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Climate change, forest fires and air quality in Portugal in the 21st century

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1. Introduction

There are regions of the world more vulnerable to climate change and some of those regions are also sensitive to forest fire occurrences. The way climate change interacts with the forests of the world and consequently with forest fire activity is a point of debate among the scientific community.

Several features dominate the forest fires of a given region and these can be described in terms of the main temporal and spatial scales of variation. From a fire event to the definition of the fire regime of a given region several drivers are determinant in the characterization of these dynamics. From the local weather conditions to the large scale weather patterns the forest fires evolve from simple events to the definition of the fire regime of a given region. The short temporal scale and the local characteristics that dominate a fire event are ruled by the local weather conditions that drive the forest fires daily variability. Additionally, the physiographic and the topographic variability that characterize the large temporal and spatial scales variations represent the broader influence of these scales on the fire regime definition.

To correctly assess the inter-connection between all analysed drivers human influence must also be considered. One of the best definitions of this relationship is given by Stephen Pyne (Pyne, 2007) who describes the area burned of a region as "a proxy of climate interacting with people". At a larger temporal and spatial scale human activities may deeply influence climate and subsequently the fire regime of a region. At local scale human activities have a remarkable impact on forest fires mainly through changes in land-use, negligent actions or simply by arson.

Wildland fire is a global phenomenon, and a result of interactions between climate–weather, fuels and people (Flannigan et al., 2009). The influence of the human activities on climate is leading to worldwide forest fire changes and disruptions. The most recent report of the IPCC (IPCC, 2007) discusses the changing of the vegetation structure and composition due to intensified wildfire regimes driven at least partly by the 20th century climate change. Worldwide the wildfire regime is changing. In the United States of America (USA) the number of forest fires is decreasing due to fire prevention strategies but they are becoming larger and consequently more severe. In this sense the fire suppression efforts are escalating (Miller, 2007).

Recently, Europe has experienced a large number of forest fires that have caused enormous losses in terms of human lives, social disturbances, environmental damage and economic disruptions. Most of the fires in Europe take place in the Mediterranean region where over 95% of the forest fire damage occurs (EC, 2003). There are several features that make the landscapes of the European Mediterranean Basin different from those of the rest of Europe. These differences are mainly related to the climate, the long and intense human impact, and the role of fire. The latter is, in turn, influenced by the other two (Pausas and Vallejo, 1999). The interaction between the human activity and the fire is a complex question that drives the majority of fire activity in southern Europe.

Since 1980, the statistics of the annual area burned in Portugal, Spain, France, Italy and Greece, have varied considerably from one year to the next, which can be an indication of how strongly the area burned depends on weather conditions. Fire occurrence increased during the 1990s, but since 2001 the number of fires has remained more or less stable (EC, 2005). This stabilization was possibly due to public information campaigns and improvements in the prevention and fire-fighting abilities of these countries. In Portugal, out of the last 30 years 2003 had the worst fire season, which resulted in the burning of almost 430,000 ha of forested lands and scrublands with global economic losses of 1,200 million Euros (DGRF, 2006). In that year the social costs were most significant with the loss of 20 human lives and the destruction of 117 houses. Due to extreme fire weather conditions (Viegas et al., 2006) the year 2005 also recorded a very high value of area burned, approximately 325,000 ha.

Even the main reason for fire increase is probably changes in land use, climatic factors should be considered as a contributing factor. Fires tend to be concentrated in summer when temperatures are high, and air humidity and fuel moisture are low (Pausas and Vallejo, 1999). Over Portugal and since 1972, there is a general trend towards an increase in the mean annual surface air temperature. Additionally, spring accumulated precipitation has registered a systematic reduction, accompanied by slight increases in the other seasons (Santos et al., 2002). Predictions of climate warming in the Mediterranean basin indicate an increase in air temperature and a reduction in summer rainfall (Christensen and Christensen, 2007)). Although there is uncertainty on the mean and variance of the precipitation changes, all predictions suggest a future increment in water deficit. These changes would lead to an increase in water stress conditions for plants, changes in fuel conditions and increases in fire risk, with the consequent increase in ignition probability and fire propagation (Pausas and Vallejo, 1999).

