Linking GCM-based climate change scenarios with agroclimatological models

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1. Introduction

- Climate change impact studies in Czechia (Czech Republic): significant boom since 1995 (thanks to "Country Studies"
- Models run in Mendel University of Agriculture and Forestry:
  - crop models (CERES-Wheat/Maize/Barley, WOFOST, STICS, …)
  - pest & diseases models (ECAMON, …)
  - soil model (SoilClim)
  - model for agroclimatological indices (AgriClim), …
- Demands on climate & weather data to run the models under present + changed climate:
  - climate change scenarios (accounting for known uncertainties)
  - daily (or 10-day or monthly) weather series representing "now" and future climate
- This contribution
  - Methodology
    - construction of weather time series: Weather Generators
    - developing GCM-based climate change scenarios
    - creating set of climate change scenarios for the impact analysis
    - bonus: climate change impact studies

Our group (present state)

- "informal" group was founded in 1995 (Zdenek Zalud and Martin Dubrovsky)

Mendel Agriculture and Forest Univ., Brno, Czech Rep. (MUAF):
- Zdenek Zalud
- Mirek Trnka
- Daniela Semeradova
- Petr Hlavinka
- Eva Kocmanková
- Lenka Bartosova

Inst. of Atmospheric Physics, Prague, Czech Rep. (IAP):
- Martin Dubrovsky

We collaborate with several other institutes in Europe + USA

Climate change impacts on crops

Methodology - basic scheme

Daily weather series for present climate conditions

Information about:
- growing site
- plant genetics
- soil properties
- management

Crop Growth Model

Model output for present climate conditions

Model output for changed climate conditions

Analysis of climate change impacts

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

Two approaches to preparing daily weather series for the changed climate

A) direct modification of observed series:
- shape of distribution preserved
- limited length
- less control on other characteristics

B) stochastic weather generator
- various characteristics may be modified
- arbitrary length
- may be interpolated!!!
- no WG model is perfect!

Ex = present ft/latemeter
T(t) = climate change scenario
x(t) = weather series representing present climate

This is our preferred approach, being permanently improved.
weather generators

(Met&Roll, … & GeNNeR, M&Rfi)

weather generator Met&Roll

- **Met&Roll** = 4-variate stochastic daily weather generator:
  - **PREC**: occurrence ~ Markov chain (order: 1-3; parameters: trans.prob.)
  - **SRAD, TMAX, TMIN**: AR(1) model (parameters: A, B, avg(X), std(X))
  - All parameters are assumed to vary during the year
  - daily WG is linked to AR(1)-based monthly WG (to improve low-frequency variability)

- **VAPO & WIND**: added by nearest neighbours resampling:

- **WG validation should precede its application**:
  - direct validation (synthetic wea.series should resemble observed series)
  - indirect validation (outputs from impact model fed by OBS and SYNT wea.series should resemble each other)

Motivation:
How the WG imperfections (to fit the structure of real-world weather series) affect output from impact models fed by synthetic series?
**validation of Met&Roll - summary**

- **Direct validation:** imperfections exist
- **Indirect validation:** good applicability for crop models

Note: hydrological models are more affected by WG imperfections

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**non-parametric weather generator GeNNeR**

- The generation algorithm is based on a nearest neighbours resampling
  - many features of the algorithm may affect the quality of the generator → these are presently a subject of optimisation

- **PROs:**
  - very general, robust, no assumptions on PDF(x)
  - the algorithm may be easily used → to fill gaps → add variables

- **CONS:**
  - much slower
  - not easy to link with climate change scenarios
  - uninterpolable

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**stochastic weather generator M&Rfi**
*(originally developed for FAO, Rome)*

- A follower of Met&Roll (*= Met&Roll Flexible and Improved)*
- The same core model:
  - PREC is main variable
  - other variables are (optional) conditioned on PREC
  - daily WG (DWG) may be linked to monthly WG (MWG)

- Many new features:
  - optional number of variables
  - optional time step
  - may better treat non-normal variables (allows parametric & non-parametric transformations) → VAPo and WIND are first candidates for inclusion
  - more user-friendly, less files, …
  - may account for more complex climate change scenarios (allows to change both high-frequency and low-frequency variability)

- It is freely available on web: [www.ufa.cas.cz/dub/wg/marfi/marfi.htm](http://www.ufa.cas.cz/dub/wg/marfi/marfi.htm) (send me an e-mail to get a latest possible version!)

