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Modeling the impacts of climate change on forest fire danger in Europe

Sectorial results of the PESETA II Project

Camia, Andrea
Libertá, Giorgio
San-Miguel-Ayanz, Jesús

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Centre

Contact information:
Name: J.San-Miguel-Ayanz
E-mail: jesus.san-miguel@ec.europa.eu

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1. Introduction and objectives

This constitutes a sectorial analysis of the PESETA II project of the European Commission Joint Research Center in the area of wildfires.

Wildfires are a serious threat to European forests, and climate is the most important driving factor affecting wildfire potential over time (Flannigan et al., 2000). Wildfires are an environmental, economic and social problem particularly in the southern European countries, where wildfires regularly burn thousands of hectares of forests and other lands. Changes in wildfire regimes may have strong impacts on natural resources and ecosystems stability, with consequent direct and indirect economic losses. On the other hand, active forest management and wildfire management practices have some potential to counteract the impacts of a changing climate.

The FOREST Action hosts the European Forest Fire Information System (EFFIS)[1]. EFFIS supports wildfire protection efforts in the EU countries and provides the European Commission services and the European Parliament with information on European forest fires. This project builds off of tools, models and datasets available in EFFIS.

Fire danger is “a general term used to express an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control and fire impact(s)” (Merrill and Alexander, 1987). Fire danger depends on many factors that can change over time (e.g., weather, fuel load, fuel type and condition, forest management practices, socio-economic context…).

Today most wildfires in Europe are caused by human activity (i.e., anthropogenic ignition sources). However, it has been shown that the total burned area in Mediterranean Europe, and thus the overall impact of forest fires, changes significantly from year to year largely because of weather conditions (Camia and Amatulli, 2009). Extreme fire danger conditions in South-eastern Europe leading to major wildfire events have, in many cases, been driven by an explosive mix of strong winds and extremely high temperatures, following prolonged drought periods (San-Miguel-Ayanz et al., 2012).

Meteorologically-based fire danger indices evaluate and summarize the fire danger considering current and past weather. These indices, normally applied on a daily basis, can also provide seasonal summaries to compare the overall wildfire potential of a given year due to meteorological conditions.

Based on these indices, maps of projected change of fire danger in Europe under climate change are being developed. In addition, statistical models linking meteorological fire danger and area burned are being developed, to support assessments of the expected impact of changed fire danger conditions.

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[1] http://effis.jrc.ec.europa.eu/

2. Methods

1.1 Fire danger assessment

This study uses the Canadian Fire Weather Index (FWI) system (Stocks et al., 1989; Van Wagner, 1987) as its meteorological fire index because of its widespread use (San Miguel-Ayanz et al. 2003) including in Europe where it is the fire danger rating system used in EFFIS.

The FWI System has six components rating fuel moisture content and potential fire behaviour in a common fuel type (i.e., mature pine stand) and in no slope conditions. A diagram showing the FWI system structure is presented in Figure 1.

Calculations are based on daily, noontime measurements of air temperature, relative humidity, wind speed and previous 24-h precipitation. The first three components of FWI consist of numerical rating values of the moisture content of forest floor layers with different drying rates and at various depths. Specifically, the Fine Fuel Moisture Code (FFMC) rates the moisture of litter and other dead fine fuels at the top of the surface fuel layer; the Duff Moisture Code (DMC) rates the moisture of the loosely compacted organic layer of moderate depth; the Drought Code (DC) represents the moisture content of the deep layer of compact organic matter. These three moisture codes carry different useful information being indicators of ease of ignition and flammability of fine fuels (FFMC), fuel consumption in medium-size woody material and moderate duff layers (DMC), fuel consumption in large logs and amount of smouldering in deep duff layers (DC) (Alexander 2008).

The last three FWI codes are fire behaviour indices that score the expected rate of fire spread (Initial Spread Index - ISI), the fuel available for combustion (Build Up Index - BUI), and the fire line intensity (FWI). FWI is the final index that combines ISI and BUI (see Figure 1) and rates, the energy output rate per unit length of the fire front, i.e. the fire line intensity calculated according to Byram's formulation (Byram 1959).

An important aspect of the FWI system is that the output only depends on weather observations and does not consider differences in fuel types or topography, providing a uniform, relative way of rating fire danger through fuel moisture and fire behaviour potential (Van Wagner 1987).

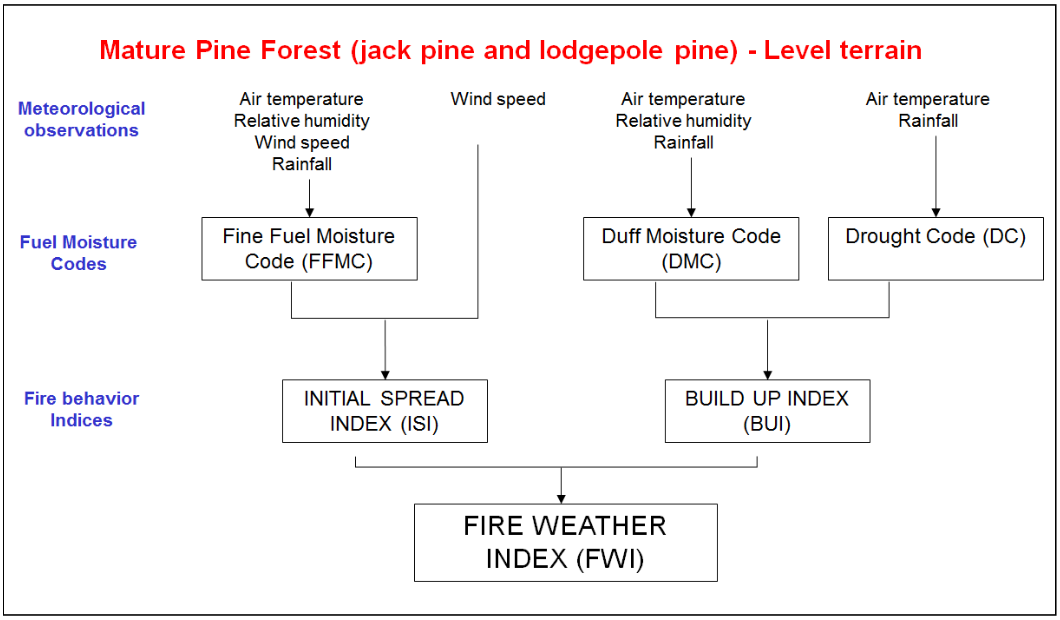

Figure 1. Diagram of the FWI system (explanations in the text)

Several uncertainties are present in projecting long-term climate change impacts on forest fires. The current assessment does not take into account changes in fuel conditions (vegetation), ignitions, and human activity e.g. adaptation or causality, that may influence burnt area and thus wildfire impact. Communicating these aspects is of paramount importance for defining the boundary conditions of the results of this study.

