Effect of climate projections on the behavior and impacts of wildfires in Messenia, Greece

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Abstract Climate change has the potential to affect many aspects of wildfires, while wildfire itself can accelerate phenomena such as environmental degradation and desertification. As a result, floods, microclimate alteration, environmental changes, destruction of infrastructures, economic losses and human causalities are some of the post-fire impacts. During the last decade, Peloponnesus in Greece experienced several large-scale wildfire events with unprecedented fire behavior and fire effects. In this study (within the XENIOS project/ NSRF-Cooperation 2009/ 09SYN-31-867), thousands of wildfire events were simulated with the well-established Minimum Time Travel fire growth algorithm and resulted in spatial data that describe burn probabilities, potential fire spread and intensity in Messenia, Greece. Present and future climate projections were derived from simulations of the KNMI regional climate model RACMO2 with a horizontal resolution of 25x25 km, under the SRES A1B emission scenario for the 1961-2100 time period. Data regarding fuel moisture content, wind speed and direction were modified for the different projection time periods. Results were used to assess the vulnerability changes for certain values-at-risk of the natural and human-made environment, such as sites of cultural, ecological and environmental interest, residential and tourist infrastructures, etc. Differences in wildfire risk in terms of burn probabilities and fire intensity were calculated for the different simulation time periods.

1 Introduction

Studies have claimed that global warming will alter temperature and precipitation patterns around the world, while changes in physical processes will affect local microclimates (IPCC 2007). Changes in climate have the potential to significantly affect wildfire frequency, size and intensity, while higher fire risks, longer fire seasons and more severe fire effects are expected. Many aspects of post-wildfire situation will affect or accelerate other natural environmental disturbances, resulting in modified vegetation patterns and succession procedures, land degradation, desertification and hydrological cycle derangement.

Fire regimes in the Mediterranean are influenced by factors beyond those related directly to weather conditions (e.g. socioeconomic, land use/ land cover types, anthropogenic pressures and intensive human influences), however, climate and weather conditions have a profound effect on fire occurrence over time. Different vegetation types are anticipated to have different responses to climate change in terms of fuel availability and flammability. Changes in temperature may have an effect on moisture-limited wildfire risks (large fires can occur when antecedent moisture results in an increased fuel loading) through their potential to affect the moisture available for the growth of vegetation during the growing season (Westerling and Bryant 2008, Westerling et al. 2003). Changes in fire regimes will impact the quantity and compactness of dead and live fuels, along with their composition (needle fuelbed, broadleaf litter, grass and shrubs) and height. Furthermore, plant succession patterns are expected to alter if climate change favors invasive species to colonize burned areas. The removal of overstory vegetation and canopy cover will result in lower fuel moisture content and, thus, increased flammability. The large fires that occurred in the Mediterranean Basin in the last decade were related not only to extremely warm and dry weather (Founda and Giannakopoulos 2009), but also to positive anomalies in the previous wet season that promoted plant growth and fuel build-up (Trigo et al. 2006).

The large-scale wildfire events of Peloponnesus, Greece, during the summer of 2007 were raging for several days under the influence of high winds and temperatures and low humidity, resulting in the most severe fire effects of the past 50 years (Koutsias et al. 2012). Agee (1997) originally raised the question about the relative importance of weather and fuel on fire behavior, creating the “weather hypothesis” and the “fuel hypothesis”. The weather hypothesis suggests that large, severe fires are driven by extreme weather events and intensely burn through forests regardless of the condition of their fuels; while on the contrary, the fuel hypothesis suggests that reduction of fuels limits fire severity. Forest fire behavior is complicated by the erratic and, often, weather-driven nature of these phenomena. Keeley and Fotheringham (2001) make the case that catastrophic fires are less dependent on fuel and more dependent on the coincidence with severe weather. In this study, the weather hypothesis will be tested by conducting fire behavior simulations for current and future climate conditions to assess the degree of expected changes in wildfire frequency and intensity and the anticipated impact on several values-at-risk in the area of Messenia in Peloponnesus.

