Analysis of a fire danger index over Southeast Europe

Péter Szabó, Rita Pongrácz, Judit Bartholy

ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Meteorology, Budapest, Hungary, Contact: szabo.p.elte@gmail.com

1. Introduction and Summary

- Rising wildfire risk in Northern Southeast Europe: Historically less prone to forest fires, the region is facing climate change with rising temperatures, more frequent heatwaves, and unpredictable rainfall creating ideal wildfire conditions.
- Wildfire disasters in 2023: Canada (largest: 170,000 km²); Greece (EU's worst wildfire since 2000); Hawaii (97 deaths); Kazakhstan (deadliest steppe fire).
- Forest Fire Danger Index (FFDI): incorporating wind speed, temperature, humidity, and soil dryness as pre-condition (using Keetch-Byram Drought Index).
- Results: FFDI reveals significant wildfire risk increase in Romania, Bulgaria, Serbia, Hungary, and Croatia after 2060, especially under the RCP8.5 scenario.
- Impacts: damage to property, life, yield losses, and air quality.
- Urgent need for action: Enhanced fire monitoring, education, and warning systems are crucial to address the growing wildfire threats in the region.

2. Methodology and Data

Fire = long-term effects and short-term conditions

Favorable daily conditions for fires:
very dry soil and vegetation (long-term)
AND
hot and dry synoptic weather situation (short-term)

KBDI: Keetch-Byram Drought Index (long-term)
- by U.S. Forest Service for the likelihood of wildfires
- net effects of evapotranspiration and precipitation
  –> cumulative daily moisture in upper soil layers and rotting leaves (usually lowest during late summer)
- already suitable for predicting fuel moisture and fire spread:
  100-150 mm: very dry soil, burn can be active
  >150 mm: extremely dry soil, increased wildfires and deep burning

$$KBDI_t = KBDI_{t-1} + ET - PNET \qquad PNET = Pre - 5 \mid Pre > 5$$

$$ET = (203.2 - KBDI_{t-1}) * \frac{0.968 * e^{0.0875*Tmax+1.5552} - 8.3}{1 + 10.88 * e^{-0.001736*AP}} * 10^{-3}$$

Pre – daily precipitation, Tmax – daily maximum temperature, AP – annual mean precipitation

FFDI: Forest Fire Danger Index (short-term)
- by CSIRO for the degree of danger, for fire spread after ignition
- combination of different weather conditions (low RH, high T, strong W)
- we need pre-condition: very dry soil by KBDI
- 5-12: moderate, 12-24: very high, >24: extreme

$$FFDI = 12.5 * e^{0.0234 * W + \frac{Tmean - RH}{30}}$$

W – wind speed, Tmean – mean temperature, RH – relative humidity

Data used

Daily surface data of 5 variables: Pre, Tmax, W, Tmean, RH

1) HUCLIM observations (ver. 2023)

homogenized for Hungary
dense network of stations
0.1° resolution
2001–2022 (by HungaroMet)

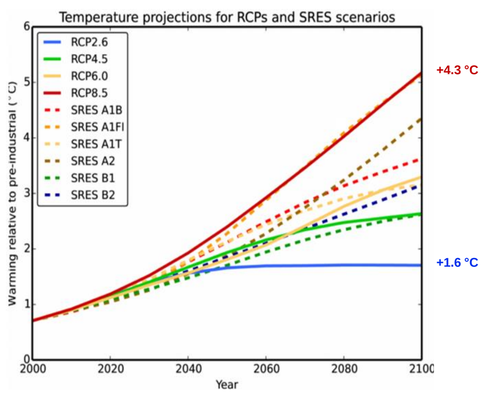
2) E-OBS observations (ver. 28)

quality-controlled, but not homogenized for Europe
few stations in some regions
0.1° resolution
2001–2022 (by Copernicus, ECA&D)

3) Simulations

5 Euro-CORDEX regional climate models
0.11° resolution
historical simulations until 2005
& scneario simulations from 2006 to 2100:
RCP2.6 (immediate mitigation),
RCP8.5 (business as usual)
uncertainty + bias-adjustment (?)