1.2 Fire danger and climate change

High resolutions climate change simulations produced in the framework of the ENSEMBLES project (Van der Linden and Mitchell, 2009) using state-of-the-art Global Climate Models (GCM) and Regional Climate Models (RCM) were the main input to compute daily values of FWI components. Data extracted from the original GCM-RCM simulations where corrected for the model biases in the context of PESETA II Project (Dosio, 2011) using the methods described by Dosio and Paruolo (2011). Corrections where applied to precipitation and air temperature, while relative humidity and wind speed were not corrected; a European wide, high resolution and robust enough dataset of weather observations to perform such corrections is currently not available. We have thus considered two options for these 2 variables: 1) maintaining the variables as given by the model output or 2) replicating the 30-year series 1981-2010 of ECMWF ERA-Interim (Berrisford et al. 2009) in future scenarios.

We compared intermediate results of the two options and concluded that the second one was preferred. In fact, Relative humidity and Wind speed as given by the models did not exhibit a clear climate change signal while having a strong inter-model offset, introducing unnecessary bias in the projections (see Figure 2).

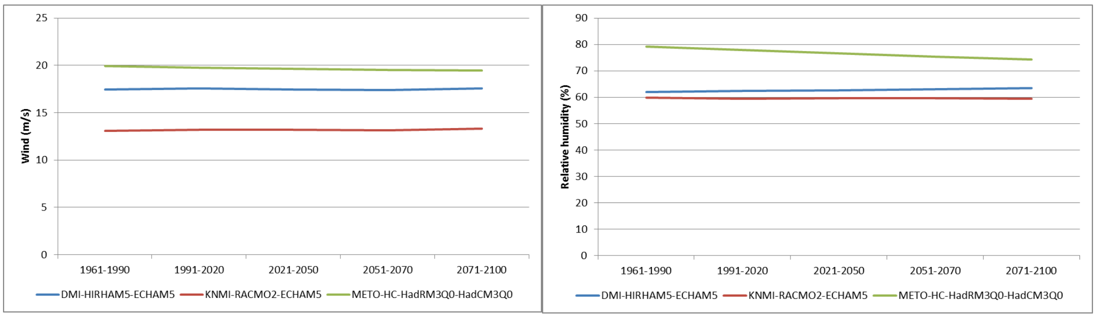

Figure 2. Multiannual European averages of Wind speed (left) and Relative humidity (right) according to three RCM simulations under A1B scenario. The inter-model differences for the two variables are much bigger than any detectable trend over time.

We considered the SRES emission scenario A1B, using the three simulations suggested by Dosio (2011) as representing average and extreme realizations of climate change under the given scenario. In addition, we considered three simulation runs for the emission scenario E1. Table 1 presents a summary of the scenarios and simulations ultimately considered are.

Table 1. Emission scenarios and simulations used for forest fire danger modelling

Scenario	Simulations (Institute – RCM – GCM)	Temporal domain
A1B	KNMI-RACMO2-ECHAM5	1961-2099
	METO-HC-HadRM3Q0-HadCM3Q0	1961-2100
	DMI-HIRHAM5-ECHAM5	1961-2099
E1	MPI-REMO-E1	1961-2099
	MPI-REMO-E2	1961-2099
	MPI-REMO-E4	1961-2099

The spatial domain of the GCM-RCM simulations in

Table **1** cover the entire European continent at about 25x25 Km^2 horizontal resolution for A1B and 50x50 Km^2 for E1. The temporal domain covers the time period 1961 to 2100.

Daily FWI components have been computed for the entire spatial and temporal domains available. 30-year averages for the periods 1961-1990 and 2071-2100 are used to define the reference and future periods for impact assessment with the difference between yearly averages for the periods calculated to estimate the potential impact of climate change on fire danger.

Maps of present and projected fire danger conditions covering Europe, at the resolution of climate data availability and using the FWI system as baseline indicator have been produced.

1.3 Impact assessment

To assess the impact of a changing fire danger, the statistical relationship of the meteorological fire danger indices with the burned areas was explored using past data series.

Burned area was computed from the European Fire Database of EFFIS (Camia et al. 2010), the main repository of individual wildfire event records in Europe. The database stores about 2 million wildfire events records from 21 countries in Europe covering a variable time period depending on the country. In southern Europe, available data start from 1985. Summarised information from the database is available through EFFIS[2].

Daily FWI components have been computed from the surface fields of the ECMWF ERA-Interim archive (Berrisford et al. 2009), daily data 1981 to 2010 with approximately 79 km spatial resolution.

The modelling efforts are being concentrated in the Mediterranean Europe, by far the most affected region in terms of burned area and impact of forest fires. In addition, in this area the available wildfire historical series is much longer than elsewhere.

Gridded FWI components have been spatially averaged over 5 southern European countries where most of the burned area is located (over 85% of the total burned area in Europe): Portugal (PT), Spain (ES), Southern France (FRMed), Italy (IT) and Greece (GR). This study area is presented in Figure 3.