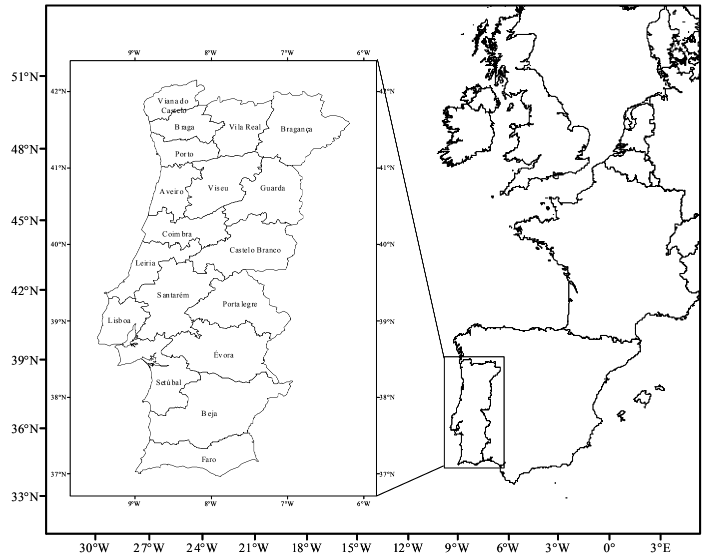
Since the late 70s biomass burning has been recognized as an important source of atmospheric pollutants (Crutzen et al., 1979). Several works have already discussed the importance of forest fires as a source of air pollutants (Amiro et al., 2001a; Miranda et al., 2005a) and in a changing climatic scenario this contribution can increase dramatically (Amiro et al., 2001b) due to larger area burned. Forest fire emissions, namely particulate matter (PM), ozone (O_3) precursor gases (like nitrogen oxides – NO_x and volatile organic compounds – VOC) and carbon dioxide (CO_2), can significantly impact the ecosystems and the air quality and consequently human health (Riebau and Fox, 2001). Particularly, they can influence plant productivity downwind of fires through enhanced ozone and aerosol concentrations (Sitch et al., 2007). In a changing climate the forest fire emissions can play an important role in all these interactions.

Air quality and its potential impacts namely in the ecosystems, structures and human health is currently one of the main concerns at global, regional and local scales. In Dentener et al. (2006) the troposphere composition change to be expected in the near future (year 2030) is investigated using 26 state-of-the-art global atmospheric chemistry transport models (CTMs) and three different emissions scenarios. Based on the ensemble mean model results, by 2030 global surface ozone is estimated to increase globally by 4.3 ± 2.2 ppb for the IPCC SRES A2 scenario (Nakicenovic et al., 2000). This study shows the importance of enforcing current worldwide air quality legislation and the major benefits of going further. Nonattainment of these air quality policy objectives, such as expressed by the IPCC SRES A2 scenario, would further degrade the global atmospheric environment.
The analysis of the climate change impacts on air quality and its feedback mechanism is nowadays a well recognised approach at the global scale. Nonetheless, studies from the regional to a country scale are not so widespread. The highest number of studies can be found for USA (e.g. Hogrefe et al., 2005). Over Europe some studies have addressed this issue (e.g. Szopa et al., 2006) pointing that by 2030 estimated ozone levels, in July, may increase up to 5 ppb. In Europe and at country level these studies are still reduced and only applied for episodic situations (e.g. Borrego et al., 2000). Additionally, the interaction between climate change, forest fire emissions and air quality is still poorly discussed. Spracklen et al. (2009) firstly investigated the potential impacts of future area burned on aerosol concentrations over the United States. In this scope, the main objective of this chapter is to investigate the role of climate change in forest fire activity and its impacts on air quality patterns over Portugal through the projection of future area burned and pollutants emissions under the IPCC SRES A2 climatic scenario.