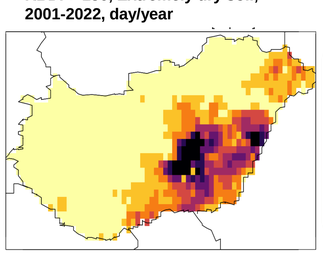
RCM\GCM	CNRM-CM5	EC-EARTH	NorESM1-M
ALADIN63	x		
HIRHAM5		x	
RACMO22E	x		
RCA4			x
REMO2015			x



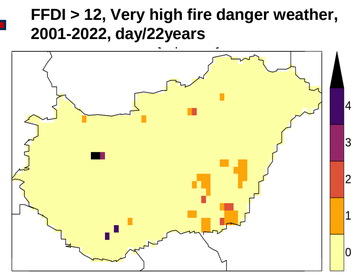
3. Observations in Hungary

We analyzed HUCLIM – has better representation of stations over Hungary

KBDI > 150, Extremely dry soil, 2001-2022, day/year



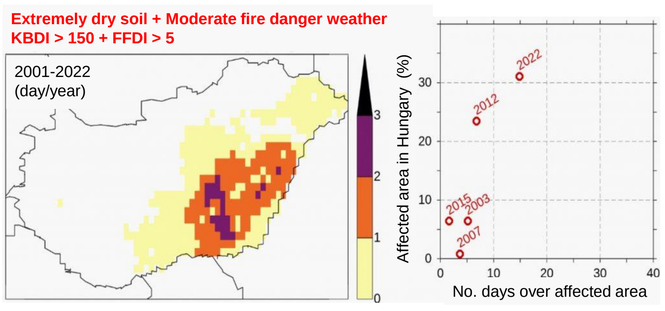
FFDI > 12, Very high fire danger weather, 2001-2022, day/22years



Some days of extremely dry soil + basically no days with very high fire danger weather. No days with both.

Take the moderate danger threshold, FFDI > 5 instead.

Extremely dry soil + Moderate fire danger weather
KBDI > 150 + FFDI > 5



Results: Currently low risk in 2001-2022

Except: Great Hungarian Plain (croplands, steppe)

0-3 day/year, but occurred only in 5 years since 2001

Most extreme: 2022, then 2012

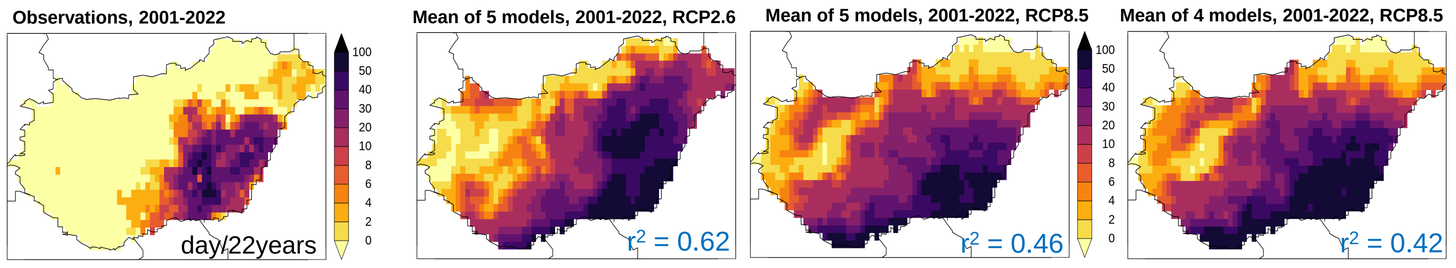
2012 and 2022 correlates well with satellite data

Satellite: 10x more burnt areas in 2022 than before, Natura2000 affected

5. Simulation results

Evaluation

- It is a complex indicator (**Fire danger = KBDI > 150 + FFDI >5**) that requires 5 daily weather variables.
- It is challenging to conduct evaluations when occurrences are few or non-existent.
- Individual models perform poorly compared to observations (HIRHAM5, RACM22E underestimate, RCA4, REMO2015 overestimate), but **their ensemble means are acceptable**.
- Which RCP is closer to observations? **RCP2.6 shows higher spatial correlation, and more model simulations perform better.**