2 Materials and Methods

To assess climatic change in the study area, daily output from the KNMI regional climate model (RCM) RACMO2 (Lenderink et al. 2003, van den Hurk et al. 2006, Van Ulft et al. 2008) was used. The KNMI RCM RACMO2 is forced with output from a transient run conducted with the ECHAM5 GCM, run on a spatial resolution of about 25x25 km under the SRES A1B emission scenario

(Nakicenovic et al. 2000). The model provides five grid points over SE Peloponnesus, three of which were used in this research. Simulations of present day (period 1961-1990) and distant future (period 2071-2100) with KNMI RCM RACMO2 were utilized including relative humidity (%), mean and maximum temperature (°C), wind speed (m/s) and the mean eastward (u) and mean northward wind components (v). The u and v components were used to calculate the wind direction, as derived from arctan (u/v), and averaged for 16 directions. Wind speed and direction were calculated at the height of 10 m a.g.l., while air temperature and relative humidity at 2 m a.s.l.

Fire behavior simulations were conducted by the command-line version of the Minimum Time Travel (MTT) algorithm (Finney 2002), called Randig (Finney 2006), making it feasible to rapidly simulate thousands of fires that can then be used to generate burn probability maps. MTT results include a burn probability (BP) grid of the area, fire perimeter shapefiles, flame length probabilities and conditional flame length (CFL) and a fire list (text file with coordinates and area in ha of each fire). The MTT algorithm accepts weather parameter inputs in the form of scenarios that define the wind speed and direction (mph at 20 ft a.g.l.) and the dead and live fuel moisture content (FMC) for each fuel model and each scenario's selection probability. To define these scenarios for Messenia, the daily wind speeds of each time period were sorted into three classes (0 to 2 m/s, 2 to 4 m/s and greater than 4 m/s) that are based on the model wind data of the region during fire season. Then, the percentage of days that fall in each category over the total number of prediction days, as well as the wind direction frequency (%) per sector was calculated. The three most frequent wind direction sectors were used for each wind speed category, with their frequency been used for defining the selection probability of every scenario on MTT simulations. Eventually, each time period has nine weather scenarios (three wind speeds with three directions each), with the relevant FMC values for each wind speed category. To estimate FMC, the relative mean air temperature and relative humidity values from each wind scenario were incorporated into the BehavePlus software (Heinsch and Andrews 2010), using the "Fine Dead Fuel Moisture Tool".

By using spatial data and information for values-at-risk, such as houses outside urban areas, economic infrastructures (greenhouses, solar power units, industrial storehouses, industries, etc.), agricultural infrastructures (corrals, residential storehouses, auxiliary buildings, etc.), hotels, wildlife habitats, monuments, archaeological sites, wildland-urban interface (WUI) areas and land use/ land cover (LULC) types, a vulnerability assessment analysis was conducted for each of them for the two time periods. The Randig results (BP and CFL) were displayed in scatter plots for each value-at-risk, indicating attributes that have the potential of facing frequent and intense fires. This analysis allowed the identification of important attributes with respect to high vulnerability (e.g. hotels, houses or LULC types).

3 Results and Discussion

Raster values of the BP and CFL files for the two time periods were subtracted (i.e. future minus present) to produce new raster files of BP (Figure 1-A) and CFL (Figure 1-B) differences. Positive values reveal an increase, while negative values reveal a decrease of the fire frequency and behavior in the future time period. Furthermore, a file with the simulated fire ignition points, along with the burned areas (ha) was derived and used to create histograms of fire size vs. frequency (Figure 2). Scatter plots were produced for vulnerability assessment of LULC types (Figure 3) and value-at-risk attributes (Figures 4 and 5).