2. Fire activity data in Portugal

Forested lands in Portugal occupy 5.4 millions of hectares and represent two-thirds of Portugal's surface area (DGRF, 2006). Eleven percent of the Portuguese territory is occupied by Maritime Pine stands or lands (*Pinus pinaster*), followed by Eucalypt (*Eucalyptus globulus*) (8 %) and Cork Oak (*Quercus suber*) (8 %). The Holm Oak (*Quercus rotundifolia*) represents 5 %, and the oak tree (*Quercus faginea*) and Stone Pine (*Pinus pinea*) exhibit 1 % each. Figure 1 shows the Portuguese districts identification and the dominant forest types. Maritime Pine is mostly common in the Castelo Branco, Coimbra, Leiria and Viseu districts. Castelo Branco, Aveiro and Santarém districts have higher forest lands of Eucalypt. On the other hand, the southern districts of Évora, Portalegre, Santarém and Setúbal have the majority of the Cork Oak in Portugal. The oak tree is most common in the northern districts of Vila Real, Bragança, and Guarda.
The Portuguese population is mainly concentrated in the urban and sub-urban areas of the coastal regions. The north region contains 35 % of the population, the Lisbon area 26 % and the central part 23 %. The remaining Portuguese regions have occupation levels below 8 % (INE, 2003). This represents a considerable population asymmetry that certainly influences forest fire ignitions and spreading.
Some aspects of the property regime in the north and centre of Portugal, namely the high number of land owners (most of them unknown) and the absence of adequate property records, have important negative consequences concerning forest management. An increase of population within the forested lands greatly enhances the forest fire risk and,

consequently, the destruction of goods and human lives and creates difficulties for the fire fighting operations. Land abandonment, due mainly to the aging of the land owners, also creates difficulties in the management of forested properties, leading to an increase in the fuel load and consequently in forest fire risk. In the southern part of the country the districts of Beja, Évora and Portalegre have a different demographic pattern. The populations are more concentrated and not spread among the forested areas, additionally the dominant forest types are resistant to forest fires. These are the regions of Portugal which reach the highest temperatures during the summer period and have lower precipitation rates throughout the year.



District name	Dominant forest type (% district area)
Bragança	Maritime Pine (5%)
Vila Real	Maritime Pine (17%)
Viana do Castelo	Maritime Pine (17%)
Braga	Eucalyptus (16%)
Porto	Eucalyptus (18%)
Aveiro	Eucalyptus (25%)
Viseu	Maritime Pine (23%)
Guarda	Maritime Pine (12%)
Coimbra	Maritime Pine (30%)
Castelo Branco	Maritime Pine (24%)
Leiria	Maritime Pine (30%)
Santarém	Cork Oak (18%)
Portalegre	Cork Oak (23%)
Lisboa	Eucalyptus (10%)
Setúbal	Cork Oak (25%)
Évora	Holm Oak (20%)
Beja	Holm Oak (16%)
Faro	Cork Oak (8%)

Fig. 1. – Location of Portugal in the Iberian Peninsula, Portuguese districts identification and dominant forest types as a percentage of district area.

The forest fire database for Portugal is provided by the Autoridade Florestal Nacional-AFN. This database constitutes the national component of the European Forest Fire Information System (EFFIS) created by the European Commission in 1994. The Commission Regulation (EC) 804/94 (now expired) established a Community system of information on forest fires for which a systematic collection of a minimum set of data on each fire occurring, the so-called "Common Core", had to be carried out by the Member States participating in the system. According to the currently in force Forest Focus, Regulation (EC) 2152/2003, concerning monitoring of forests and environment interactions in the community, the forest fire common core data should continue to be recorded and notified in order to collect comparable information on forest fires at the Community level.

