Crop calorie supply under climate change and vulnerability to drought events at +2°C of global warming threshold in Europe

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IIASA, BOKU, CRI, JRC
Outline

• Methods

• Tools validation
  • Vulnerability to drought events
  • Impact of a +2°C global warming
  • Bracketing uncertainties
Environmental Policy Integrated Climate (EPIC) model

The EPIC model (Williams et al. 1996)

Climate change
- T, PRCP distr., patterns
- Extremity
- atm. CO2 effect

Production
Embedded C,N,P
Emb. energy

Weather
- daily T, PRCP, RAD, wind, RHUM
- Weather generator
- CO2 fertilization / WU efficiency
- PET
- Temperature stress

Management
- N,P,K and manure fertilization
- Irrigation
- Tillage
- Crop rotation, intercropping,....
- Drainage
- Pesticide fate
- Grazing/mowing
- Residue management

Evaporation
Transpiration Uptake

Rainfall
Irrigation
Water erosion

Surface runoff
Subsurface flow

Water table dynamics
Percolate
Water route

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**EPIC-IIASA GGCM** to simulate agricultural systems at large scale

- EU-version gridded at 1-km resolution (Balkovič et al. 2013)

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EPIC-IIASA GGCM Agricultural crop calorie yield

\[ y_{t,p,s,c} = (1 - f_{c,p}) \cdot y(r)_{t,p,s,c} + f_{c,p} \cdot y(i)_{t,p,s,c} \]

\[ Y_{t,p,s} = \sum_{c=1}^{k} g_c \cdot y_{t,p,s,c} \]

- \( y_{t,p,s,c} \): simulated crop yield (in t ha\(^{-1}\))
  - \( c \): crop (maize, wheat, rye, barley, rapeseed, sunflower, sugar beet, potato, soya, rice)
  - \( p \): grid cell,
  - \( s \): climate change scenario
  - \( t \): year

- \( y(r), y(i) \): simulated crop yield under rainfed (r) and irrigated conditions (i)

- \( f_{c,p} \): fraction of irrigated area of the \( c \)-th crop in the \( p \)-th grid,

- \( Y_{t,p,s} \): aggregated calorie yield (in Gcal ha\(^{-1}\))
  - \( k \): number of crops

- \( g_c \): calorie content in the unit yield

**BAU:** BAU-fertilization and irrigation (Balkovič et al. 2013; Wriedt et al. 2009)

**POT-RF:** yield potential for rainfed systems

**POT-IR:** yield potential for irrigated systems and environments not limited by water

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MODEL VALIDATION Long-term historical crop calorie yields

- CGMS weather data from 1990 to 2000
- Aggregated at EU NUTS2 regions (EPIC vs EUROSTAT)

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MODEL VALIDATION  Anomalies in crop calorie yields due to drought events

- Heat wave and drought 2003

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EPIC-IIASA VALIDATION  Anomalies in crop calorie yields due to drought events

- Heat wave and drought 2007

Russo et al. (2015, ERL 10)

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**VULNERABILITY** Concept of vulnerability to drought events

- **Yield vulnerability** ($V$) is quantified as a fraction of crop yield that may be lost due to harmful effects of climate.

- The meteorological drought was identified using SPEI (Vicente-Serrano et al. 2010) calculated monthly.

- Drought: mean SPEI over the growing season $< -1$ (Van Oijen et al. 2014)

- Vulnerability to meteorological drought ($V_d$):

$$V_d = \sum_{c=1}^{k} \left( \frac{1}{n} \sum_{t=1,s=1}^{n} g_c \cdot y_{t,p,s,c} \right) - \sum_{c=1}^{k} \left( \frac{1}{m} \sum_{t=1,s=1}^{m} g_c \cdot y_{t,p,s,c} \right)$$

- $m$ years with SPEI $< -1$
- $n$ years with SPEI $\geq -1$

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VULNERABILITY Proof Of Concept

- mean SPEI of crop growing season
- regionalized index of drought

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VULNERABILITY SPEI to determine yield vulnerability

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+2°C WARMING Background

- The Quantifying Projected Impacts Under 2°C Warming (IMPACT2C) Project (http://impact2c.hzg.de)
- Bias-corrected data from EURO-CORDEX database form IMPACT2C

- CSC-REMO/MPI-ESM-LR (RCP 4.5)
- SMHI-RCA4/EC-EARTH (RCP 4.5)
- KNMI-RACMO22E/EC-EARTH (RCP 4.5)
- SMHI-RCA4/HadGEM2-ES (RCP 4.5)
- IPSL-WRF331F/IPSL-CM5A-MR (RCP 4.5)

- +2°C period when the 30-year running mean temperature calculated from the base period 1971–2000 exceeds the +2°C threshold globally (Vautard et al., 2014)
+2°C WARMING Mean impact

- EURO-CORDEX-mean calories change
- Robustness across CC projections

Conventional impact approach:
- BAU-scenario, all available cropland
- Full physiological impact of elevated atm. CO₂

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high vulnerability (> 40 Gcal/ha) in the Pannonian zone, namely Bulgaria, Romania, and Hungary
followed by Greece and Spain (> 30 Gcal/ha)

Figure. Crop calorie yield distribution under +2°C (red: years with dry GS, blue: years with normal GS)
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+2°C WARMING Projection uncertainty (T and CO₂)

- Uncertainty analysis of elevated CO₂ and temperature impacts (wheat example)
- KNMI projection
- Ample nutrients; rainfed and irrigated

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Soil degradation (D)
Soil degradation with conservation practices (Dc)
Crop intensification (POT)
Elevated CO₂ impact (+/− CO₂)
Temperature impact

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Thank you for your attention!