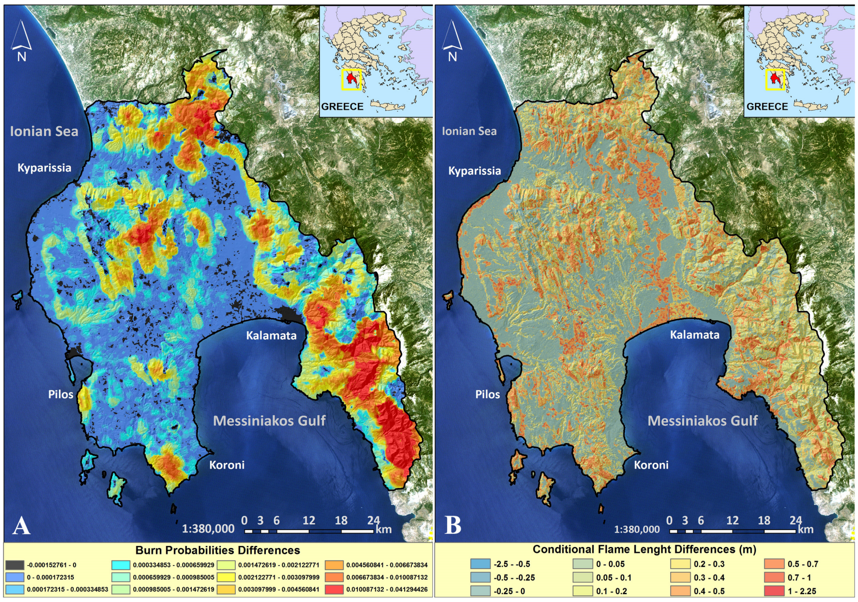

Figure 1. Burn probability (A) and conditional flame length (B) differences of current and future time periods in Messenia, Greece

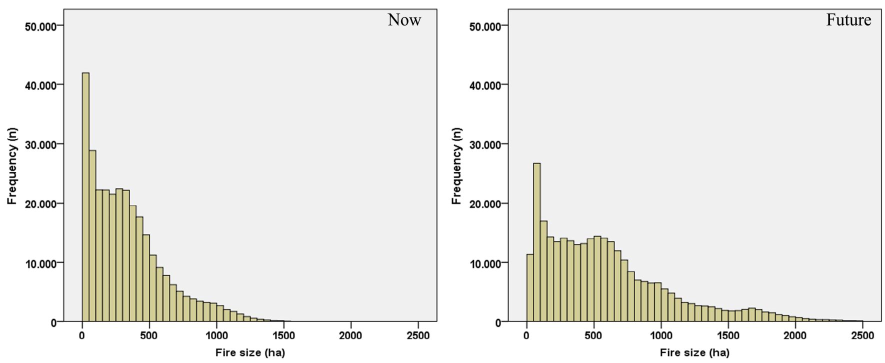

Figure 2. Histograms of fire size vs. frequency of current and future time periods

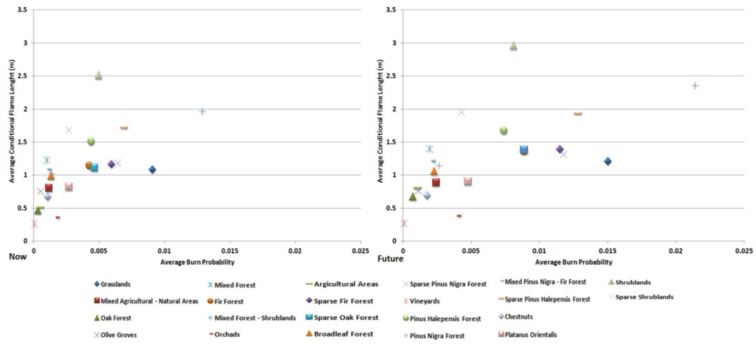

Figure 3. Vulnerability scatter plots of the two time periods for LULC types of Messenia

Spatial results revealed that fire frequency and intensity are projected to increase under future climate change conditions. A low (from 0.0001 to 0.001 or 1 to 100 more fire events), moderate (from 0.001 to 0.006 or 600 fire events) and high (more than 0.006) increase on future BP values was calculated on 55%, 25% and 15% of the total study area, respectively, with only a 5% decrease across the landscape. A low (from 0.01 to 0.2 m), moderate (from 0.2 to 0.5 m) and high (more than 0.5 m) increase on future CFL values was calculated on 25%, 28% and 9% of the total study area, respectively. A substantial decrease by 0.25 m was calculated on 37% of the landscape, located mainly in the coastal zones of Messenia.

The SE tip of the Messenia region (i.e. Mt. Taigetos and Mani areas) is expected to experience a large increase in BP vs. the current predicted conditions, ranging from 0.006 to 0.04 (i.e. 600 to 4,000 more fires); i.e. about 7% of total study area. The primary vegetation types of the area to carry the wildfires are conifer forests, evergreen shrublands and reforested agricultural areas. An increase of approximately 0.3 m in the CFL values was estimated for these areas. Another area with high BP increase is on the northern part (about 4% of total study area), covered with evergreen shrublands, oak woodlands and reforested agricultural areas with values ranging from 0.004 to 0.02 (i.e. 400 to 2,000 more fires). The area west of Koroni in the south (about 3% of total study area), mainly covered by evergreen shrublands has also increased BP values as well as the area of Pilos on the west, both having a well developed touristic sector. CFL values in these two areas are also expected to have a large average increase of 0.5 m. Large increase in CFL values (>0.5 m) was calculated for the small islands south and west of Messenia. The area east of the Aigaleo-Mali forest (central part of Messenia) also has increased BP values for the future time period. The coastal zone south from Kyparissia has increased CFL values of 0.4 m on average, covered mainly by agricultural zones.

