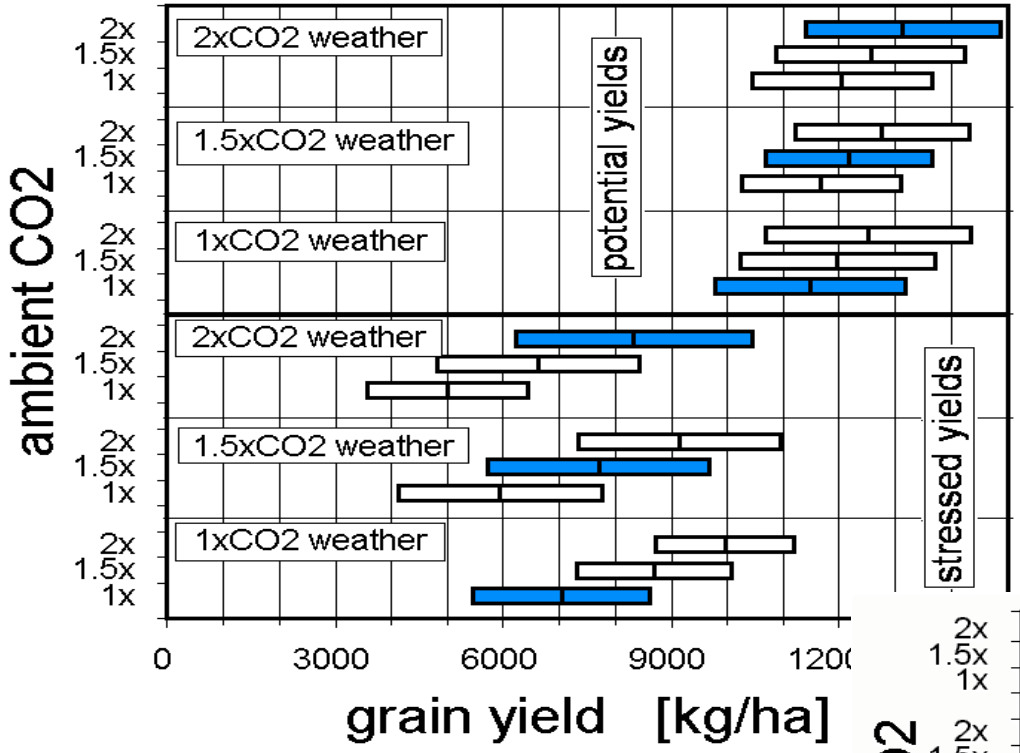
preparing daily weather series for changed climate

b) stochastic weather generator:

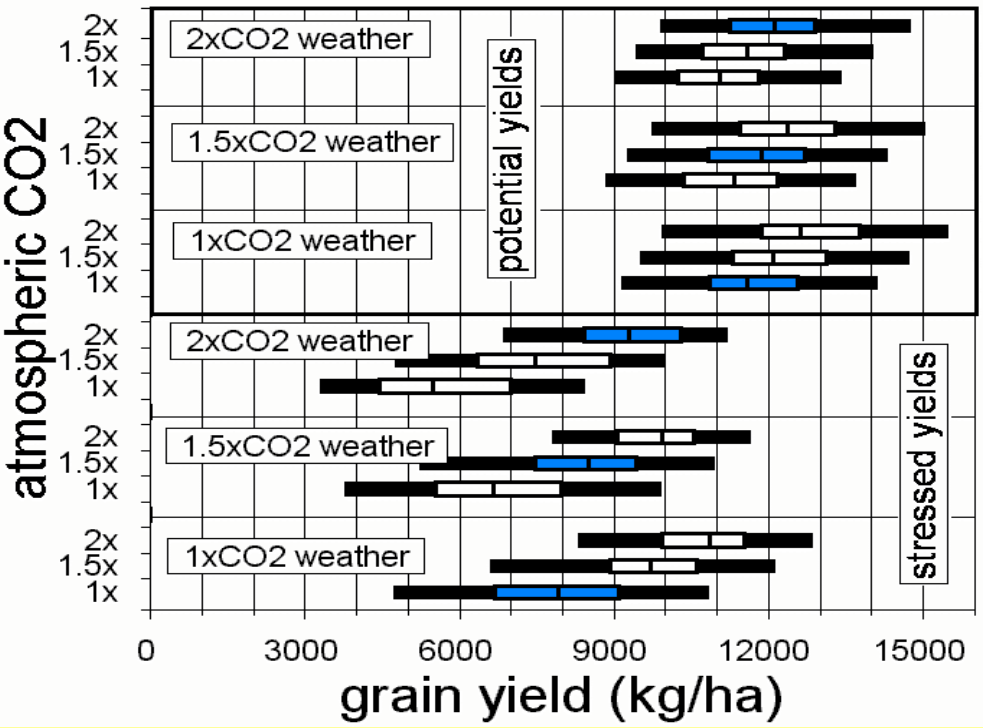


impacts on maize
(Zalud and Dubrovsky, 2002)

a) direct modification approach
(17 years series)