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[2] http://effis.jrc.ec.europa.eu/fire-history

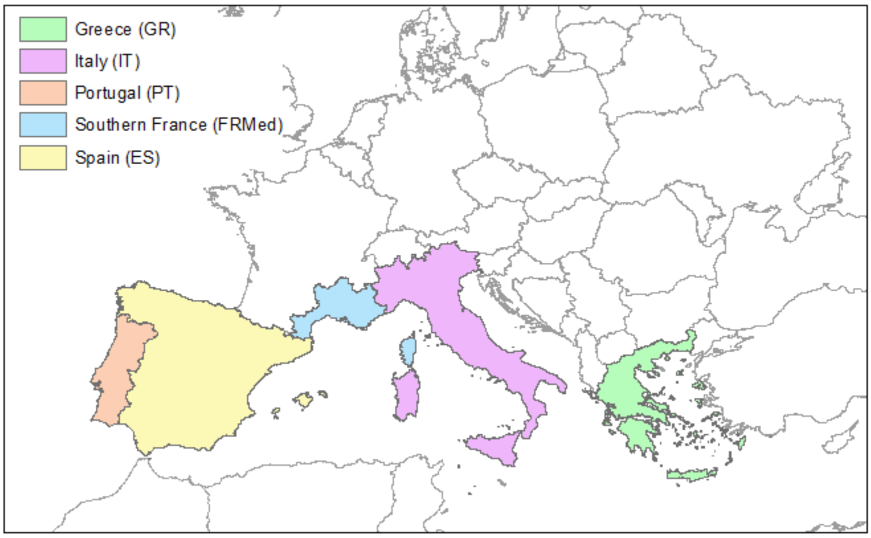

Figure 3. Countries and sub-country region of France for spatial aggregation of FWI and burned area historical series to support impact assessment with statistical modelling.

The modelling approach to calculate burned area based on the FWI projections was initially based on simple and multiple linear regression techniques. After the first attempts, it was decided to base the statistical modelling on Multivariate Adaptive Regression Spline (MARS) techniques (Friedman 1991). This technique was considered more appropriate than linear regression because the built piecewise functions allow a more robust extrapolation of the results outside the original data range. This is desirable in view of the predictions in projected climate scenarios. This technique was already successfully applied in similar studies performed elsewhere (Balshi et al. 2009).

Following the modelling results and combining them with the projected fire danger, we estimated changes in burned area under changing climate conditions for the selected European Mediterranean countries.

The economic impact of the projected burned area under future fire danger conditions has been carried out following the methodology in Mavsar et al. (2011) based on restoration cost. The method moves from the idea that the cost of replacing goods and services provided by a natural resource can offer an estimate of the value of the resource. The underlying assumption is that, if people incur a cost to restore the services of an ecosystem, then the service must worth at least what people has paid to replace them. A similar approach is applied for the analysis of financial damages to infrastructures or to the economic evaluation of environmental damages following natural disasters (e.g. storms, floods).

The damage value DV for a given location is estimated using:

$$DV = DL * RC * (1 + r)^t$$

Where:

DL = Damage Level

RC = Restoration Cost

r = Discount rate

t = Restoration period

The damage level is a function of the fire severity level in the land cover affected, with three classes foreseen (low, medium, high)

The restoration cost of forest and other wooded lands was estimated using as proxy the afforestation premium from the EU Rural Development Programs as defined by national and regional authorities. The afforestation costs include full planting and maintenance costs for the first 5 years discounted at the initial year, with a discount rate of 3%. Base year for the prices was 2009 and data were adjusted to the average EU Purchasing Power Parities (PPP).

The restoration costs of land cover types other than forest and other wooded lands where derived and adjusted from the literature.

The discount rate was set to 3% after the critical analysis of the social discount rates applied to Cost-Benefit Analysis of investment projects in EU, given that there is no official social discount rate for forestry or environmental projects at the EU level.

The restoration period depends on the age of the burned forest. For the assessment of the damage cost, three age classes were considered with corresponding reference restoration times: 0-30 years (t=15); 30-50 years (t=40); >50 years (t=60).

The restoration period of other land cover types was set to 1 year (e.g. grasslands, heathlands, annual crops) or 5 years (e.g. other wooded lands, multi-annual crops).

Using the damage value formula applied to data such as current land cover map, forest age and administrative boundaries, a map of potential economic impact of fires in Europe was derived for different fire severity levels (Oehler at al., 2012). The map provides an assessment of the expected damage value per ha for each 250x250 m^2 pixel under different fire severity scenarios (Figure 4).

