Modelling forest fire under climate change scenarios.

Giuseppe Amatulli
Overview

- Introduction to the forest fire issues
  - Objectives of the research
  - Dataset
    - EU fire database (Burnt Area) (response variable)
    - Weather data (ECMWF-ERA40 / PRUDENCE-DMI) (predictor variables)
  - Methodology
    - Data integration
    - Model fitting and prediction
  - Results
    - Model performance and visualization
  - Conclusions
  - Technical details
Introduction to the forest fire issues

Variables
- Weather cond.
- Vegetation cond.

FIRE RISK Assessment
- Topography
- Fuel Types
- Soils
- Fire history
- Population
- Socio-ec.

Approach
- DYNAMIC (short-term)
- STATIC (long-term)

Fire management
- Pre-suppression
- Suppression
- Prevention

INTEGRATED
Introduction to the forest fire issues
Fire Weather Index (FWI)

Mature Pine Forest (jack pine and lodgepole pine) - Level terrain

Meteorological observations
- Air temperature
- Relative humidity
- Wind speed
- Rainfall

Fuel Moisture Codes
- Fine Fuel Moisture Code (FFMC)
- Duff Moisture Code (DMC)
- Drought Code (DC)

Fire behavior Indices
- Initial Spread Index (ISI)
- Build Up Index (BUI)

FIRE WEATHER INDEX (FWI)\textsubscript{(DSR)}

Each individual component is a fire danger index, revealing different aspects of fire danger which are finally difficult to synthesize with one single number (Alexander 2008)
## Interpretation of Fireline intensity

<table>
<thead>
<tr>
<th>Fireline Intensity (kW/m)</th>
<th>Flame Length (m)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 350</td>
<td>Under 1.2</td>
<td>Fires can generally be attacked at the head or flanks by persons using hand tools. Hand line should hold the fire.</td>
</tr>
<tr>
<td>350-1750</td>
<td>1.2-2.4</td>
<td>Fires are too intense for direct attack on the head by persons using hand tools. Hand line cannot be relied on to hold the fire. Equipment such as dozers, pumpers, and retardant aircraft can be effective.</td>
</tr>
<tr>
<td>1750-3500</td>
<td>2.4-3.4</td>
<td>Fires may present serious control problems - torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.</td>
</tr>
<tr>
<td>Over 3500</td>
<td>Over 3.4</td>
<td>Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.</td>
</tr>
</tbody>
</table>

(Rothermel 1983)
The European Forest Fire Information System (EFFIS)
email: effis@jrc.it  web: http://effis.jrc.ec.europa.eu

Meteorological Data from Deutscher Wetterdienst
(c)EuroGeographics for the Administrative Boundaries
Processing by JRC/IES/MNH - Forest Action

The European Forest Fire Information System (EFFIS) supports the services in charge of the protection of forests against fires in the EU member states.
EFFIS has been developed jointly by the Directorate General for the Environment and the Joint Research Centre.
It provides the European Commission services and the European Parliament with updated and reliable information on wildland fires in Europe.
Objectives of the research

Objectives

- To build up a statistical model based on historical data (1985-2004) at EU-Mediterranean and Country level:
  Monthly burnt areas -> Monthly weather data (Fire Weather Index)

- To analyze potential trends under present and future climate condition

- To consider possible applications for monthly forecasting using ECMWF products
The EU Fire Database is a collection of fire events recorded by the EU member states and compiled at EU level at JRC.

- NUTS3 level (province), reporting date, burnt area, etc.
- Available period for EU-Med 1985 - 2004 (20 years)
Dataset: ECMWF-ERA40

ERA40  1958-2002
MARS  2003-2007
Resolution 1.125°

ERA40 1961-1990
ERA40 1985-2004

Parameters:
Temperature
Precipitation
Wind
Humidity
Dataset: PRUDENCE-DMI

PRUDENCE DMI (RCM) HIRHAM
Resolution 50 km
Control 1961-1990
A2 2071-2100
A2 2071-2100

Parameters:
Temperature
Precipitation
Wind
Humidity

The Control under-estimate the parameters

Not easy to re-project the data
Methodology

- Daily calculation of FWI and sub-indexes
  - Prudence DMI -> Control and A2 B2 scenarios
  - Monthly average for each sub-indexes
- Finally weighted average for each NUTS3 based on the area
- NUTS3 weighted aggregation at EU-Med. and Country level

- Multiple regression with step-wise selection
  Sum of Burnt Area -> Indexes Monthly Average (240 observations)

\[
\text{Burnt Area}_{\text{sum}} = a \text{FFMC}_{\text{avg}} + b \text{DMC}_{\text{avg}} + c \text{DC}_{\text{avg}} + d \text{ISI}_{\text{avg}} + f \text{BUI}_{\text{avg}} + g \text{DSR}_{\text{avg}} + h + \varepsilon
\]