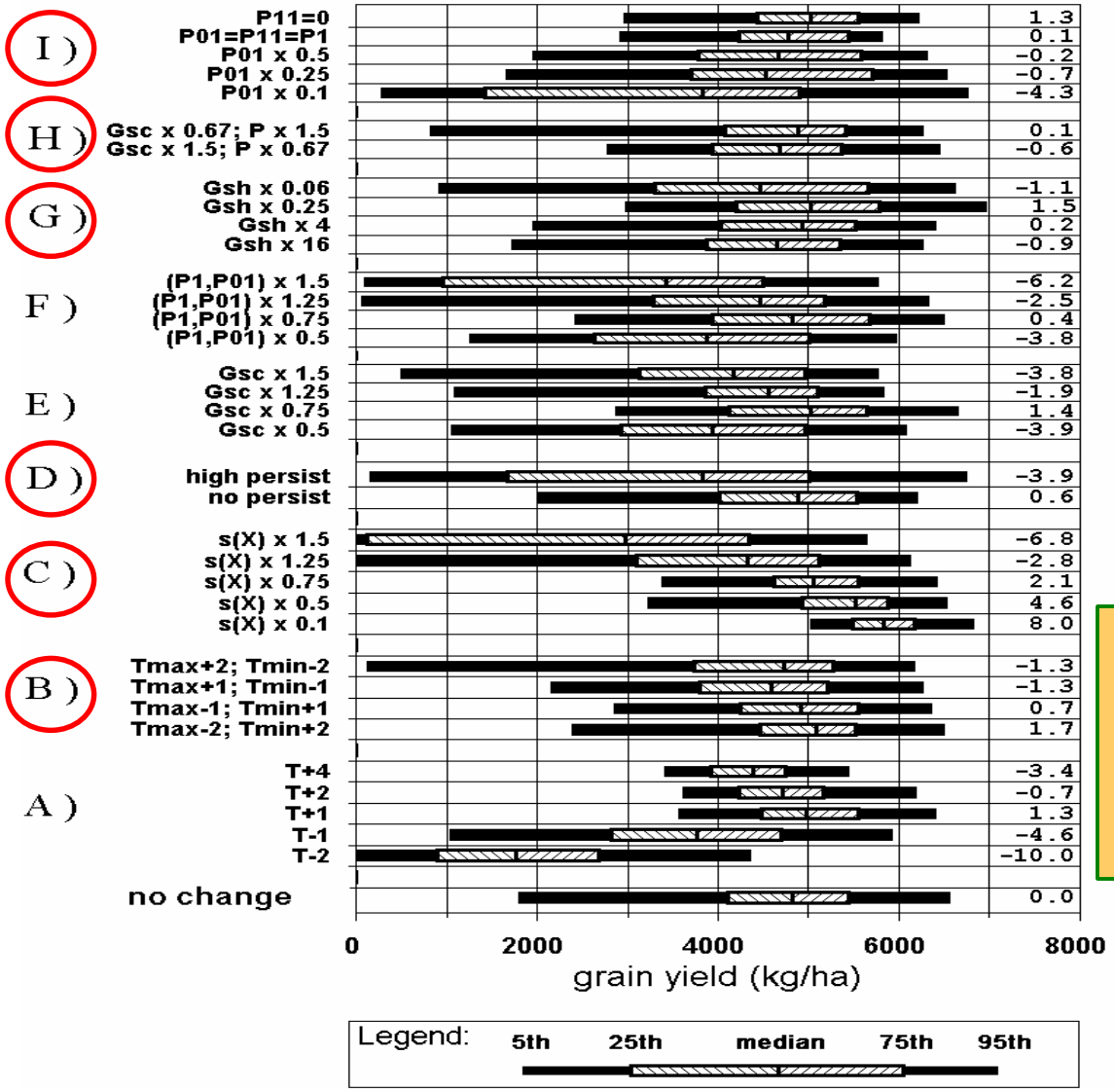


b) Weather Generator approach
(99 years series)



® **trends obtained by both WG and DM approaches are similar**

Results obtained with Met&Roll: sensitivity of model yields to changes in WG parameters



Variability of model [CERES-Maize] grain yields simulated with modified characteristics of daily weather series [quantiles from 99 years]. Wilcoxon statistics (mumbers on the right): values beyond <-1.96, 1.96> indicate statistically significant (level of significance = 5%) difference with respect to “no change data”.

Motivation: you cannot get reliable forecast of changes in some climatic characteristics, but you can test the sensitivity to these changes!

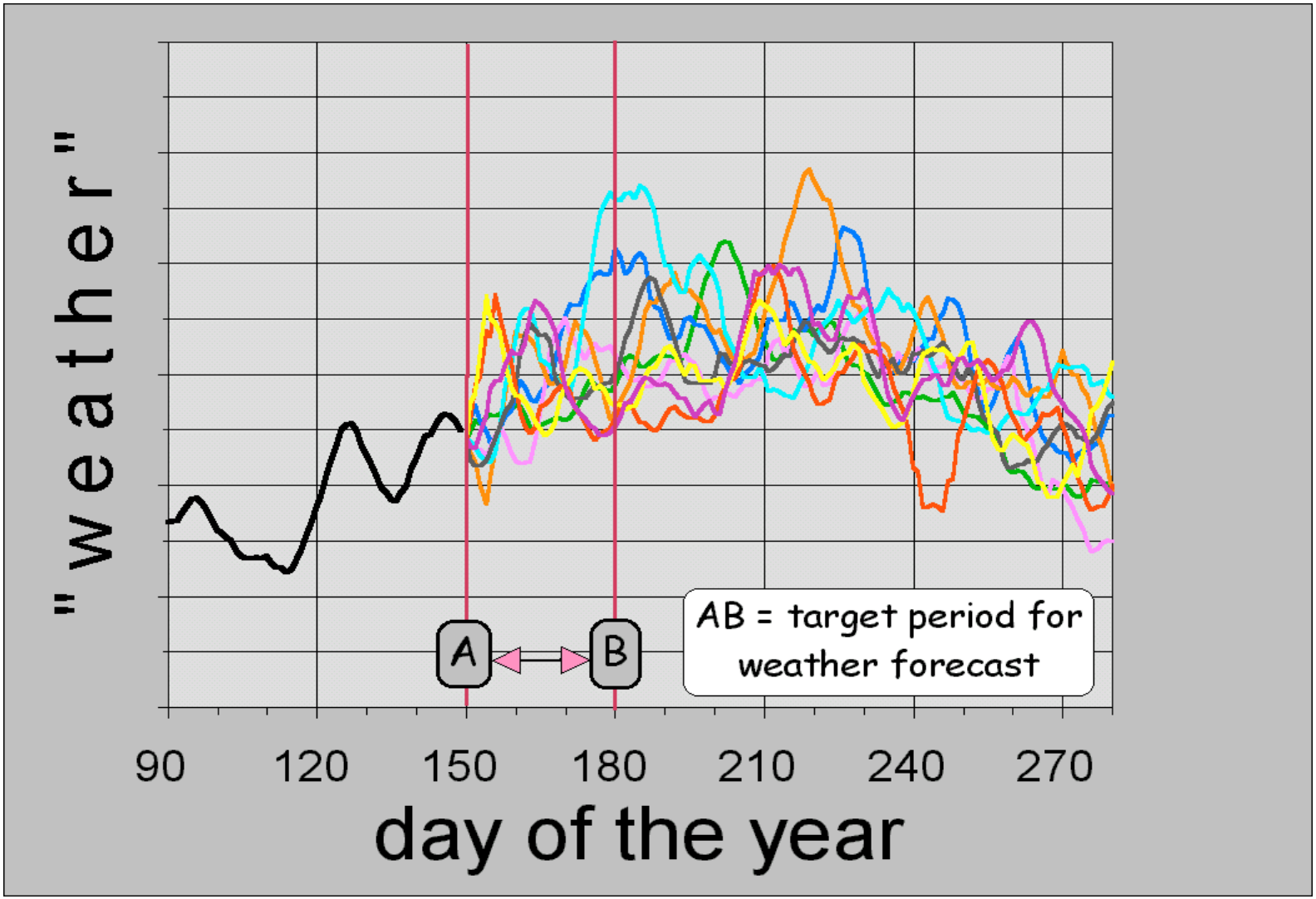
(Dubrovsky et al, 2000, Climatic Change)

