Stochastic weather generator M&Rfi: it works not only with the daily step and normally distributed variables

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 ÅM&Rfi = multivariate single-site stochastic weather generator for use in agrometeorological modelling under present and future climates

Åsubmitted abstract:
1. focus on the time step in M&Rfi
2. focus on the non-normal variables in M&Rfi
3. impact experiment in terms of climatic & agroclimatic indices

Åreality (relates to my last months priorities & 15 minutes for the presentation):
1 + 2: will be only briefly mentioned
3. the impact experiment
   Åfollower of the experiment presented last year in Reading (EMS-2013)
   Åonly 8 extreme climatic characteristics are employed (no agroclimatic)
   Åfocus on implementing the monthly weather generator
A multivariate stochastic (daily) weather generator

The basic version used here:

1. (primary variable) PREC occurrence ~ Markov chain (1\textsuperscript{st} order)
   parameters: \text{Prob(wet)}, \text{Prob(dry>\text{wet})}

1b (if \text{PREC}(t) > 0) : PREC. amount ~ Gamma distribution
   parameters: \text{Gshape}, \text{Gscale} (\text{Gscale} \times \text{Gshape} = a\text{PREC})

2. Variables conditioned on PREC occurrence:
   \text{X} = (\text{SRAD}, \text{TMAX}, \text{TMIN}) \sim AR(1);
   parameters: \text{avg(Xi), std(Xi)}; matrices \text{A, B}

(all parameters are assumed to vary during the year)
**M&Rfi weather generator: transformations**

**Motivation:** to include also (significantly) non-normally distributed variables (RHUM, WIND, etc.) to be modelled by multi-variate AR model.

**Transformations may be**
- **parametric** - linear, exponential, logarithmic, power
- **non-parametric:** quantile transformation (number of quantiles and what quantiles may be defined by user)

**Application of transformation:**
- before calibration (to make the variable near-normal)
- after generation (to make the variable's distribution realistic)

**Use of transformations (examples)**
1. in daily WG: RHUM, WIND ~ quantile transformed
2. in monthly WG: PREC → PREC1/4
apart from daily WG, two other time steps are given a special attention:

$\Delta t = \text{hour} \sim 2 \text{ step procedure} \ (developed \ with \ MeteoSwiss)$

1. daily WG is applied to daily series derived from hourlies,
2. resampling is used to generate hourlies

$\Delta t = \text{month} : \text{more details on mWG will be given later…}$
1. weather variability affects crop yields (Dubrovsky et al 2000: Sensitivity of CERES-Maize yields to statistical structure of daily weather series...)

Experiment:
- 1 Czech site
- crop model: CERES-Maize
- scenarios = changes in selected WG parameters: means, std, Markov, persistence
- 99-year synt.weather series (Met&Roll)

Wilcoxon stat.: values beyond <-1.96, 1.96> indicate statistically significant (level of significance = 5%) difference from “no change”.

Legend: 5th 25th median 75th 95th
2. **WG-friendly scenarios** were introduced last year (Dubrovsky et al, 2013; also presented in EMS-2013 conference in Reading): the scenarios include changes in WG parameters, which affect the (inter)diurnal weather variability.

**WG-friendly CC scenarios** were defined in terms of changes in:
- dTAVG, d(aPREC),
- dDTR, d(stdTAVG), d(stdDTR), d(probWET), d[prob(DRY>WET)]
weather variability matters (3. monthly WG)

3. variability deserves to be better represented by WG.

In 2004 (Dubrovsky et al 2004), daily WG (dWG) was linked to monthly WG (mWG) to improve low-frequency (~inter-monthly) variability:

**step 1**: daily weather series is generated by dWG

**step 2**: monthly weather series is generated by mWG

**step 3**: daily series is fitted to monthly series linking

**Figure 3.** Adjustment of the daily weather series to the monthly averages (only 25-day segment from the daily series is shown). \(\langle x\rangle\) is the series of monthly averages derived from the daily series, \(\langle x\rangle'\) is the series of monthly averages generated by monthly generator, \(x\) is daily series generated by daily generator, \(x'\) is the daily series modified to fit \(\langle x\rangle'\).