- 2 Models: Summer-Autumn (May to November) (140 observation)
  Winter-Spring (December to April) (100 observation)
- Future climate condition = ERA40 1961-1990 + (Scenario PrudenceDMI – Control PrudenceDMI)

www.spatial-ecology.net
BurntArea = \exp^\left( a X_1 + b X_2 + \ldots + c \right)

### Summer-Autumn (May to November)

<table>
<thead>
<tr>
<th>Country</th>
<th>Intercept</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>AV_DC</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>AV_ISI</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>Res.Std.Err</th>
<th>Rsq</th>
<th>p-value</th>
<th>Adg.R-sq</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUmed</td>
<td>4.8504</td>
<td>0.1733</td>
<td>0.0000***</td>
<td>0.0036</td>
<td>0.0000***</td>
<td>0.6462</td>
<td>0.0293</td>
<td>0.0000***</td>
<td>0.6462</td>
<td>0.0293</td>
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<td>0.6462</td>
<td>0.0293</td>
<td>0.0000***</td>
<td>0.6462</td>
<td>0.0293</td>
<td>0.0000***</td>
</tr>
<tr>
<td>PT</td>
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<td>0.3257</td>
<td>0.0000***</td>
<td>0.0048</td>
<td>0.0000***</td>
<td>0.8372</td>
<td>0.0540</td>
<td>0.0000***</td>
<td>0.8372</td>
<td>0.0540</td>
<td>0.0000***</td>
<td>0.8372</td>
<td>0.0540</td>
<td>0.0000***</td>
<td>0.8372</td>
<td>0.0540</td>
<td>0.0000***</td>
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<tr>
<td>ES</td>
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<td>0.2509</td>
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<td>0.0335</td>
<td>0.0000***</td>
<td>0.4862</td>
<td>0.0335</td>
<td>0.0000***</td>
<td>0.4862</td>
<td>0.0335</td>
<td>0.0000***</td>
<td>0.4862</td>
<td>0.0335</td>
<td>0.0000***</td>
</tr>
<tr>
<td>FRmed</td>
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<td>0.2813</td>
<td>0.0000***</td>
<td>0.0049</td>
<td>0.0000***</td>
<td>0.8919</td>
<td>0.0760</td>
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<td>0.0760</td>
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<td>0.0760</td>
<td>0.0000***</td>
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<td>0.0000***</td>
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<td>0.0000***</td>
<td>0.5514</td>
<td>0.0418</td>
<td>0.0000***</td>
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<td>0.0000***</td>
<td>0.5514</td>
<td>0.0418</td>
<td>0.0000***</td>
</tr>
</tbody>
</table>

### Winter-Spring (December to April)

<table>
<thead>
<tr>
<th>Country</th>
<th>Intercept</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>AV_FFMC</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>AV_DC</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>AV_ISI</th>
<th>Std.Err</th>
<th>P-value</th>
<th>Signif</th>
<th>Res.Std.Err</th>
<th>Rsq</th>
<th>p-value</th>
<th>Adg.R-sq</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUmed</td>
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<td>0.0129*</td>
<td>0.1447</td>
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<td>0.0000***</td>
<td>0.76</td>
<td>0.6913</td>
<td>0.6854</td>
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</tr>
<tr>
<td>PT</td>
<td>1.1440</td>
<td>0.4329</td>
<td>0.0097**</td>
<td>1.2776</td>
<td>0.6343</td>
<td>0.00017</td>
<td>0.0009</td>
<td>0.0650</td>
<td>0.3241</td>
<td>0.1757</td>
<td>0.0681*</td>
<td>1.5000</td>
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<td>1.5000</td>
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<tr>
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<td>0.0009</td>
<td>0.0650</td>
<td>0.3241</td>
<td>0.1757</td>
<td>0.0681*</td>
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<td>0.5031</td>
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<td></td>
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<tr>
<td>FRmed</td>
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<tr>
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<td>0.6343</td>
<td>0.0770</td>
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<td>0.0008</td>
<td>0.0001***</td>
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<td>0.6937</td>
<td>0.0000***</td>
<td>0.8796</td>
<td>0.7030</td>
<td>0.6937</td>
<td>0.0000***</td>
<td></td>
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<tr>
<td>GR</td>
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<td>0.0940</td>
<td>0.0328</td>
<td>0.0051**</td>
<td>0.7161</td>
<td>0.2476</td>
<td>0.0047**</td>
<td>1.9450</td>
<td>0.5945</td>
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<td>1.9450</td>
<td>0.5945</td>
<td>0.5860</td>
<td>0.0000***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Signif. Codes: 0 **** 0.001 *** 0.01 ** 0.05 * 0.1 '.' 1
Results: Model fitting