In Figure 2, a clear trend for increased fire size exists, having higher frequency for fire sizes more than 500 ha. It is expected that the number of small forest fires (<10 ha) will be reduced in favor of larger fires. Current situation produced 30% of fire events greater than 500 ha, while future situation outputs had about 50%. Fire sizes of 1,000 ha were very rare for current situation (almost 5%), increased to 15% for future conditions. Vegetation types' scatter plot on Figure 3 shows that most values have an increase in vulnerability (a shift from lower far left to upper far right). In particular, shrublands and mixed forest-shrublands will have a substantial CFL increase (almost 0.5 m), along with an increase in BP values. Sparse costal pine forests have also a similar trend. A moderate increase in CFL values (almost 0.3 m) will happen in sparse shrublands, coastal pine, fir and sparse oak forests. Grasslands will have a large increase in BP values, with small changes in CFL. Most of the rest vegetation types will have small increases in both CFL and BP values.

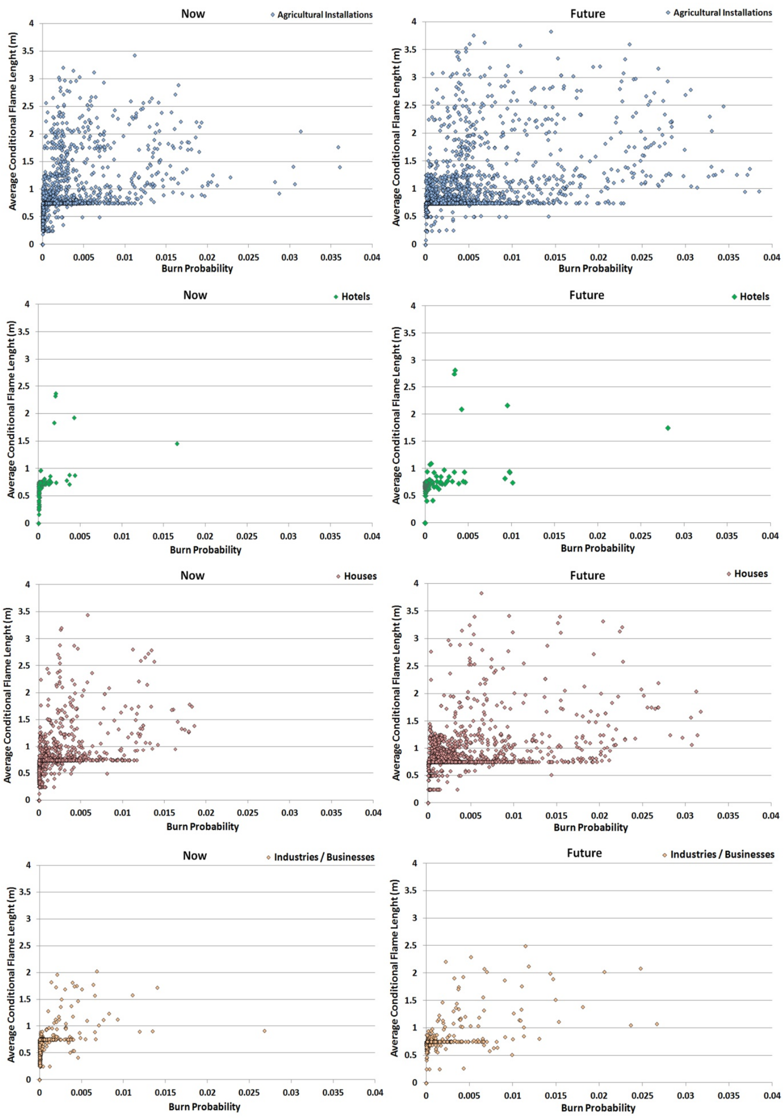

Figure 4. Vulnerability scatter plots of the two time periods for agricultural installations, hotels, houses and industries/ businesses