probabilistic seasonal crop yield forecasting

(implemented in PERUN system)

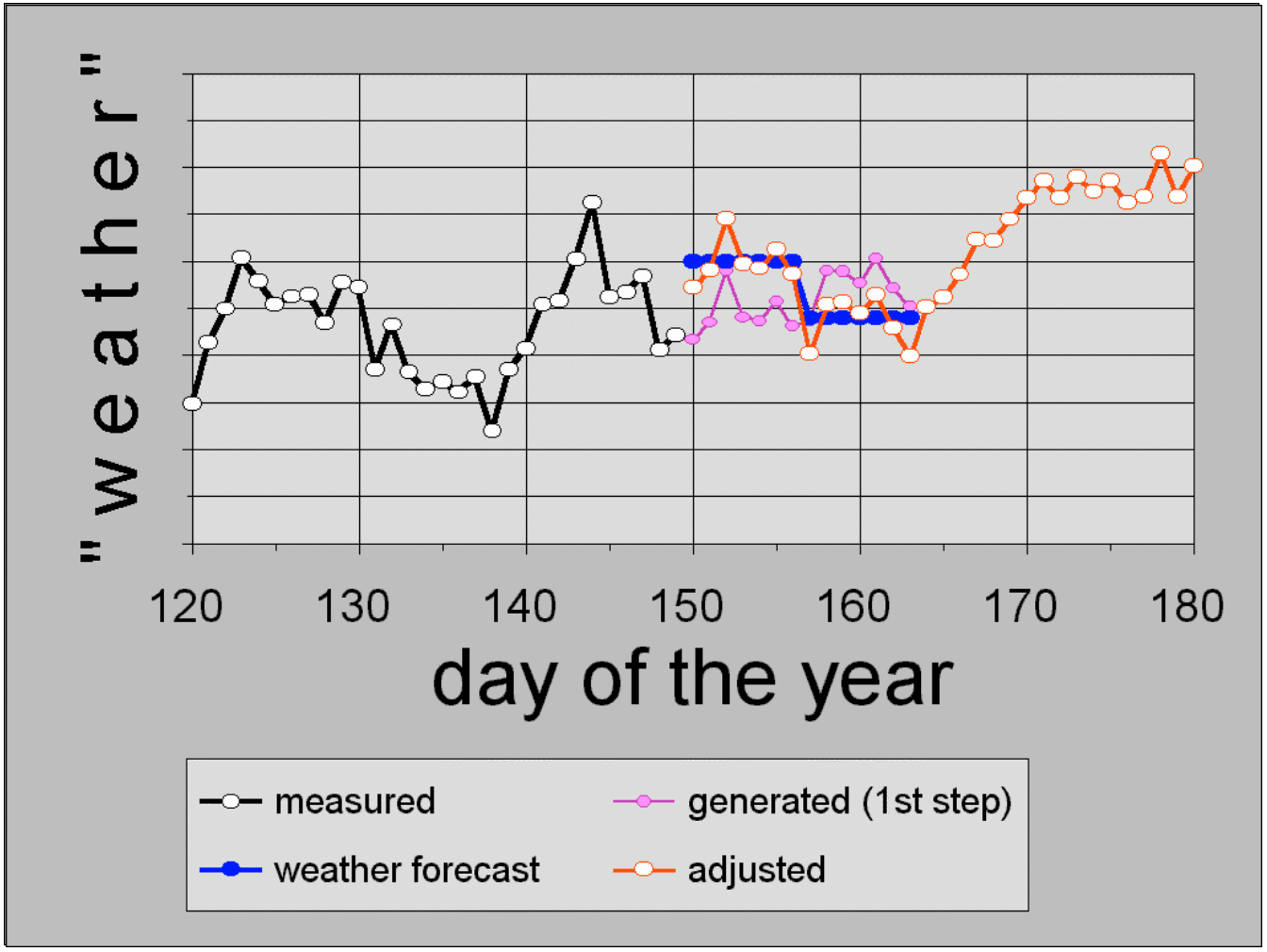
seasonal crop yield forecasting

1. construction of weather series



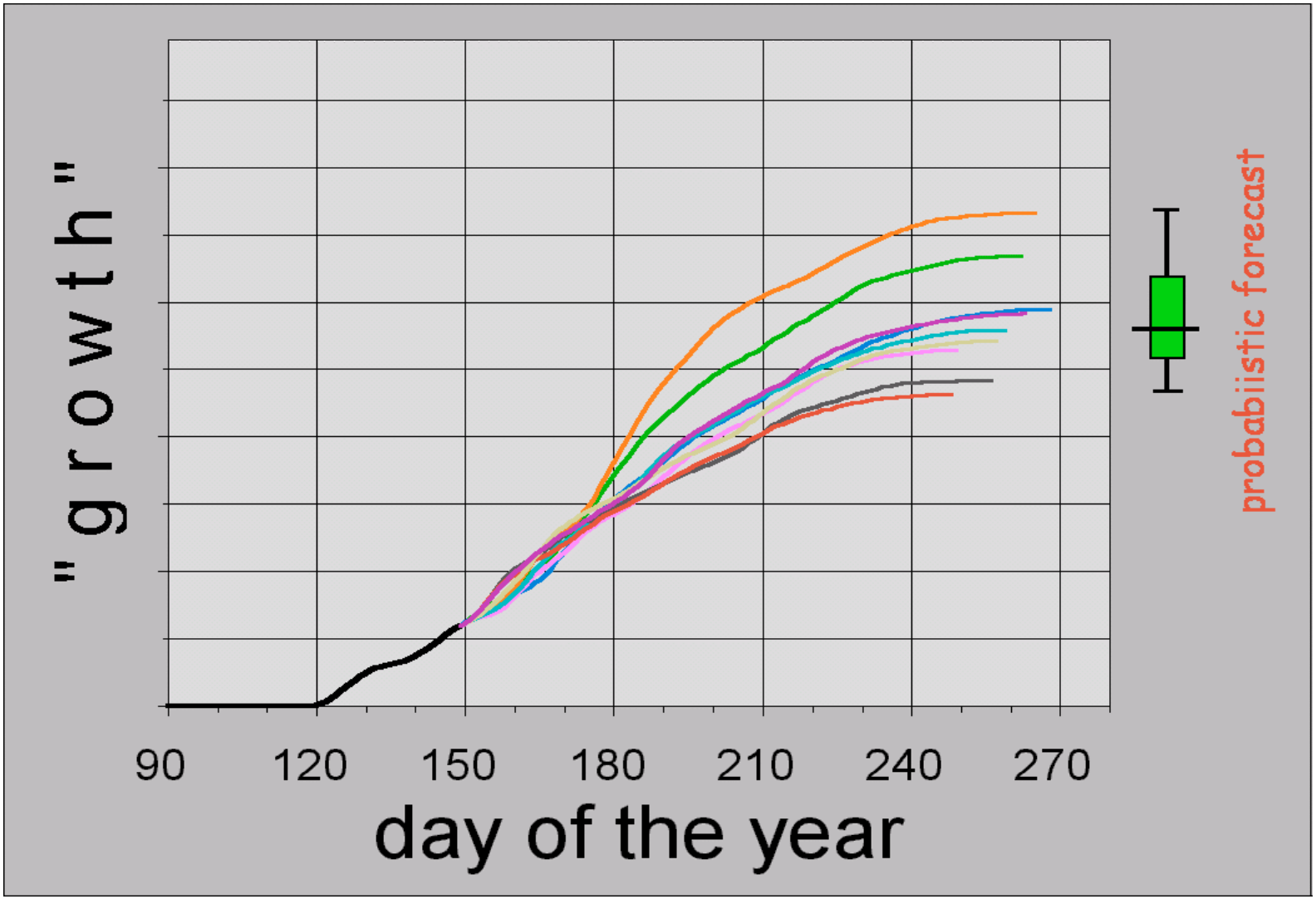
skip

C) modification of the synthetic weather series so that it fits the weather forecast:



seasonal crop yield forecasting

2. running the crop model



weather forecast is given in terms of:

a) expected values valid for the forthcoming days

(e.g., first day/week: 12±2 °C, second day/week: 7±3 °C, …)

alternative formats of the weather forecast (useful in climate change/sensitivity analysis):

b) increments with respect to long-term means

(1st day/week/decade: temperature = + 2 C above normal;
precipitation = 80% of normal;
2nd day/week/decade: ….., ….)

c) increments to existing series

a) weather forecast given in terms of the expected values

```
* weather forecast                                  random component
METHOD  = 1
                    ...averages...    ..std. deviation..
@JD-from JD-to   TMAX TMIN PREC    TMAX    TMIN    PREC
99121    99130    17    6   30      2       2       10
99131    99140    14    4   60      3       3       20
99141    99150    21   10   10      4       4       10
@
```