At national level, the recorded information includes daily area burned and daily number of fires per district, among other variables. From 1980 to 2009, the dataset record illustrates a total of $3.1x10^6$ ha of area burned, approximately 30 % of Portugal's total area, and 487,000 of forest fire occurrences. The AFN database is based on *in situ* information provided by the

Ministry of Agriculture and the National Civil Protection Service. Since 1990, the annual area burned is mapped based on satellite information.
Simple statistics for forest fire activity in Portugal were performed in order to better understand its main characteristics in terms of spatial and temporal distribution. Figure 2 represents the annual area burned and number of fires between 1980 and 2009. The maximum number of annual forest fires occurred in 1995, 1998, 2000 and 2005, reaching 35,000 occurrences. In terms of area burned the year of 2003 reached the highest value ever registered – 430,000 ha, followed by 2005 with 337,000 ha. It is interesting to observe that between 1980 and 2000 the annual number of forest fires registered an increase from year to year except in some specific years. In addition to this and according to the Portuguese Meteorological Institute since 1974 there is a clear increase in the average temperature values in Portugal. The years of 1995, 1997, 1998 and from 2000 to 2006 present higher average temperatures than the normal. From 1995 to 2000 the number of forest fires registered a clear increase, although since 2001 they tend to remain almost constant except in 2005 and 2009.

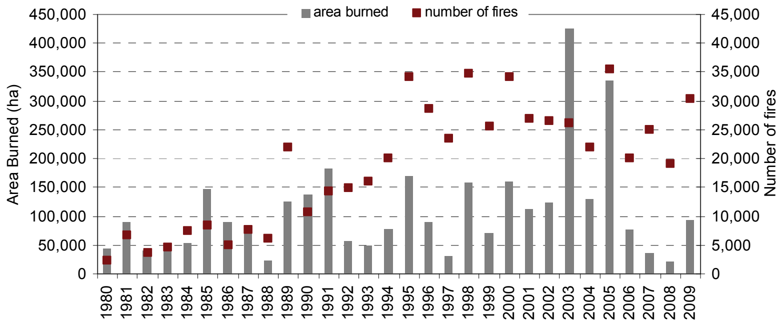


Fig. 2. Annual area burned (bars) and number of fires (square points) in Portugal between 1980 and 2009.

The number of fire occurrences in the months of June (8 %), July (22 %), August (32 %), and September (20 %) represent 82 % of the yearly total (not shown). The area burned peak is observed in August accounting for 45 % of the yearly total (not shown) with the districts of Guarda, Castelo Branco, Viseu, and Coimbra presenting the highest area burned values in Portugal (not shown). According to the National Plan for Forest Fires Prevention, the ignitions peak occurs along the weekend, and especially during the afternoon, denoting an important human influence on fire starts (APIF, 2005).
The annual number of forest fires is higher in the most urban and sub-urban districts (Aveiro, Braga, Lisboa, Porto, Viana do Castelo, and Setúbal) (not shown). In terms of forest fire occurrences, the Porto district (urban/sub-urban region) represents the highest percentage of fire occurrences reaching almost 22 % of the total. Additionally, the Guarda district (rural region) accounts for almost 18 % of the area burned in Portugal, followed by Castelo Branco with 11 % (not shown).
An analysis performed for the period between 1993 and 2003 revealed that 97 % of the forest fire ignitions were due to human influence with 37 % to arson, 28 % to negligence, and 32 % to unknown causes (APIF, 2005). Arson is mainly related to fraud, hunting conflicts, and

building construction interests, and is most notorious in the northern part of the country especially in the coastal regions. Negligence is the most important cause in the south mainly due to clearance activities. In the southern districts of Beja, Évora, and Portalegre the principal cause of negligence is related to agricultural machinery use. Specific regional characteristics are also responsible for forest fires starts such as fireworks activity in the northern districts of the country (APIF, 2005). Portugal, like the majority of the southern European countries, has fewer forest fires due to natural causes because phenomena such as lightning have a low frequency of occurrence during the summer period.