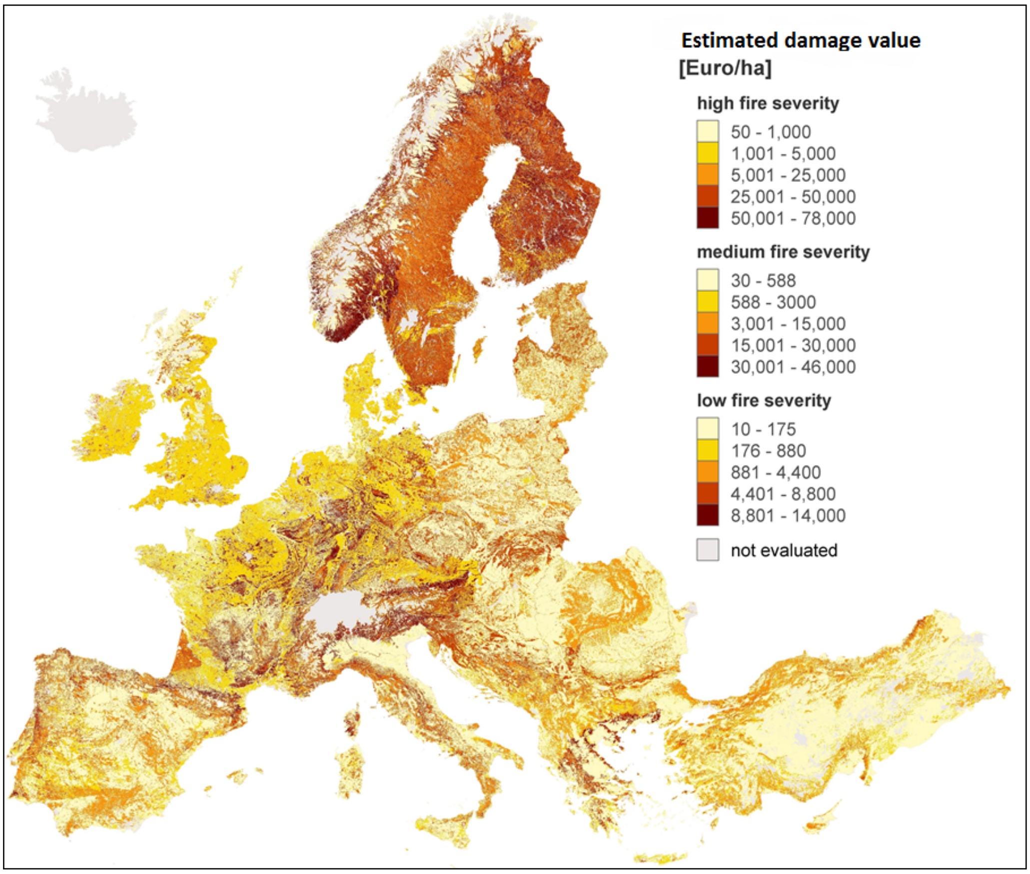

Figure 4. Map of estimated wildfire damage value in Europe according to low, medium and high fire severity scenarios (from Oehler at al., 2012. Modified)

For the assessment of the economic impact of the projected burned area under future fire danger conditions we assumed a medium fire severity level throughout southern Europe and averaged the restoration cost for each of the 5 regions (PT, ES, FRMed, IT and GR). The economic impact was than computed as product of the projected burned area and the average restoration cost of each region.

1.4 Adaptation options

Forest fire mitigation options vary from country to country and from region to region, and no single comprehensive database of wildfire mitigation measures exists in Europe. In addition, funding of measures related to wildfire mitigation is different at European, country and regional level, and often scattered among different administrations.

This makes it difficult setting a European picture of expenditure on wildfire prevention and the observed effects at European level. Therefore, modelling the effect of adaptation measures is challenging without having baseline information, even more difficult for long-term multi-decadal scenarios. Rough estimates of forest damages due to fires exist for the current climatic conditions.

Future climate scenarios foresee the increase in drought periods in the Mediterranean region and the worsening of fire danger conditions, which are expected to affect fire frequency and burnt areas in the region, severity of fire events and their potential impact.

Adaptation of wildfire management strategies to a changing climate implies evaluating and implementing a range of options and activities with an integrated approach. There is no a generalized approach applicable, since fire environments and socio-economic context change significantly across Europe, as well as the expected impact of forest fires.

Although no quantitative data are yet available in this respect for Europe, it is widely recognized that enforcing and optimizing fire suppression efforts is not a solution since fire prevention activities are at least equally important. We consider that this concept has to be strengthened face to a changing climate. Already today, when extreme weather conditions occur in areas where little or no fire prevention has been carried out (e.g., fire hazard reduction, fuel treatment, prescribed fires), there is no suppression effort sufficient to stop a catastrophic spreading fire.

In this sense, we believe that fire exclusion policies are a risky option for the Mediterranean regions, while on the contrary integrated management and prescribed burning are important components of future fire management.

Climate change will alter fire regimes bringing more severe burning conditions and more frequent wildfires. Altered fire regimes will have in turn an ecological impact affecting forest composition, structure and biomass storage, with a feed-back effect on the fire environment. Therefore, fire management strategies adapted to a changing climate should be integrated with forest management, because of the ecological impact of future fire regimes on forests, and for the effects of forest management on wildfire hazard.

3. Results

1.5 Fire Danger

Maps of present and projected fire danger conditions in Europe, at the resolution of climate data availability and using the FWI system as baseline indicator are given in Figures 5 to 8.

The maps in Figure 5 show annual averages of FWI over 30 years' periods, 1961-1990 (reference) and 2071-2100 for both emission scenarios A1B and E1.

The fire danger maps in the reference period 1961-1990 are quite similar confirming the effectiveness of corrections for models biases. Maps of end of the century projected fire danger show marked differences among A1B simulations, while are more similar for E1 simulations.

Figure 6 presents maps of difference between 2071-2100 and 1961-1990 annual FWI averages (referred to as climate change signal). Here it is even more clear that the three simulations driven by A1B emission scenario exhibit different spatial patterns for the projected change in fire danger.

Specifically, the DMI simulation, which is the overall colder and wetter case of the three A1B runs (see Dosio 2011 for details), resulted almost everywhere in a relative reduction of fire danger increase versus the other A1B simulations, with larger differences in the Eastern boundary of the modelled area. Furthermore, in a large area of central and northern Europe fire danger is projected to decrease.

In the METO simulation, the warmer and drier or the three runs, fire danger increases sharply in Eastern Europe relative to the other A1B scenarios. It also increases in South-western Europe but not as much as in the KNMI simulation.

The simulations driven by the E1 emission scenario show overall less increase in fire danger and less pronounced diversification in the spatial distribution of change in the three runs. All three simulations exhibit a stronger increase in fire danger in the Southern regions, with a more pronounced change in the E1, especially in the South-west, less pronounced in E2 and intermediate in E4. In the latter simulation, an absolute reduction of fire danger is predicted in Western Russia, while a reduction is also predicted in Ireland according to the E2 simulation.

For a better focus on Southern Europe the same variable, i.e. FWI difference between 2071-2100 and 1961-1990, is presented at the greater scale in Figures 7 and 8 for scenarios A1B and E1 respectively.