b,c) increments with respect to the long-term means or w.r.t. existing series

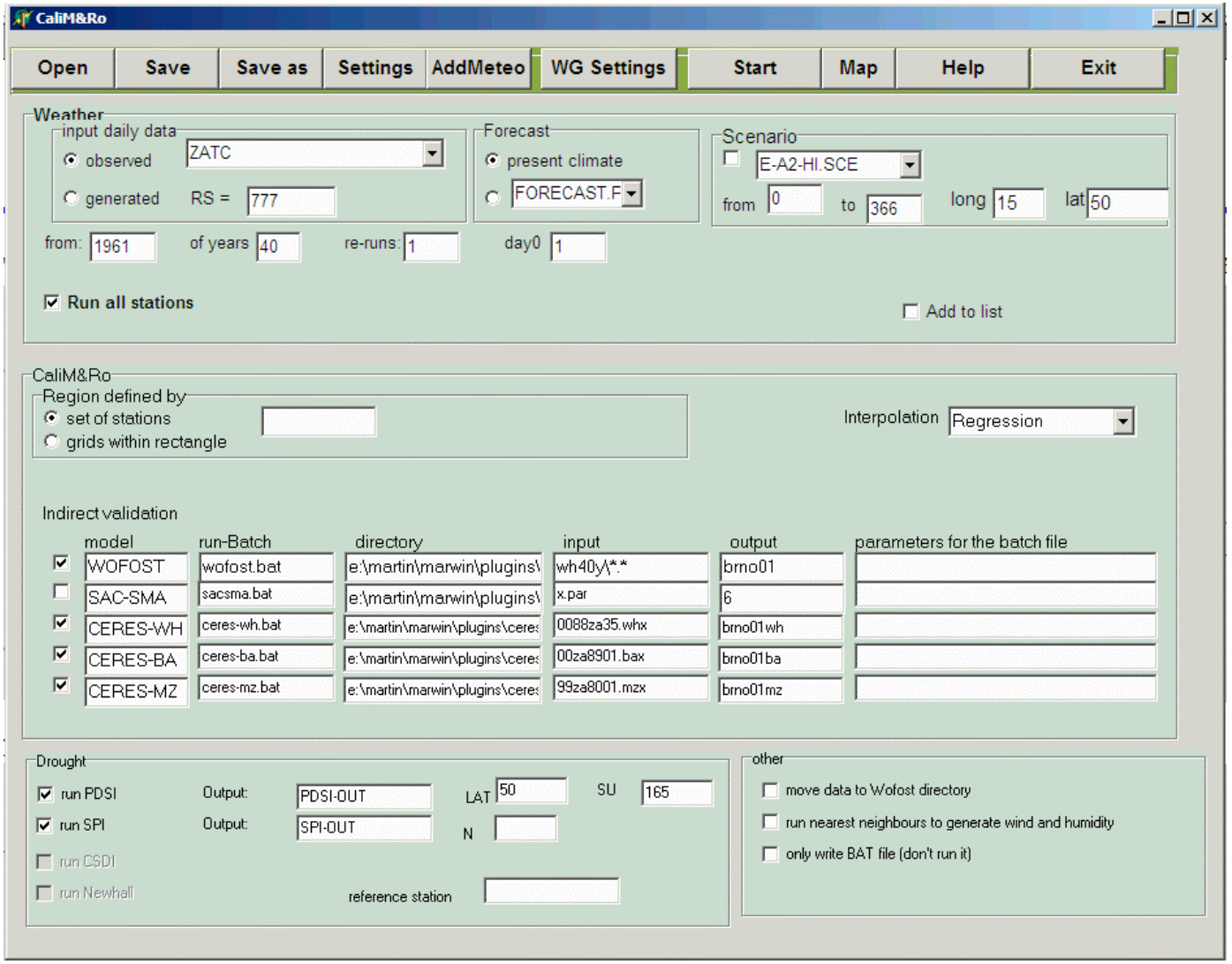
random component

```
* weather forecast
METHOD  = 3
                    ...averages...    ..std. deviation..
@JD-from JD-to   TMAX TMIN PREC    TMAX    TMIN    PREC
99121    99130     1    1   1.2     2       2       0.1
99131    99140     0    0   1.0     2       2       0.1
99141    99150    -1   -1   0.9     2       2       0.1
@
```

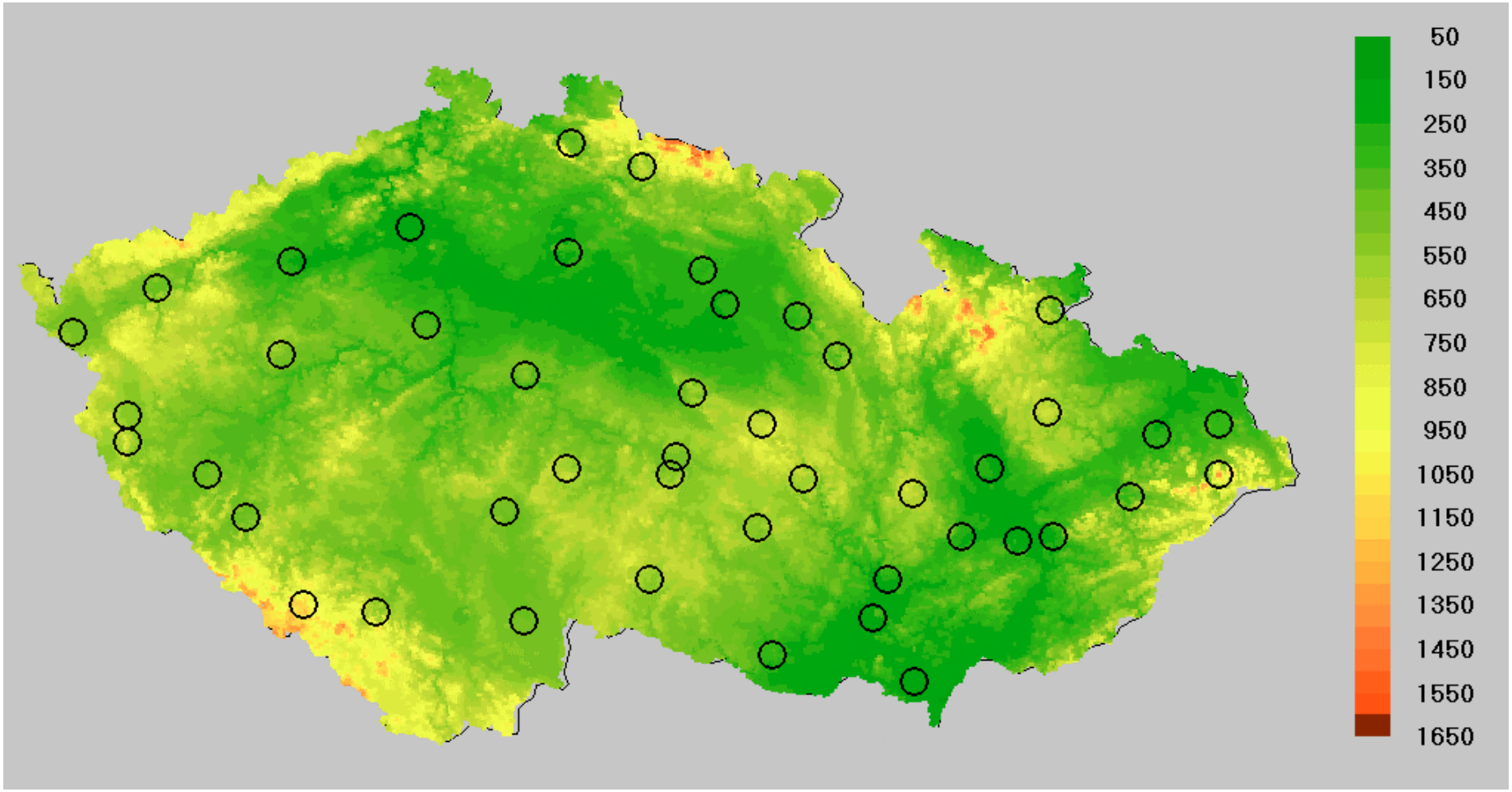
Future of Met&Roll: caliM&Ro project

- **New project:** 2005 - 2007
- **Main aim:** interpolation of Met&Roll parameters
- Met&Roll is linked to several crop models and hydrological models, allowing to run in a single batch:
  - all models
  - for multiple stations or for a set of grid points within rectangular area
  - climate change scenario might be employed