3. Observed fire weather risk in Portugal

The Canadian Forest Fire Weather Index (FWI) System is a system that monitors forest fire risk and supplies information to support fire management. The components of the FWI System can be used to predict fire behaviour and can be used as a guide to policy-makers in developing actions to protect life, property and the environment.

The FWI system was developed for Canadian forests but has also been applied in other countries and environments such as Mexico, Southeast Asia, Florida and Argentina (Moriondo et al., 2006). For the Mediterranean basin, several studies showed that the FWI system and its components were well suited to the estimation of fire risk for the region (Viegas et al., 1999). Moreover, the FWI is currently the fire risk index used by the Joint Research Centre (JRC) to map fire risk at the European Union level (JRC, 2006). The success of this system is due both to the simplicity of its calculation procedures and to the simulation of the moisture of a generalized fuel type, which has been successfully applied to model fire potential in a broad range of fuel types (Van Wagner, 1987).

The FWI System (Figure 3) is a weather-based system that models fuel moisture using a dynamic bookkeeping system that tracks the drying and wetting of distinct fuel layers in the forest floor. There are three moisture codes that represent the moisture content of fine fuels (fine fuel moisture content, FFMC), loosely compacted organic material (duff moisture code, DMC), and a deep layer of compact organic material (drought code, DC). The drying time lags for these three fuel layers are 2/3 of a day, 15 days, and 52 days respectively for the FFMC, DMC, and DC under normal conditions (temperature 21.1ºC, relative humidity 45%). These moisture indexes are combined to create a generalized index of the availability of fuel for consumption (build up index, BUI). The FFMC is combined with wind speed to estimate the potential spread rate of a fire (initial spread index, ISI). The BUI and ISI are combined to create the FWI which is an estimate of the potential intensity of a spreading fire. The daily severity rating (DSR) is a simple exponential function of the FWI intended to increase the weight of higher values of FWI in order to compensate for the exponential increase in area burned with fire diameter (Van Wagner 1970).

For the purposes of this study, the FWI System components were computed using daily mean values of temperature, relative humidity, wind, and daily total precipitation. The Statistical Analysis System (SAS) version 9.1.3 (SAS, 2004) was used for the FWI System components estimation. The FWI System components have been estimated for the period between 1980 and 2005 were meteorological data was available at 12 synoptic sites across Portugal.

Figure 4 presents the daily mean fire weather index (FWI) from 1980 to 2005. Porto district exhibits the lowest values. The southern region formed by Portalegre, Évora, and Beja districts presents the highest interquartilic interval (interquartile range from 25th percentile to 75th percentile) of FWI values. In terms of yearly distribution, 2005 (Figure 4b) presents the highest interquartilic interval of values but the maximum FWI index was attained in 2004. According to the monthly distribution (Figure 4c), July presents the maximum FWI value but the interquartilic interval remains almost the same between July and August. As expected, the period between May and October presents the highest FWI values.