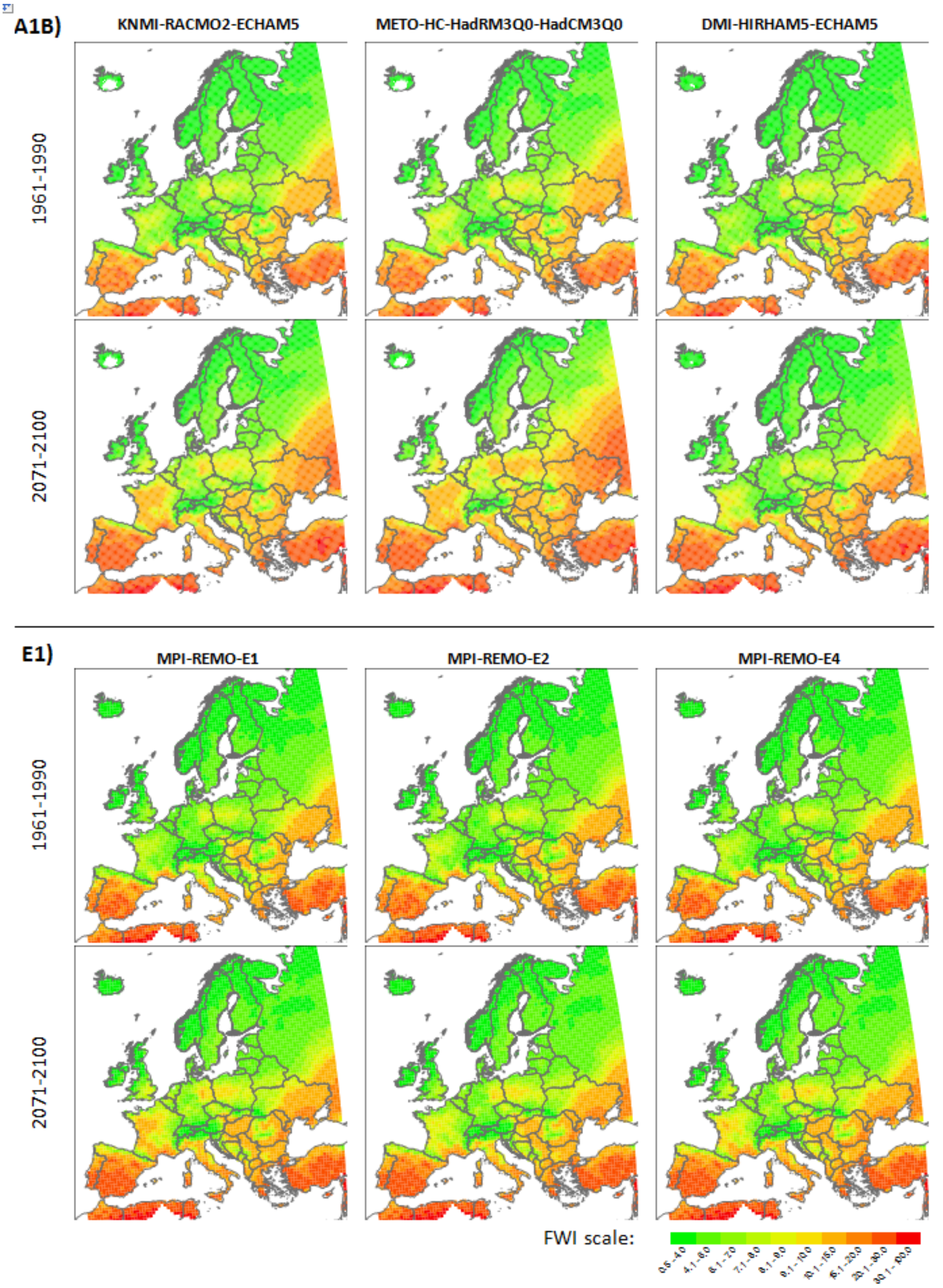

Figure 5. Fire danger maps (annual FWI averages) in reference (1961-1990) and future (2071-2100) periods, according to selected simulations under A1B and E1 emission scenarios.

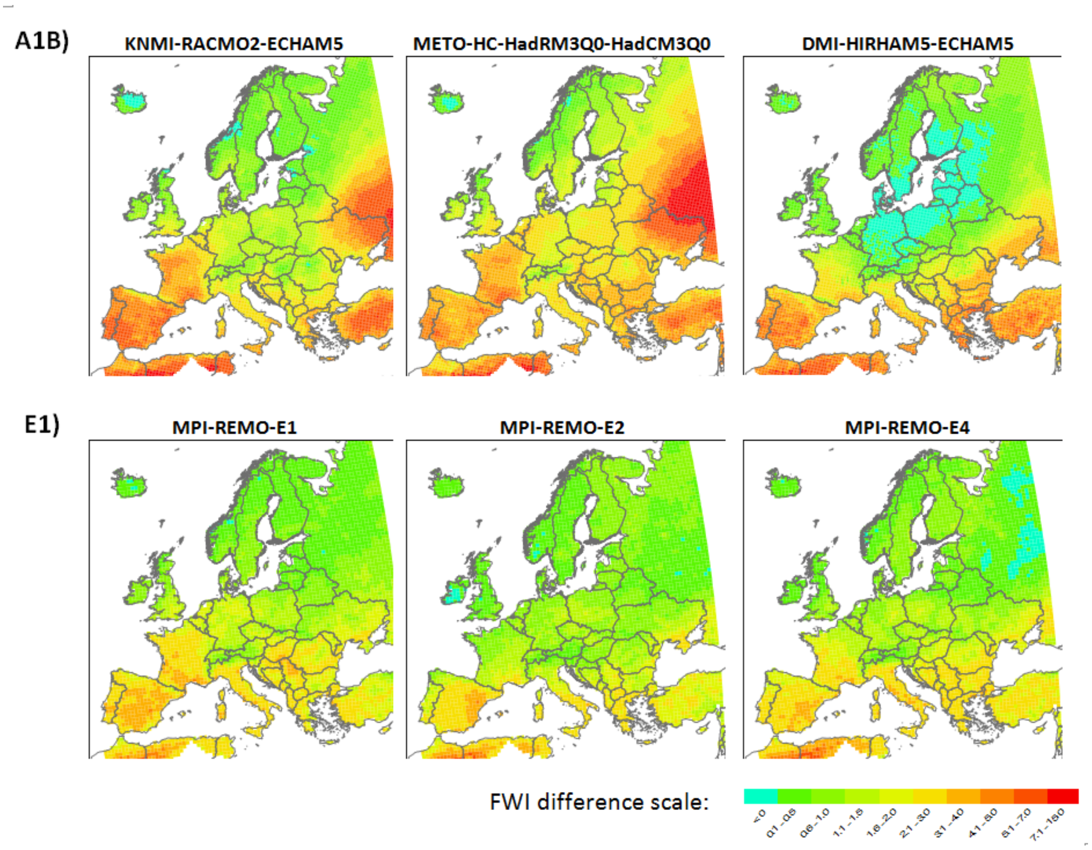

Figure 6. Climate change signal, i.e., arithmetic difference between future and reference periods FWI averages according to selected simulations under A1B and E1 emission scenarios.