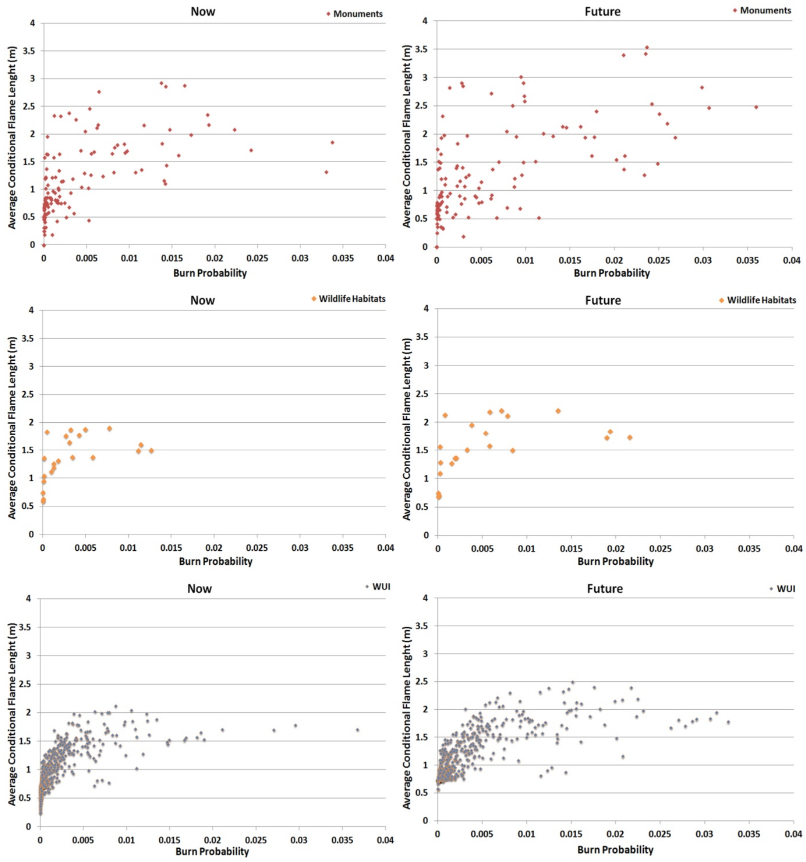

Figure 5. Vulnerability scatter plots of the two time periods for monuments, wildlife habitats and WUI

Values-at-risk in Figure 4 show that agricultural installations have a moderate percentage of attributes that portray increased vulnerability, with most of the rest attributes having CFL and BP values smaller than 1.5 m and 0.01, respectively. Although, most of the hotels seem relatively less vulnerable, with lower BP and CFL values, extra attention must be given for these facilities with high expected vulnerability in the future time period. Hundreds of houses are also expected to increase their BP and CFL values, but the vast majority will remain under low threat status. About 15% of industries and businesses will have an increase of about 0.5 m on CFL and 0.01 on BP, with the rest attributes remaining on current time period levels. Values-at-risk in Figure 5 show that there are several monuments around Messenia that have high vulnerability and need to be protected against future catastrophes. Wildlife habitats have moderate vulnerability, as moderate and small increases are expected in BP and CFL, respectively. Finally, there is a large number of WUI sites of formerly cultivated areas that have been abandoned, which can have a substantial increase in BP under future climate change.

4 Conclusion

Based on the results, wildfires with increasing frequency and intensity are expected to occur in the Messenia region towards the end of the 21st century. In addition, fire size is likely to have an increase that can substantially affect several values-at-risk. It is expected that vegetative fuel availability conditions for most of the LULC types studied will intensify in the next 50 years. Changes in vegetation composition, structure and arrangement lead to analogous modifications in fuel models used in the simulation procedure. If future vegetation/ fuel conditions could be projected and accounted for in MTT simulations, more intense and larger fires would probably be simulated. Since weather patterns cannot be changed or modified directly by humans on a local or regional scale and during the time needed (weather hypothesis), the only option left for protecting societies and values-at-risk is by modifying vegetation and fuel patterns (fuel hypothesis) to reduce and control wildfire activity. This study's outcomes emphasize the need for fuel treatment techniques aiming at reducing vegetation fuel accumulations, strategically implemented around areas and facilities that have high hazard and vulnerability.

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