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**Climate change scenarios**

Our aim in climate change impact studies: probabilistic assessment reflecting existing uncertainties …at least some of them

For this, we need scenarios from

Several emission scenarios X several GCM simulations

(GCMs: various models, various settings, various realisations)

- … but: GCM simulations need huge computer resources → only limited number of GCM simulations available
  → GCM simulations do not cover existing uncertainties in emissions, climate sensitivity)

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**cascade of uncertainties in developing regional climate change scenarios**

1. emission scenario
2. concentration of GHG and aerosols >> radiation forcing
3. large-scale patterns of climatic characteristics
4. site-specific climate scenario
Global temperature growth at SRES-A2: 11 GCMs (colour time series) vs MAGICC model run at various climate sensitivities (yellow bar on the right)

pattern scaling technique

**assumption**: pattern (spatial and temporal/annual cycle) is constant, only magnitude changes proportionally to the change in global mean temperature:

\[ \Delta x(t) = \Delta x_S \times \Delta T_G(t) \]

where \( \Delta x_S \) = standardised scenario (\( \sim \) scenario related to \( \Delta T_G = 1 \) °C)

a) \( \Delta x_S = \Delta x_{S_{(a,b)}} / \Delta T_{G_{(a,b)}} \)

b) linear regression \( x = \Delta x_S; y = \Delta T_G(t) \) going through zero

\( \Delta T_G = \) change in global mean temperature

!! \( \Delta T_G \) may be estimated by other means than GCMs !!

(e.g. simple climate models /~ MAGICC/)

validity of pattern scaling

\( \Delta T_G \): well correlated with \( \Delta T_{G_{(a,b)}} \)

\( \Delta \)PREC, DTR, SRAD, VAPO, WIND: low correlation with \( \Delta T_G \)

- natural variability dominates?
- ..... this may be simulated by WG

\( \Delta \)be careful with extrapolation ! (smoothing annual cycles may help)

the set of scenarios must reflect uncertainties

\( \Delta \) uncertainty in \( \Delta T_G \):

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>emissions</th>
<th>clim. sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>high scenario:</td>
<td>SRES-A2</td>
<td>4.5 K</td>
</tr>
<tr>
<td>low scenario:</td>
<td>SRES-B1</td>
<td>1.5 K</td>
</tr>
<tr>
<td>middle scen.:</td>
<td>middle</td>
<td>2.5 K</td>
</tr>
</tbody>
</table>

\( \Delta \) uncertainty in pattern:

set of GCMs

\( \Delta \)natural variability is modelled by WG
concluding remarks – summary of methodology

\[ \text{weather series(future)} = W[G(\text{PAR(OBS)} \times \text{CCS(GCM)})] \]

where
- WG = M&Rf
- CCS (climate change scenario)
  - includes changes in means and variability (both daily and monthly)
  - is determined by the pattern scaling technique:
    \[ \text{CCS} = \text{CCS(GCM)} \times \Delta T_G(MagicC(clim.sens.,emis.scen)) \]

- the methodology accounts for several uncertainties:
  - between-GCM differences (by using several GCMs)
  - uncertainties due to clim. sensitivity and emission scenario (by using several \( \Delta T_G \) values modelled by MAGICC)
  - natural variability (through WG/dWG coupled to mWG)

concluding remarks - problems to be solved
(to adapt our methodology to AR4 data)

- reduce number of GCMs
  - IPCC-AR4 GCM database: 24* models, 19 institutes, 17 modelling groups

- solve problems with VAPO and WIND
  - VAPO: available only in a set of pressure levels
  - WIND: only meridional and zonal components available
  - implementation of these variables into WG
    (meanwhile, we’ll keep using NN-resampling. Problem is, that some models are quite sensitive to changes in VAPO and WIND)

- creating climate change scenario from a mixture of monthly and daily GCM outputs (daily GCM series are shorter)
  - some variables are available only daily series (which are shorter than monthly series)

B1: CC impacts on spring barley
(Trnka et al., 2004, Clim Change)

- 3 Czech sites
- crop model: CERES-Barley
- climate change scenarios: 3GCMs (from IPCC-AR2) scaled by \( \Delta T_G \), projected by MAGICC (assuming B30a emission scenario) for 2xCO
- 99-year weather series generated by Met&Roll
- Results presented in terms of percentiles: 5%, 25%, 50%, 75%, 95%
- shown here:
  - direct and indirect effects of doubled CO₂ on crop yields
  - sensitivity to planting date
  - effect of cultivar

Spring barley: Adaptation to the climate change through the shift in the planting date

Figure 5. Adaptation to the climate change through the shift in the planting date in Region 2. The shift is given in terms of the deviation in days from the representative year’s planting date (29th March). The bars represent quantiles (5th, 25th, median, 75th, 95th) of the model yields obtained in the 99-year crop model simulations for present and changed climate. The changed climate is represented by ANG scenarios. The shaded bars refer to the representative year’s planting date.