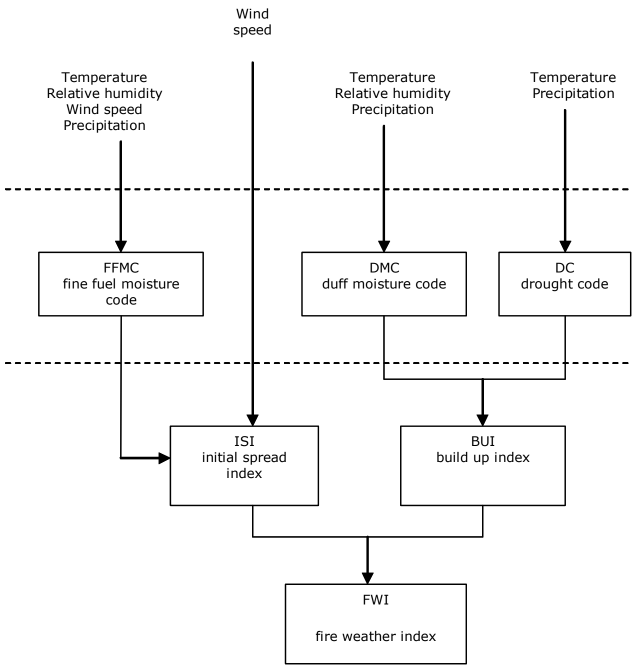
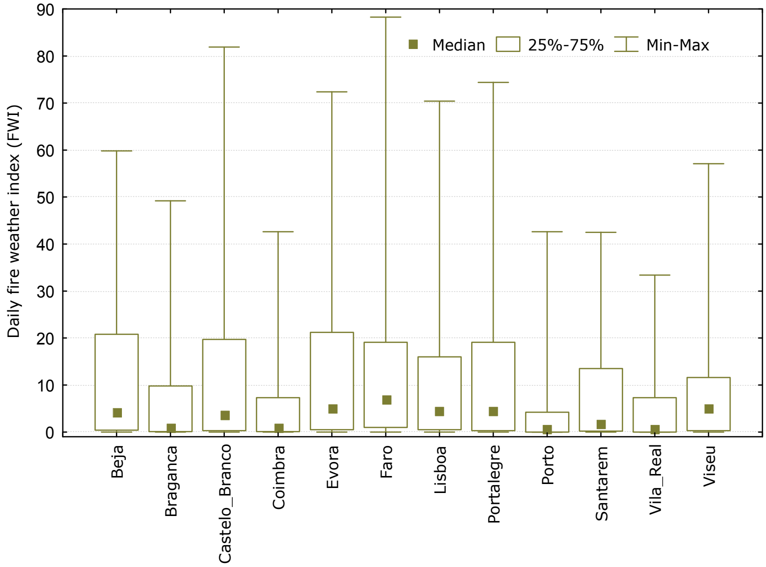


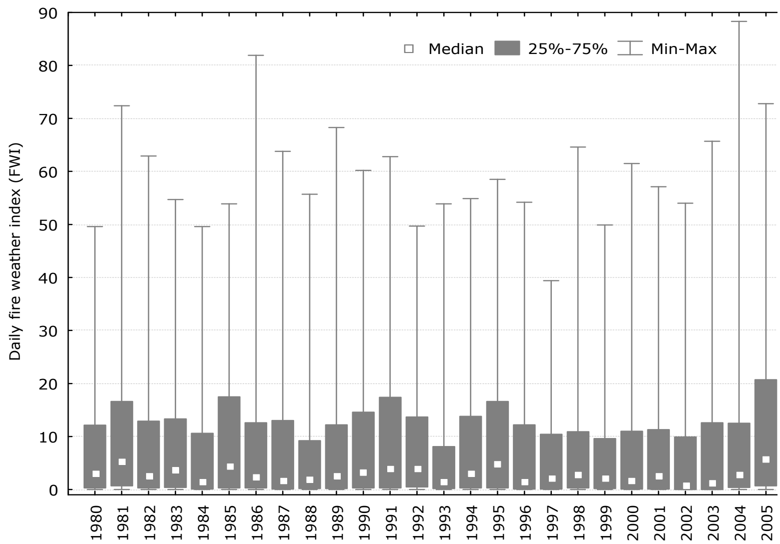
Fig. 3. Canadian Fire Weather Index (FWI) System components (adapted from Van Wagner, 1987).

The 12 stations fire weather data was used to estimate the FWI spatial pattern for Portugal. A Geographic Information System (GIS) software was used to compute a spline interpolation (Schumaker, 1981) over the monthly means of the FWI daily values estimated between 1980 and 2005. Figure 5 presents the FWI spatial distribution over Portugal, from May to October, between 1980 and 2005. According to Figure 5 July and August register the highest values and the southern regions are also the main affected. The monthly mean FWI values range from 1 to 32 depending on the region giving an indication on the associated fire danger. According to Viegas et al. (2004) the highest FWI values registered in the southern region are associated to low fire danger classes. On the contrary, in July and August the districts of the centre and north interior present FWI values ranging from 13 to 29, which are related to moderate to high level of, fire danger. The coastal regions in the north and Centre show the lowest FWI values ranging from 1 to 12. In these regions the obtained FWI values are related to a low to moderate level of fire danger.