caliM&Ro - main panel

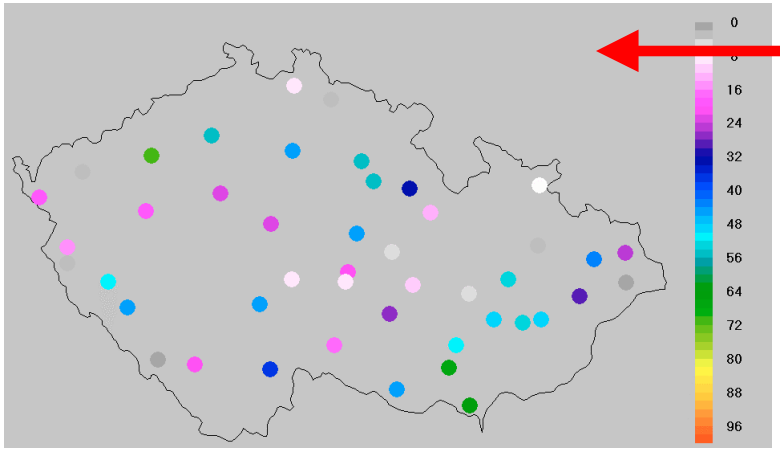


Topography of the study area and location of the 45 stations with available observational weather data

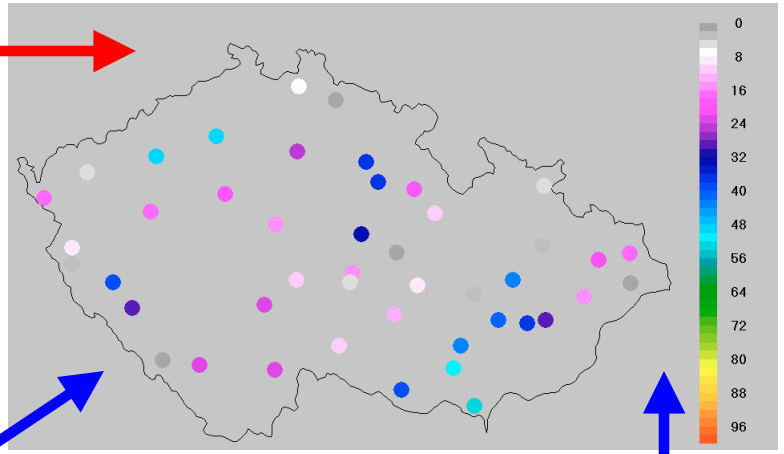


Direct validation of interpolated WG - number of heat waves in 40y series

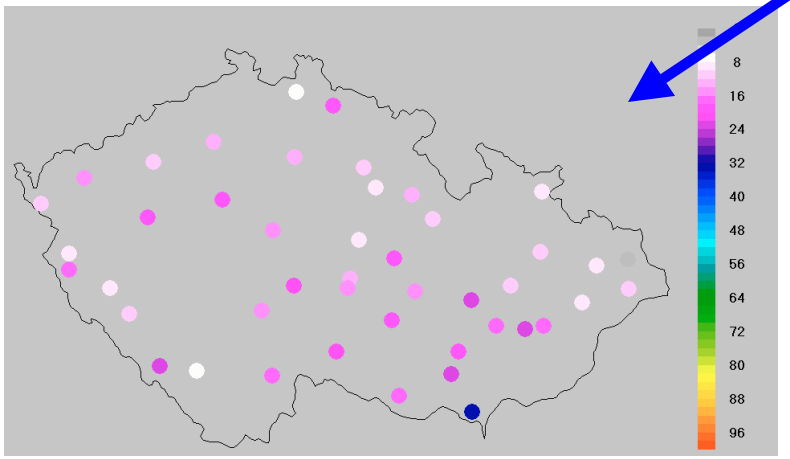
A. observed weather series



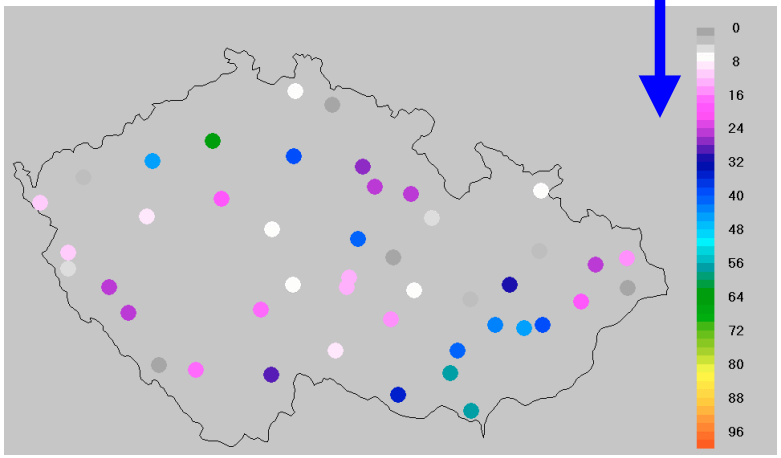
B. synthetic weather series (site-calibrated)