3d interpolated surface

- Burned Area (ha)
- ISI_AVG

- May
- June
- July
- August
- September

- October
- November
- Interpolated Surface
- Interpolated Surface + Std. Error
- Interpolated Surface - Std. Error
Results: Model fitting

3d interpolated surface

Burned Area (ha)
Results: Present and future trends

Potential burnt area trend under present and future climate conditions.
Prediction of September

Interpolated Surface based on Observations 1985-2004
Observations 1985-2004
68.27% of the Observations 1985-2004
Prediction 1961-1990
68.27% of the Prediction 1961-1990
Prediction A2 2071-2100
68.27% of the Prediction A2 2071-2100
Prediction B2 2071-2100
68.27% of the Prediction B2 2071-2100
Observations average 1985-2004
Observations average+std 1985-2004
Prediction average 1961-1990
Prediction average+std 1961-1990
Prediction average 1961-1990
Prediction average+std 1961-1990
Prediction average A2 2071-2100
Prediction average+std A2 2071-2100
Prediction A2 2071-2100
Prediction+std A2 2071-2100
Prediction B2 2071-2100
Prediction+std B2 2071-2100
Prediction B2 2071-2100
Prediction+std B2 2071-2100
Prediction B2 2071-2100

Burned Area (ha)

ISI_AVG

DC_AVG
Results: Present and future trends

Potential burnt area trend under present and future climate conditions.

Prediction of May

Interpolated Surface based on Observations 1985-2004
Observations 1985-2004
68.27% of the Observations 1985-2004
Prediction 1961-1990
68.27% of the Prediction 1961-1990
Prediction A2 2071-2100
68.27% of the Prediction A2 2071-2100
Prediction B2 2071-2100
68.27% of the Prediction B2 2071-2100
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Observations average+std 1985-2004
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Prediction average 1961-1990
Prediction average+std 1961-1990
Prediction average+std 1961-1990
Prediction average A2 2071-2100
Prediction A2 2071-2100
Prediction A2 2071-2100
Prediction B2 2071-2100
Prediction B2 2071-2100
Prediction B2 2071-2100
Prediction average B2 2071-2100
Prediction average B2 2071-2100
Prediction average B2 2071-2100
Prediction+std B2 2071-2100
Prediction+std B2 2071-2100
Prediction+std B2 2071-2100

Burned Area (ha)
Results: Inter-annual variability

Monthly burned areas in EUmed

- Winter-Spring
  - Observation 1985-2004
  - Prediction 1985-2004
  - Prediction 1961-1990
  - Prediction A2 2070-2100
  - Prediction B2 2070-2100

- Summer-Autumn

Burnt Area at ln scale (ha*1000)

Month

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Results: Inter-annual variability
Results: Inter-annual variability

Monthly burned areas in IT

Winter-Spring
- Observation 1985-2004
- Prediction 1985-2004
- Prediction 1961-1990
- Prediction A2 2070-2100
- Prediction B2 2070-2100

Summer-Autumn

Burnt Area in ha (log scale)

Month
Jan 2 3 4 5 6 7 8 9 10 11 12
Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

www.spatial-ecolc
Results: Annual variability

Summer-Autumn burnt area trend

- Observation 1985-2004
- Observation average 1985-2004
- Prediction 1958-2007
- Prediction average 1958-2007
- Prediction A2 2070-2100
- Prediction average A2 2070-2100
- Prediction B2 2070-2100
- Prediction average B2 2070-2100

Prudence dataset
- Prediction Prudence Control
- Prediction Prudence A2 2070-2100
- Prediction Prudence B2 2070-2100

Year

Burnt Area (ha x 1000)

Anomaly
Conclusions

- Ability of FWI/sub-index to predict Monthly burnt area
  - Good correlation for the Summer-Autumn fire season (by DC-ISI)
  - Discrete correlation for the Winter-Spring fire season (by FFMC DC ISI)
- Potential prediction under future climate change (drastically increment of burnt area)
- Foreseen in the use of obtained models to predict monthly forecasting

Improvements

- Use several future climatic change models (ensemble prediction)
- Building up model at regional scale
Technical details

Hardware:
• Server-cluster of twelve 32bit bi-processor machines running Linux operating system (running bash scripts in processing chains)

Software: (under the GNU General Public License)
• Weather data manipulation (NetCDF-GRI) -> CDO - Climate Data Operators
• Geoprojection change -> GDAL library
• FWI/sub-indexes calculation and average -> AWK language
• Model fitting and prediction -> R
• 3d visualization -> GNUPLOT
• 2d graphs -> R

Thanks giuseppe.amatulli@gmail.com