**present version of mWG:** \[\text{TMAX, TMIN, PREC1/4} \sim \text{AR(1)}\]
This presentation is a follower of my EMS2013 year presentation.

The present experiment is similar, but **the main focus is on mWG**, which

- was not involved in 2013
- not yet fully validated
- not yet properly linked with CC scenarios
- may contribute to better representation of future climate conditions

**this presentation will:**

1. provide **further validation** of mWG
2. **add changes in mWG parameters into WG-friendly CC scenarios** (including changes in monthly variability)
3. **examine effect of involving mWG** on CC impacts

validation & impacts assessed in terms of **8 extreme TEMP & PREC indices**
A. Climate change scenarios ~ 9 GCM simulations (3 CGCM3 runs + 6 other GCMs were available; SRES-A2 simulations from CMIP3 database)

<table>
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<th>Model</th>
<th>Center</th>
<th>resolution $n_{\text{lat}} \times n_{\text{lon}}$</th>
<th>present</th>
<th>future</th>
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<td>192×96</td>
<td>1961-78</td>
<td>2081-2100</td>
</tr>
</tbody>
</table>

B. WG calibrated for 87 European stations

(data taken from ECA&D database)
WG-friendly climate change scenarios

WG-friendly CC scenarios derived as:

\[ \Delta \text{WG} = \text{WG} \left[ \text{GCM}(2081-2100) \right] \text{ vs. } \text{WG} \left[ \text{GCM}(1961-1990) \right] \]

- difference in the case of temperature averages
- ratio in other cases [std(*), PREC, DTR, prob(*)]
- GCM series were detrended within the time slice before comparing future vs now
\[ \Delta W G p a r \]

precipitation

- 2 main PREC parameters
  - \( d(P_{wet}) \sim d(P_{dry}>wet) \)
  - \( \rightarrow \) no change in autocor. in wet days series

- Good between-GCM fit:
- Large GCM uncertainty:

- Summer - S. EU: PREC↓ due to \( P_{wet} \)
- Winter - NE EU: PREC↑ mainly due to aPREC↑ increase
**\( \Delta W Gpar \)**

**Temperature**

**Summer** – S.EU: high aTAVG↗ + sTAVG↗ + aDTR↗ may result in significant increase in extreme daily max. temperatures

**winter**: NE EU: aTAVG↗ + sTAVG↘ + aDTR↘ may result in significant reduction of winter low temperatures

\( \Delta d[sTAVG] \sim d[DTR] \)
inclusion of mWG into WG-friendly CC scenarios

**Precipitation)**

- **d(WG)**
  - **summer**: d(aPREC) [%] (on wet days)
  - **winter**: d(Pwet) [%]
  - **winter**: d(aPREC1/4) [%]
  - **winter**: d(sPREC1/4) [%]

**Temperature**

- **d(WG)**
  - **summer**: d(aTAVG) [°C]
  - **winter**: d(sTAVG) [%]
  - **winter**: d(aDTR) [%]

**Winter vs. Summer**

- **Temperature**
  - **winter**: Temperature increases
  - **summer**: Temperature decreases

**Precipitation**

- **summer**: Precipitation decreases
  - **winter**: Precipitation increases
6 WG-friendly scenarios of different degree of complexity:

- **A**: Pa+Ta = simplest scenario
- **B**: Pa+Ta+D
- **C**: Pa+Ta+D+sT
- **D**: Pa+Ta+Pp = A + Pp
- **E**: Pa+Ta+D+sT+Pp = C + Pp

**Scenarios involving mWG:**

- **AX**: A + mWG(dM)
- **AY**: A + mWG(dM+dV)
- **EX**: E + mWG(dM)
- **EY**: E + mWG(dM+dV)

Where:

- \( Ta \sim \Delta [T_{avg}] \)
- \( Pa \sim \Delta [\text{PREC} \text{amount}] \)
- \( D \sim \Delta [T_{MAX}-T_{MIN}] \)
- \( sT \sim \Delta [\text{std}(T.)] \)
- \( Pp \sim \Delta [\text{prob}(\text{PREC})] \)
- \( \text{MWG}(dM) \sim \text{changes in monthly means} \)
- \( \text{MWG}(dM+dV) \sim \text{changes in monthly means and variability} \)
$$\Delta TX_{\text{MAX}} [= \text{change in average annual max}(T_{\text{max}})]$$

A ($\sim$Pa+Ta); CC signal

bias wrt A

WG vs OBS
($\sim$ quality of WG)

E: Pa+Ta+D+sT+P

A + mWG (dM)

E + mWG (dM)

A + mWG (dM+dV)

E + mWG (dM+dV)

[1] quality of WG:
- TXmax are under/over-estimated by WG ($\sim$spatial variability)
- mWG improves reproduction of some indices (not this one)

[2] CC signal $\gg$ WG bias (not for all other indices)

[3] effect of (inter)diurnal variability
- significant in 45-50°N belt

MWG

[4] MWG: effect smaller than [3],
(but significant for hot spells - next slide)

[5] effect of monthly variability:
tends to intensify extremes, but effect mostly small wrt [3]
\[ \Delta[L_{\text{max}}(\text{HotSpell})] \] (annual longest hot spell)

- **A (\sim P_a + T_a); CC signal**
- **bias wrt A**
- **WG vs OBS** (~ quality of WG)
- **E:** \( P_a + T_a + D + sT + P_p \)
- **WG bias**
- **OBS**

**[1] quality of WG:**
- WG-based spells are shorter

**[2] CC signal > WG bias**

**[3] effect of (inter)diurnal variability**
- in some areas

**[4] MWG:** significant effect (comparable with [3])

**[5] effect of monthly variability**
- small
\( \Delta T_{N_{\text{MIN}}} \) [= change in average annual min(\( T_{\text{min}} \))]
\[
\Delta[L_{\text{max}}(\text{ColdSpell})] = \text{annual longest cold spell}
\]

1. Quality of WG:
   - WG-based spells are shorter
   - Effect of mWG small

2. CC signal > WG bias

3. Effect of (inter)diurnal variability
   - Small

4. MWG:
   - Small effect (~ [3])

5. Effect of monthly variability:
   - Insignificant
\[ \Delta [L_{max}(\text{DrySpell})] = \text{annual longest cold spell} \]

**WG vs OBS**

(\textit{quality of WG})

- [1] **quality of WG:**
  - length of dry spells is underestimated by WG

- [2] **CC signal vs WG bias**
  - CC signal not present in A scenarios

- [3] **effect of (inter)diurnal variability**
  - generates CC signal
  - CC signal only in S EU (longer spells)

- [4] **MWG:** no effect
  (follows from mWG model)

- [5] **effect of monthly variability:** no effect
\[ \Delta [L_{\text{max}}(\text{WetSpell})] = \text{annual longest cold spell} \]

1. **Quality of WG:**
   - Spell length under/over-estimated in NW / SE Eu

2. **CC Signal:**
   - \( \text{CC signal} < \text{WG bias} \)

3. **Effect of (inter)diurnal variability:**
   - Generates the whole CC signal

4. **MWG:**
   - No effect

5. **Effect of monthly variability:**
   - No effect
\[ \Delta [ PR_{\text{max}} ] = \Delta (\text{annual maximum daily prec.sum}) \]

- **WG vs OBS**
  - (~ quality of WG)

- **Bias wrt A**
  - Pa+Ta+D+sT+Pp

- **A (~Pa+Ta); CC signal**

- **multiGCM’ICS’A-PRECmax rel**
  - Pa+Ta+D+sT+Pp

- **E: Pa+Ta+D+sT+Pp**

- **A + mWG (dM)**

- **E + mWG (dM)**

- **A + mWG (dM+dV)**

- **E + mWG (dM+dV)**

- **dWG**
  - NOW-PRECmax bias

- **dWG+mWG**
  - NOW-PRECmax bias

- **WG vs OBS**
  - (~ quality of WG)