With reference to Figure 7 (A1B scenario), according to the DMI simulation a relative sharper increase of fire danger versus the other simulations is visible in the southern Balkan area, Greece and southern Italy. The increase of fire danger in the KNMI simulation is much more pronounced in the Western study regions (Portugal, Spain and southern France). METO simulation exhibits an increase in fire danger which overall looks higher than the DMI and DMI, though more distributed throughout the study area.

Differences in the E1 simulations are subtler (Figure 8). A relative overall higher increase is predicted in E1, especially in Spain, Portugal and southern France. E2 simulation results in a relative lower increase of fire danger as compared to the other two of the same emission scenario, with significant changes restricted to the more southern regions. E4 simulation predicts changes in fire danger conditions somewhere in the middle of the E1 and E2 extremes.

Country averages of FWI (reference and future) are given in Table 3 of next section, allowing a quantitative appreciation of the estimated evolution of fire danger in the countries of Southern Europe.

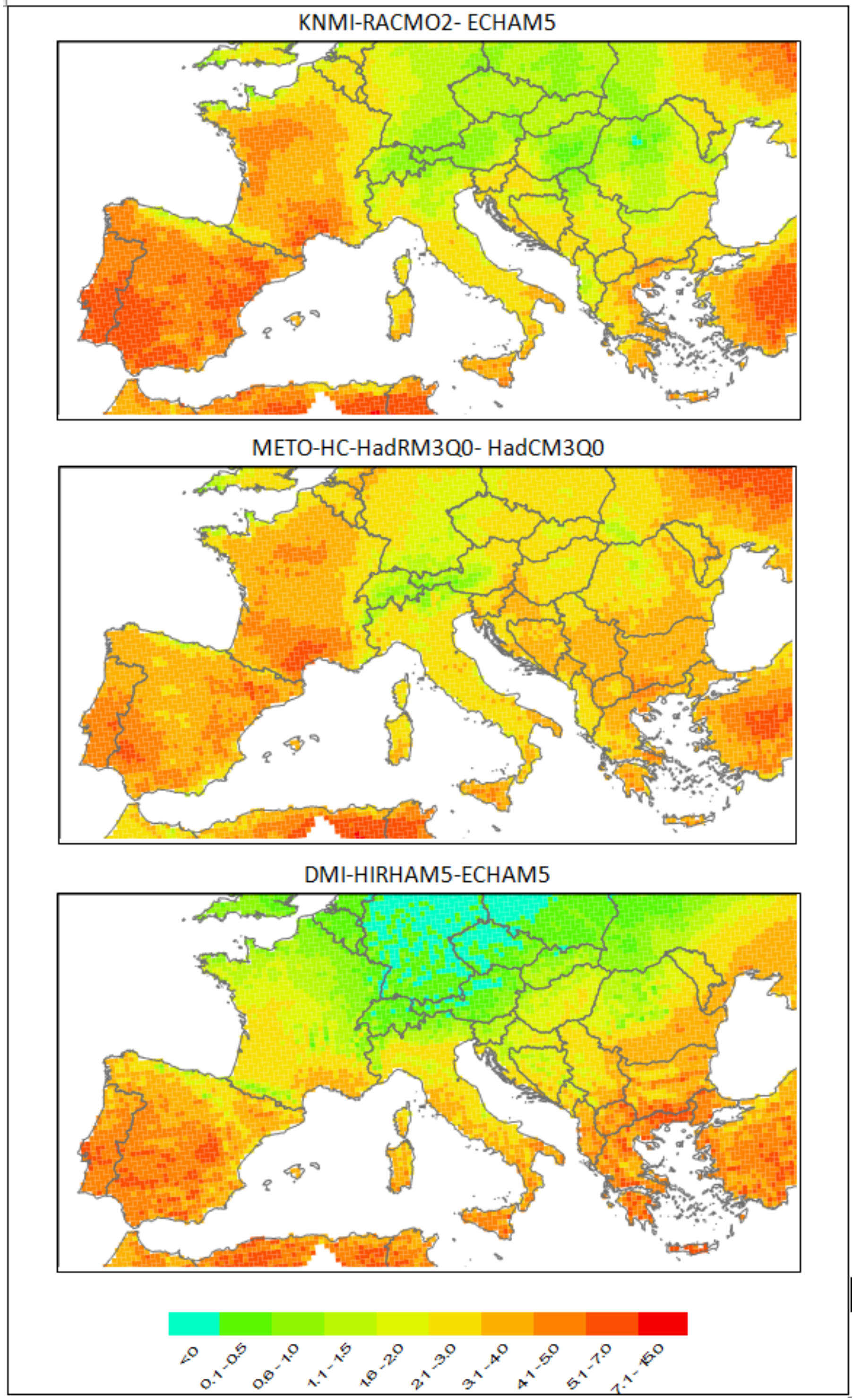

Figure 7. Climate change signal in Southern Europe according to selected simulations under A1B emission scenario.