(Trnka et al., 2004, Clim Change)

Spring barley: Adaptation to the climate change through the use of cultivars with different length of vegetation

Figure 6. Adaptation to the climate change through the use of cultivars with different length of vegetation. Legend: early = 5 days shorter vegetation period than the presently used Akcér cultivar; semi-early = 2 days shorter; late = 5 days longer; semi-late = 2 days longer. The bars represent quantiles (5th, 25th, median, 75th, 95th) of the model yields obtained in the 99-year crop model simulations present and changed climate. The 2xCO weather is based on ANG scenarios.

(Trnka et al., 2004, Clim Change)
B2: Impact of climate change on winter wheat

- A site specific study for 7 sites in Czechia
- 3 projection periods: 2025, 2050, 2100
- A crop model: CERES-Wheat
- Climate change scenarios: 7 GCM (IPCC-SAR)
  - high: A2+(K=4.5)
  - low: B1+(K=1.5)
- 99-year input weather series generated by Met&Roll
- Results presented in terms of MIN / AVG±STD / MAX

B3. Spatial crop model simulations for Czechia

- A crop model = CERES-Wheat (Mirek Trnka's words: 'very carefully calibrated')
- A weather generator = M&RS (daily, 4-variate [TMIN, TMAX, PREC, SRAD]; here - Met&Roll)
- A data: 0.5x0.5 km soil map (394 soil types) produced by MUAF
- 125 weather stations (provided by CHMI)
- A spatial analysis (for given climate scenario):
  - step 1: the model is used to simulate crop growth for all 49250 possible combinations of [weather station, soil type]
    - each simulation: 99-year crop model run with synthetic weather series
    - present climate: WG is calibrated using station daily weather series
    - changed climate: WG parameters modified according to CC scenario
  - step 2: crop yields are interpolated into 0.5x0.5 km grid map. For each grid box, the yield is interpolated from the 125 simulations made for a given grid-specific soil type
  - interpolation method = nearest neighbours with accounting for the x-y-z trends

Spatial crop model simulations for Czechia - soil types

Interpolated model wheat yields for now and 2050

data: 125 weather stations X 394 soil types; HadCM3/SRES-A2-high scenario

CC impact on wheat yields - arable lands
(2050 - HadCM3/SRES-A2-high scenario)

- a) only changed weather effect
- b) combined effect of CO2+weather
- c) difference: combined effect minus weather effect
  ( = CO2 fertilisation effect under changed climate)

B4. Modelling climatological niches of European corn borer in Changed climate

- model: ECAMON (Trnka et al., 2007, Ecological Modelling)
- climate change scenarios:
  - 4 GCMs x 3K x 7 periods
  - IPCC-AR3 (standardised scenarios):
    - HadCM3, ECHAM, NCMR-PCM, CSIRO
  - 3 values of ΔT: low / middle / high
  - 7 target periods: 2010, 2015, 2020, 2025, 2030, 2040, 2050
- results:
  - future:
    - significant increase of area affected by corn borer: from 18% (1961-1990) to 30-100% (2050)
    - main crop production regions will be regularly endangered by 2nd generation
  - similarly dramatical changes may be expected for other insects
**B5. Climate change impacts on drought**

- **Data:** 7 GCMs from IPCC–AR3 (2001)
- **Projection Period:** 2070–99
- **Method:** Relative PDSI applied to GCM grids + combining information from all GCMs

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**Combining information from 7 GCMs**

**Motivation:**
To show the multi-model mean/median + uncertainty in a single map.

**Step 1:** Results obtained with each of 7 GCMs are re-gridded into 1x1° resolution.

**Step 2:** Median (med[X]) and std [std(X)] from the 7 values in each grid box are derived.

**Step 3:** (Map): the median is represented by a color, the shape of the symbol represents value of uncertainty factor $Q$:

$$Q = \frac{\text{std}(X)}{\text{med}(X)}$$

**Interpreting the uncertainty:**
- Squares and circles: $\text{std}(X) < 0.5 \times \text{med}(X)$ indicate that med[X] differs from 0 at significance level higher than 95% (roughly).
- 4-point stars indicate high uncertainty: $\text{std}(X) > \text{med}(X)$

Or: the greater is the proportion of grey (over sea) or black (over land) colour, the lower is the significance, with which the median value differs from 0.
2070-99 drought conditions in Europe in terms of rel. drought indices

PDSI: year

W: winter

S: spring

S: summer

A: autumn

end

find more:

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