C. interpolated (X-Y) WG



D. interpolated WG (X-Y-Z)

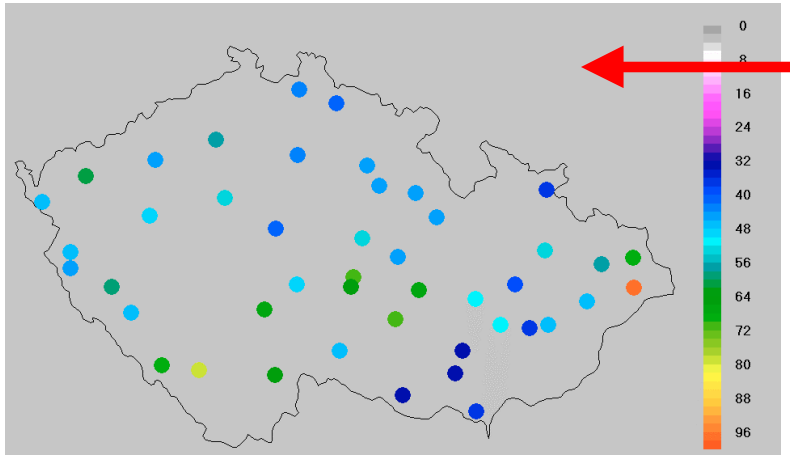


validation of the weather generator

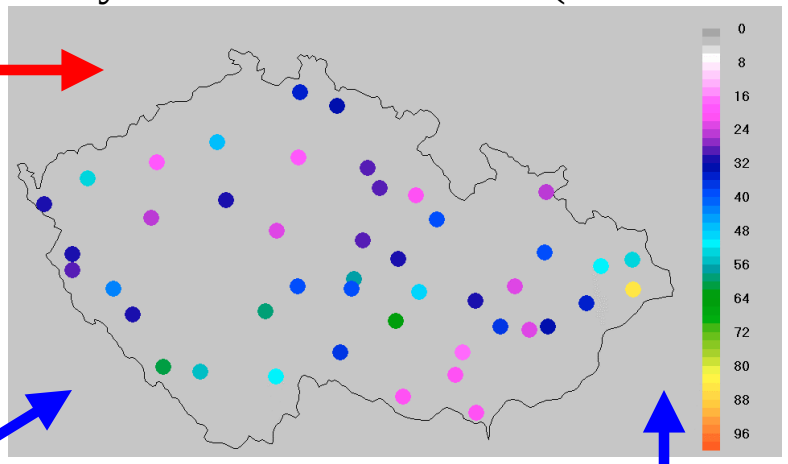
validation of the interpolation technique

Direct validation of interpolated WG - number of cold waves in 40y series

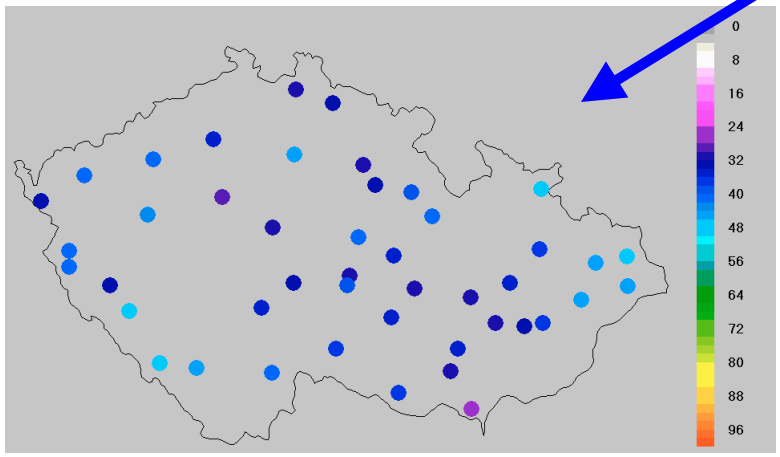
A. observed weather series



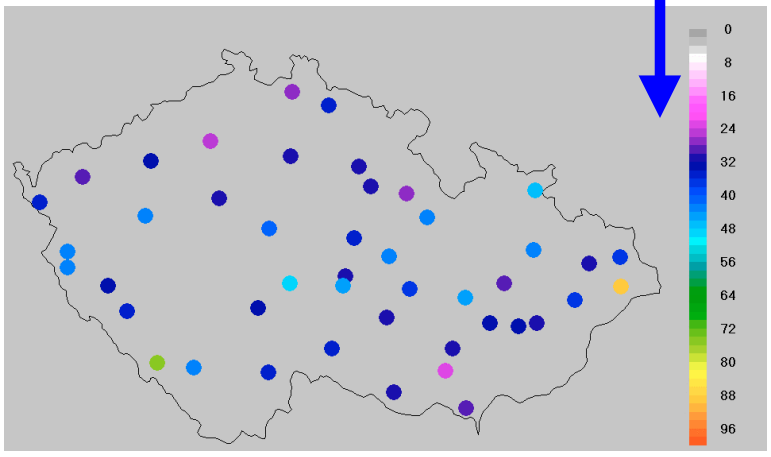
B. synthetic weather series (site-calibrated)