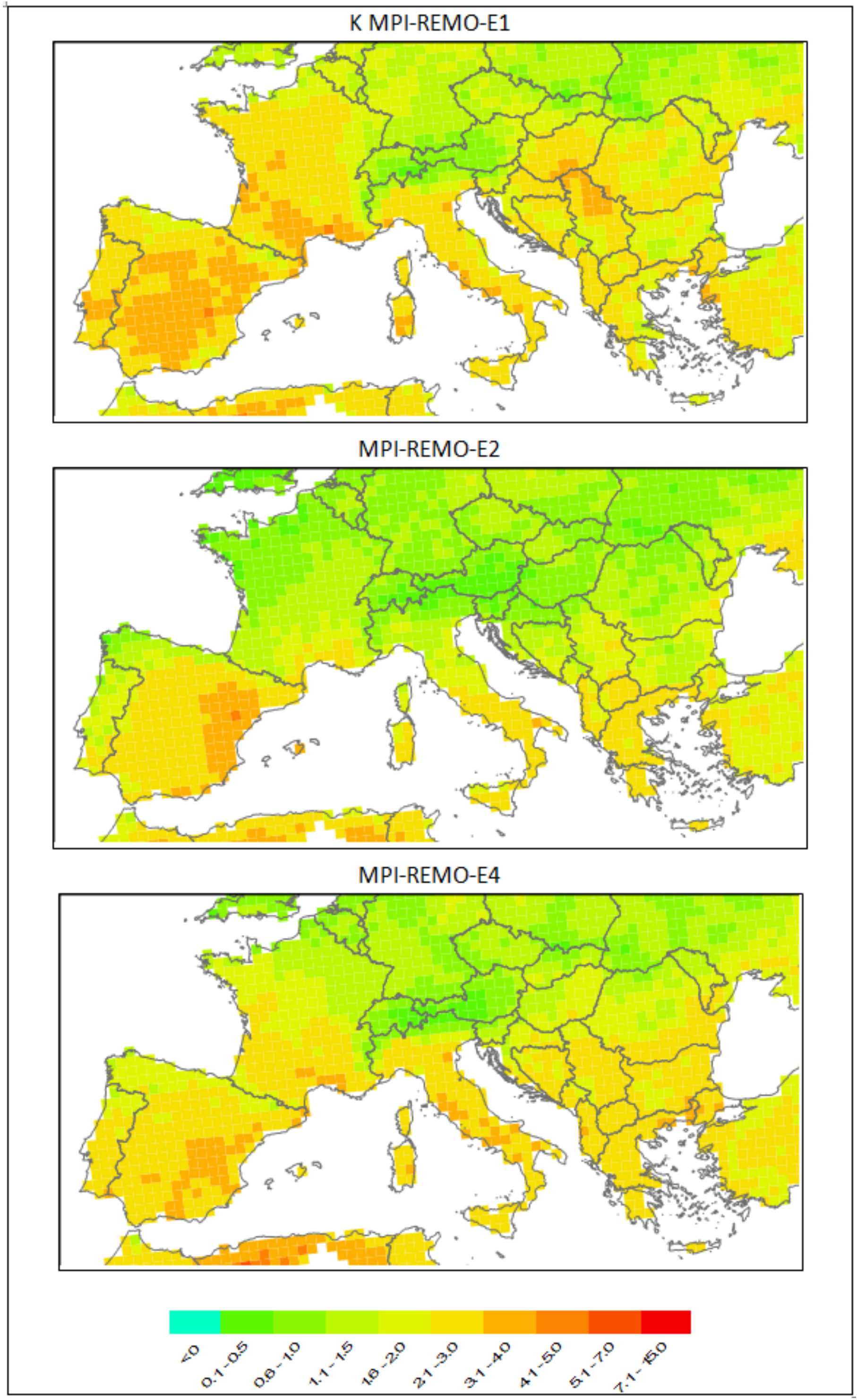

Figure 8. Climate change signal in Southern Europe according to selected simulations under E1 emission scenario.

1.6 Impact assessment

Burned area as a function of fire danger indices was explored with MARS; resulting basal functions and R squared are given in Table 2. Models estimate the log of the monthly burned area using as input monthly averages of FWI and ISI over each region.

The historical series used to build the models was from 1985-2010 for ES, FRMed and IT, 1981-2010 for PT and 1983-2000 for GR. The time series for Greece was stopped on 2000 because wildfire data of the last decade was considered not reliable enough for modelling purposes.

We focused the models on the main fire season in the Mediterranean, i.e. the summer months of June through October (86% of the annual burned area in the region happens on average from June through October).

Region	Equation	R^2	Cross validation R^2
Portugal	7.206315 + 0.2875863 * max(0, FWI - 12.95) - 0.5236354 * max(0, 12.95 - FWI) - 0.5736034 * max(0, ISI - 3.76)	0.80	0.74
Spain	7.669756 + 0.1504978 * max(0, FWI - 14.59) - 0.4332947 * max(0, 14.59 - FWI) + 0.6127046 * max(0, 5.78 - ISI)	0.68	0.61
France Med	6.283384 - 0.4090681 * max(0, 12.91 - FWI) + 0.3973366 * max(0, FWI - 15.43) - 1.10153 * max(0, ISI - 5.62)	0.69	0.62
Italy	6.886724 + 0.2024325 * max(0, FWI - 6.04) - 0.761246 * max(0, 6.04 - FWI)	0.80	0.75
Greece	8.237785 - 0.2898507 * max(0, 18.27 - FWI) + 0.2992717 * max(0, FWI - 24.75) - 0.4916414 * max(0, ISI - 6.02)	0.79	0.72

Table 2. Multivariate Adaptive Regression Spline models. Explained variable is the logarithm of the monthly burned area; predictors are monthly averages over the region.

In Table 3 we present average observed and projected FWI values according to the different simulations. In A1B emission scenario the average overall change is in the order of 30% increase, less pronounced towards East, with the exception of DMI where a large increase is predicted in Greece. In E1 the overall expected increase is around 20%, evenly shared across southern countries.

Results of the implementation of the MARS model on the projected fire danger scenarios are given in tables 4 and 5. Note that what is for brevity reported in the tables as annual average actually refers to the months of the main fire season (June to November).

With reference to the modelled burned area (Table 4), in the A1B emission scenario the average increase goes from 72% and 93% in the Iberian Peninsula, to 184% increase in Southern France, with Italy and Greece having 121% and 112% increases respectively.

The sharper rise in the burned area as compared to the FWI change reflects the exponential nature of the relationship.