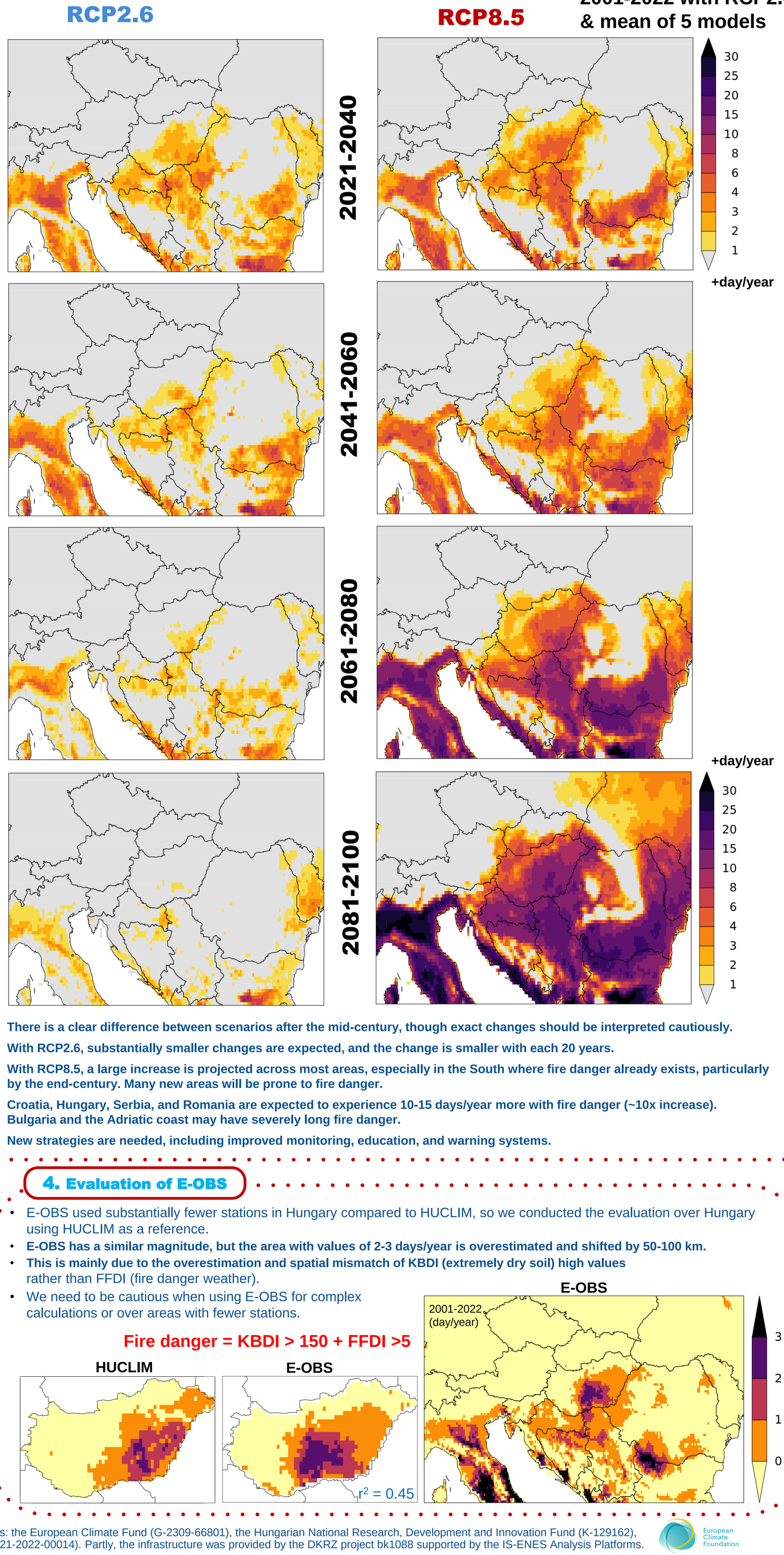


Future results

- We tested bias correction methods of both absolute and relative deltas.
  The relative delta (*MOD_future/MOD_past*OBS_past*) does not generate values where none existed in the past.
- Since the spatial correlation is worse for E-OBS compared to the RCP2.6 mean of 5 models, **we present the results of raw changes instead of those derived from the absolute delta** (*MODEL_future-MODEL_past+OBS_past*).

Change of fire danger

Reference: 2001-2022 with RCP2.6 & mean of 5 models



There is a clear difference between scenarios after the mid-century, though exact changes should be interpreted cautiously.

With RCP2.6, substantially smaller changes are expected, and the change is smaller with each 20 years.

With RCP8.5, a large increase is projected across most areas, especially in the South where fire danger already exists, particularly by the end-century. Many new areas will be prone to fire danger.

Croatia, Hungary, Serbia, and Romania are expected to experience 10-15 days/year more with fire danger (~10x increase). Bulgaria and the Adriatic coast may have severely long fire danger.

New strategies are needed, including improved monitoring, education, and warning systems.

4. Evaluation of E-OBS

- E-OBS used substantially fewer stations in Hungary compared to HUCLIM, so we conducted the evaluation over Hungary using HUCLIM as a reference.
- **E-OBS has a similar magnitude, but the area with values of 2-3 days/year is overestimated and shifted by 50-100 km.**
- **This is mainly due to the overestimation and spatial mismatch of KBDI (extremely dry soil) high values** rather than FFDI (fire danger weather).
- We need to be cautious when using E-OBS for complex calculations or over areas with fewer stations.

Fire danger = KBDI > 150 + FFDI >5

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