- **[1] quality of WG:**
  - dWG significantly underestimates OBS
  - mWG fails!!!!! (wrong linking procedure)

- **[2] CC signal < WG bias**

- **[3] effect of (inter)diurnal variability**
  - significant

MWG fails due to wrong dWG-mWG linking procedure for precipitation!!!
\[ \Delta[PR5D_{max}] = \Delta(\text{annual maximum 5-day prec. sum}) \]

- **A (~Pa+Ta); CC signal**
- **bias wrt A**
- **WG vs OBS (~ quality of WG)**
- **dWG**
- **dWG+mWG**

... the same as for PR$_{max}$

- **effect of conditioning dWG on mWG**
- **effect of changes in monthly variability**
- **effect of changes in (inter)diurnal variability**
1. **WG friendly scenarios** were introduced in 2013:
   - they add new information [~ changes in (inter)diurnal variability] into CC scenarios
   - changes in some WG parameters are affected by higher uncertainty, but
   - the CC signal is mostly larger than WG-OBS bias

2. CC impacts in terms of extreme TEMP / PREC characteristics:
   - even basic scenarios (dT + dP) imply increases in some of these characteristics
   - more complex WG-friendly scenarios show their further intensification:
     - PROBwet↑ > aPREC↑ \(\Rightarrow\) longer+more intensive droughts (*Mediterr.*)
     - std(TEMP)↑ + DTR↑ \(\Rightarrow\) higher TMAX extremes in S. EU
     - std(TEMP)↑ + DTR↑ \(\Rightarrow\) reduced TMIN extremes in NE. EU
1. mWG slightly improves WG ability to reproduce some climatic characteristics.

2. including changes in mWG parameters into CC scenarios intensifies CC signal in some climatic indices, but mostly less significantly compared to the effect of including (inter)diurnal variability.

3. Precipitation in mWG: major problem was found in the dWG-mWG linking procedure. New version will be available soon.
This is not the end of the presentation...

Inclusion of changes in high-frequency & low-frequency weather variability into CC scenarios may modify CC impacts (with respect to using the basic scenarios).

It is therefore recommended to include these changes into account, but the results should be handled with great care due to
(a) higher uncertainty in determining these changes, and
(b) lower reliability to represent variability and extremes (in both WG and GCM)

... next slides warn against possible “problem” in interpreting results obtained with WG and WG-friendly scenarios
mean annual maximum of TMAX

\[ \text{OBS + SYNT}_{(\text{now})} \]

\[ \tilde{\text{synthetic}}_{(\text{future})} \]

\[ (\text{median from 9 GCMs}) \]

\[ (\text{projection based on the “warmest” GCM}) \]

\[ \text{OBS + SYNT}_{(\text{now})} \]

\[ \tilde{\text{synthetic}}_{(\text{future})} \]

\[ (\text{median from 9 GCMs}) \]

\[ (\text{projection based on the “warmest” GCM}) \]
mean annual maximum of TMAX

OBS + SYNT\textsubscript{(now)}

\textit{\textsuperscript{\textcircled{synthetic}}future} (\textit{\textsuperscript{\textcircled{median}}from 9 GCMs})

\textit{\textsuperscript{\textcircled{synthetic}}future} (\textit{\textsuperscript{\textcircled{MAX}}from 9 GCMs}) (projection based on the “warmest” GCM)

\textbf{is it realistic ??}
mean annual max. length of hot spell

**OBS + SYNT**(now)

**synthetic** future

*median* from 9 GCMs

(projection based on the “warmest” GCM)

**effect of diurnal variability**

**effect of monthly variability**
Final conclusion

Please,

- use the weather generator and WG-friendly scenarios,
- but remember the limitations in WG quality and uncertainties in CC scenarios, and be careful when interpreting the results!

find more: www.ufa.cas.cz/dub/crop/crop.htm


freely available:
- M&Rfi weather generator
- GCM-based WG-friendly scenarios