Impacts of Climate Change on Agriculture in the Czech Republic
Part 1: Methodology

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

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Part 1: methodology - outline

1. methodology of climate change impact analysis

2. climate change scenarios (including uncertainties)

3. weather generator (Met&Roll)

4. PERUN system
   crop yield forecasting
   climate change impact analysis

5. crop yield potential of the Czech Republic (recent experiments)

6. future plans
1. Impacts on crop yields - methodology

- daily weather series for present climate conditions
- information about:
  - growing site
  - plant genetics
  - soil properties
  - management
- daily weather series for changed climate conditions

CROP GROWTH MODEL

- model output for present climate conditions
- model output for changed climate conditions

analysis of climate change impacts

multi-year simulation is made to assess mean and variability of crop yields !!!
Two approaches to multi-year crop growth simulations (using crop model)

a) Direct Modification approach

b) Weather Generator approach
a) **Direct Modification (DM) approach**

Legend:
- \( WO(i) \) = observed weather (present)
- \( WO'(i) \) = modified observed weather
- \( INP(i) \) = non-meteo input to crop model
- \( Y, Y'(i) \) = crop yield
- \( i = \) index of the year
b) **Weather Generator (WG) approach**

Legend:
- WS(i) = synthetic weather (present)
- WS'(i) = synthetic weather (future)
- INP(R) = non-meteo input based on a representative year

Y(i), Y'(i) = crop yield

i = index of the year

analysis of climate change impacts
a) direct modification approach (17 years series)

impacts on maize (Zalud and Dubrovsky, 2002)

b) Weather Generator approach (99 years series)

→ trends obtained by both WG and DM approaches are similar
2. Stochastic weather generator (Met&Roll)

basic version of Met&Roll ~ WGEN (Richardson, 1981)

**PREC:**
- occurrence ~ 1st order Markov chain
- amount ~ Gamma distribution

**SRAD, TMAX, TMIN** ~ AR(1)
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
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

→ **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]
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 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]
indirect validation of Met&Roll using rainfall-runoff model
monthly maxima of daily model (SAC-SMA) streamflows (39-y simulations)

[DBZ, 2004]
Probability distribution of 5-day average model streamflow simulated with observed (CB) and synthetic weather series

[DBZ, 2004]
Met&Roll - indirect validation (comments)

• inclusion of the annual cycle of correlations has 
  no apparent effect on the results obtained by crop 
  model and hydrological model

• increased order of the Markov chain improves 
  reliability of output from the two simulation models

• conditioning the daily generator on monthly 
  generator improves the statistical properties of the 
  output from both simulation models (the greatest 
  improvement of the three modifications)
sensitivity of maize yields
to stochastic structure of input weather series

| I | P11=0 |
P01=P11=P1  
P01 x 0.5  
P01 x 0.25  
P01 x 0.7 |
|---|-------|
| H | Gsc x 0.67; P x 1.5  
Gsc x 1.5; P x 0.67 |
| G | Gsh x 0.06  
Gsh x 0.25  
Gsh x 4 |
| F | (P1,P01) x 1.5  
(P1,P01) x 1.25  
(P1,P01) x 0.75 |
| E | Gsc x 1.5 |
| D | high persist  
no persist |
| C | s(X) x 1.5  
s(X) x 1.25  
s(X) x 0.75  
s(X) x 0.5  
s(X) x 0.1 |
| B | Tmax+2; Tmin-2  
Tmax+1; Tmin-1  
Tmax-1; Tmin+1  
Tmax-2; Tmin+2 |
| A | T+4  
T+2  
T+1  
T-1  
T-2 |
| no change |

Legend: 5th 25th median 75th 95th

[DZS 2000]
3. Climate change scenario (old version)

- **data:** 7 GCMs run at IS92a (or similar) emission scenario
  GCMs were validated using Czech station data and CRU climatology

- **method:** pattern scaling
  \[ dX = dX^* \times \Delta TG \]
  - where \( dX^* \) is standardised scenario
  - \( \Delta TG \) is change in global mean temperature (estimated by MAGICC)

- **set of climate change scenarios** suggested to be used in impact studies to cover uncertainties

- **changes in variability** were not included in the scenario, but the effect of variability was studied (sensitivity analysis)
uncertainties in climate change scenario
standardised climate change scenario
- uncertainty due to regression
standardised climate change scenario:
- uncertainty due to regression
uncertainties in climate change scenario: TAVG
(avg ± std)
uncertainties in climate change scenario: PREC
(avg ± std)
set of climate change scenarios

3 GCMs

- **HadCM2**: lower temperature increase and insignificant change in annual precipitation

- **NCAR or CSIRO**: lower temperature increase and moderate precipitation increase

- **ECHAM4**: higher temperature increase and slight precipitation decrease

• **3 values of ∆TG** (estimated by MAGICC):

  low / middle / high
4. PERUN
system for crop model simulations at various meteorological conditions

- tasks solved by PERUN:
  - probabilistic seasonal crop yield forecasting
  - climate change impact analysis
  - sensitivity analysis (up to 3 parameters simultaneously)
  - single-site or multiple-site analysis
PERUN - components

1) WOFOST crop model
   - provided by Alterra Wageningen)
   - calibrated for several crops and several locations in the Czech Republic

2) Met&Roll weather generator

3) user interface
   - input for WOFOST (crop • soil and water • weather & climate • start/end of simulation • production levels • fertilisers ...)
   - launching the process (preparing weather series, crop model simulation)
   - statistical and graphical processing of the simulation output
PERUN - user interface
5. Crop yield potential of the Czech Rep. (in present and future climate)

(~ integral of model crop yields over CR’s territory)

input data:
- soil map (25 soil types) in 1x1 km resolution
- 45 weather stations

method

1) crop simulations for 25 x 45 soil-climate combinations (PERUN system is used)

2) crop yield in [x,y] is obtained by interpolation using 45 crop model simulations for [x,y]'s soil type
Soil types
Czech Republic: relief + weather stations
mean limited yields [preliminary results]

HadCM2 climate (2050)

present climate
mean potential yields [preliminary results]

HadCM2 climate (2050)

present climate
6. plans (wishes) for future

- **weather generator:**
  - better representation of the additional variables
  - interpolation of the WG parameters
  - make the generator more user-friendly

- **climate change scenarios:**
  - new GCMs
  - RCM (are daily data simulated by RCM applicable?)

- **PERUN system:**
  - implementation of CERES model

- **crop yield potential of the Czech Republic**
  - optimise the upscaling technique
• Nemesova I., Kalvova J., and Dubrovsky M., 1999: Climate change projections based on GCM-simulated daily data. *Studia Geophysica et Geodaetica* 43, 201-222.
• Trnka M., Dubrovsky M., Semeradova D., Zalud Z., 2004: Projections of uncertainties in climate change scenarios into expected winter wheat yields. *Theoretical and Applied Climatology*, 77, 229-249
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