The projected increase of burned area in the E1 scenario are accordingly much less remarkable, going from 26% and 35% in Portugal and Spain respectively to 49% and 71% in Greece and Italy respectively. Southern France in this case remains in the middle range with an estimated increase of 35%.

Despite the relative less remarkable percentage increase in hectares burned in the South-western countries, the majority of the projected burned area would still remain in the Iberian Peninsula in both emission scenarios reflecting the higher baseline values.

		Projected 2071-2100 FWI (A1B)					**Projected 2071-2100 FWI (E1)**				
Region	**Observed average FWI**	**KNMI**	**METO**	**DMI**	**Average A1B**	**A1B Average change (%)**	**MPI-E1**	**MPI-E2**	**MPI-E4**	**E1 Average**	**E1 Average change (%)**
Portugal	21.2	28.9	28.3	26.9	28.0	**32%**	26.1	25.4	26.0	25.8	**22%**
Spain	21.4	28.4	27.9	26.6	27.6	**29%**	25.9	25.8	25.7	25.8	**21%**
France Med	15.1	21.0	22.0	17.8	20.3	**35%**	18.0	17.4	18.0	17.8	**18%**
Italy	13.5	17.2	17.6	17.0	17.2	**28%**	16.8	16.0	16.8	16.5	**22%**
Greece	22.5	26.0	26.8	29.9	27.6	**22%**	26.4	26.3	26.9	26.5	**18%**

Table 3. Observed and projected fire danger assessed with FWI annual (June to November) averages over the regions.

		Projected 2071-2100 annual burned area - ha (A1B)					**Projected 2071-2100 annual burned area - ha (E1)**				
Region	**Observed annual burned area (ha)**	**KNMI**	**METO**	**DMI**	**Average**	**A1B Average change (%)**	**MPI-E1**	**MPI-E2**	**MPI-E4**	**Average**	**E1 Average change (%)**
Portugal	106,874	237,028	211,873	169,894	206,265	**93%**	144,552	138,786	142,668	142,002	**33%**
Spain	133,323	253,039	225,394	210,702	229,712	**72%**	165,415	168,046	172,066	168,509	**26%**
France Med	16,442	52,406	60,440	27,290	46,712	**184%**	22,301	19,996	24,085	22,127	**35%**
Italy	67,976	151,532	148,916	150,153	150,200	**121%**	123,240	102,234	123,693	116,389	**71%**
Greece	53,030	93,290	99,371	145,089	112,583	**112%**	75,301	74,060	87,575	78,979	**49%**

Table 4. Observed and projected burned area assessed with MARS models (June to November)

			Projected 2071-2100 annual cost (kEURO)				Projected 2071-2100 annual cost (kEURO)			
Region	**Average reconstruction cost (EURO/ha)**	**Current estimated annual reconstruction cost (kEURO)**	**KNMI**	**METO**	**DMI**	**Average A1B**	**MPI-E1**	**MPI-E2**	**MPI-E4**	**Average E1**
Portugal	6,117	**653,738**	1,449,874	1,296,004	1,039,219	**1,261,699**	884,206	848,936	872,682	**868,608**
Spain	3,422	**456,205**	865,849	771,252	720,979	**786,027**	566,016	575,018	588,775	**576,603**
France Med	10,306	**169,461**	540,108	622,916	281,254	**481,426**	229,836	206,085	248,230	**228,050**
Italy	6,657	**452,546**	1,008,820	991,403	999,637	**999,953**	820,470	680,619	823,484	**774,858**
Greece	4,505	**238,879**	420,231	447,628	653,565	**507,141**	339,200	333,608	394,492	**355,767**

Table 5. Current and projected reconstruction costs in the regions (main fire season, June to November)

In Table 5 we present the expected economic impact estimated using the reconstruction cost model applied to the projected burned area, assuming an intermediate average fire severity level. The relative intra-country projected cost increase is obviously equivalent to the relative burned area increase. In terms of inter-country comparison, note that differences are also driven by the varied average reconstruction costs in the countries, which are also due to the different age structures of forest stands (as the cost also depends on time needed to recover), which may be different at the end of this century.

The average annual cost for all the southern European countries considered is projected to increase from the current estimated 1,971 M€ per year to 4,036 M€ under emission scenario A1B and 2,804 M€ under emission scenario E1. In both scenarios Portugal is projected to remain the country with the highest overall costs due to forest fires, followed by Italy (while currently is followed by Spain).

As mentioned in the introductory section several other factors relevant for wildfires are not taken into account in this approach such as changes in fuel conditions and human activities. These factors may also influence the burned area and thus wildfire impact. Stressing these aspects is of paramount importance for defining the boundary conditions of the results of this study.

4. Discussion and conclusion

In this work, we present a first attempt to quantify the estimated economic impact of wildfires in southern European countries. The assessment is done for current years and for end of the century projections, according to two different climate change scenarios respectively driven by A1B and E1 atmospheric emissions scenarios.

The assessments are based on meteorologically based indices under the assumption that the main driver of fire regimes in Mediterranean Europe is weather. However other important factors such as fuel (biomass) availability and conditions, ignitions sources and human activity (adaptation or causality) affect fire activity and thus wildfire impact. This aspect has not been considered in the study.

The damage value based on the restoration cost approach underestimates the actual economic losses. Costs which are not accounted for are those incurred because of the missed benefits until the forest is restored (i.e., temporary loss of ecosystem services), or the direct cost of fire fighting.

Other associated costs related to indirect effects of wildfires on aspects such as human health or secondary effects on other natural hazards, such as e.g. increased potential for flooding, are also not accounted for.

A consistent, significantly higher impact of scenario A1B is observed, with an average 97% increase of burned area in southern Europe projected at the end of the century, which is on average 2.4 times bigger than the burned area increase predicted with E1 scenario.

Results vary greatly across Europe, with marked differences among model runs within the scenarios. The use of ensemble models is therefore essential in this respect, as well as site specific differentiation of adaptation strategies.

Fire management strategies adapted to a changing climate should be integrated with forest management and strengthen fire prevention activities such as targeted fuel treatments and prescribed fires.

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