C. interpolated (X-Y) WG



D. interpolated WG (X-Y-Z)

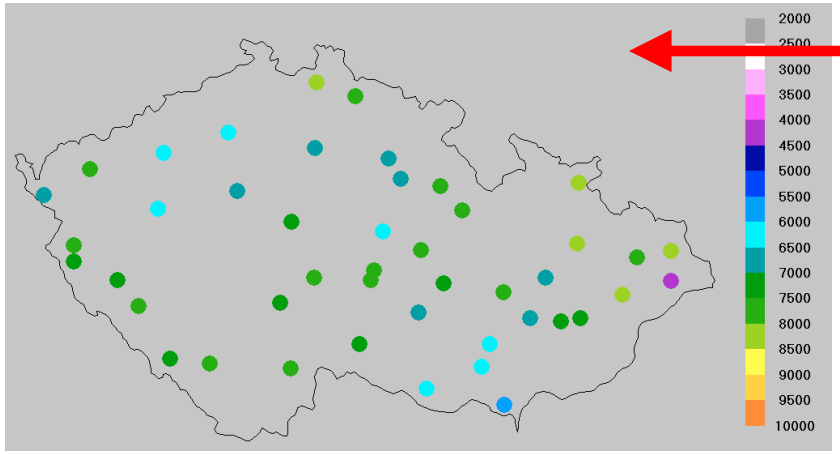


validation of the weather generator

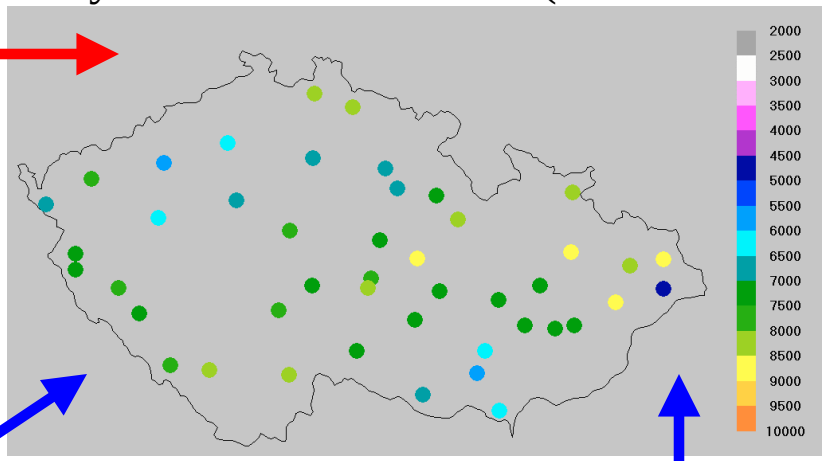
validation of the interpolation technique

Indirect validation of interpolated WG
- Mean (40-years) WOFOST-simulated wheat yields using

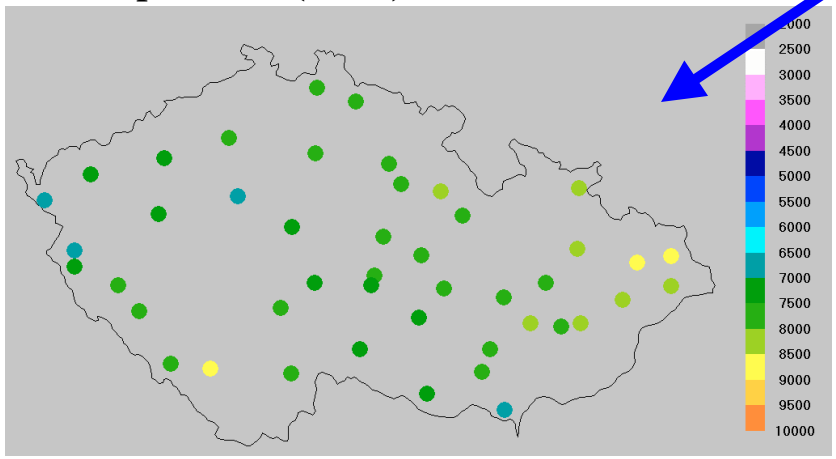
A. observed weather series



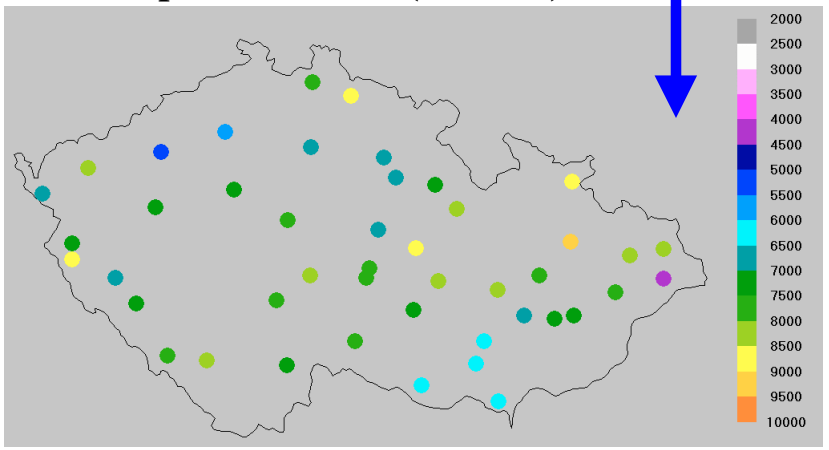
B. synthetic weather series (site-calibrated)



C. interpolated (X-Y) WG



D. interpolated WG (X-Y-Z)



validation of the weather generator

validation of the interpolation technique

Conclusions

- At present time, Met&Roll is available as a part of the PERUN system. Come in the afternoon to see the software demonstration!

- Met&Roll is free for your use, potential users are welcome!!! (sorry for the bugs, but we may help you to use it and your suggestions may help us to improve the software and make it available also for others)

- see web page for the papers:

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

Installation of PERUN (incl. Met&Roll)

1. If you agree that

PERUN is installed to **c:\MADSOFT\PERUN**

WOFOST is installed to **C:\WOFOST**

then

1.1 install only PERUN: run **InstallPerun.bat**

1.2 install PERUN + WOFOST: run **InstallWofostAndPerun.bat**

2. otherwise:

a. copy CD contents into any directory

b. edit InstallPerun.bat or InstallWofostAndPerun.bat

c. run respective batchfile

Installation of PERUN (incl. Met&Roll) (contents of InstallWofostAndPerun

```
SET "DIRPERUN=c:\MADSOFT\PERUN"
SET "DIRWOFOST=c:\WOFOST"

mkdir %DIRPERUN%
mkdir %DIRWOFOST%

7z x -y -o%DIRPERUN% installperun.zip
7z x -y -o%DIRWOFOST% installwofost.zip

writefile P %DIRWOFOST% %DIRPERUN%
    %DIRPERUN%\dir.set
```

References (related to Met&Roll)

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