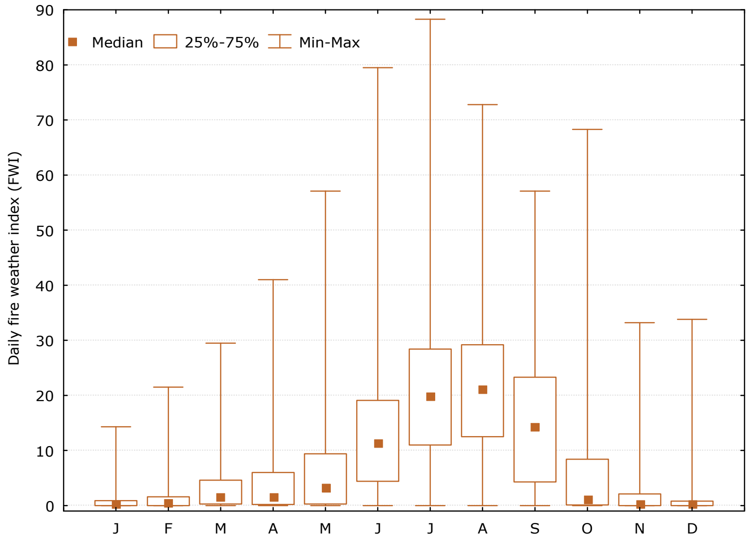
The FWI index spatial distribution has a markedly NW-SE gradient. The NW region of Portugal exhibits the lowest FWI values and the SE the highest. This gradient is in agreement with the temperature patterns and the mean sea level pressure field of the summer climatology observed over the Iberian Peninsula (Hoinka et al., 2009).



a)

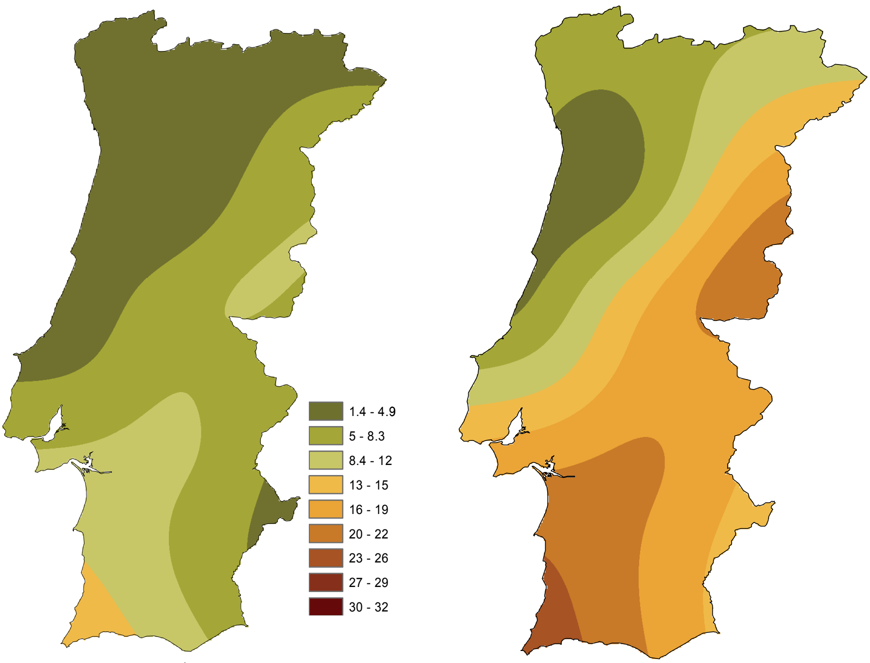


b)

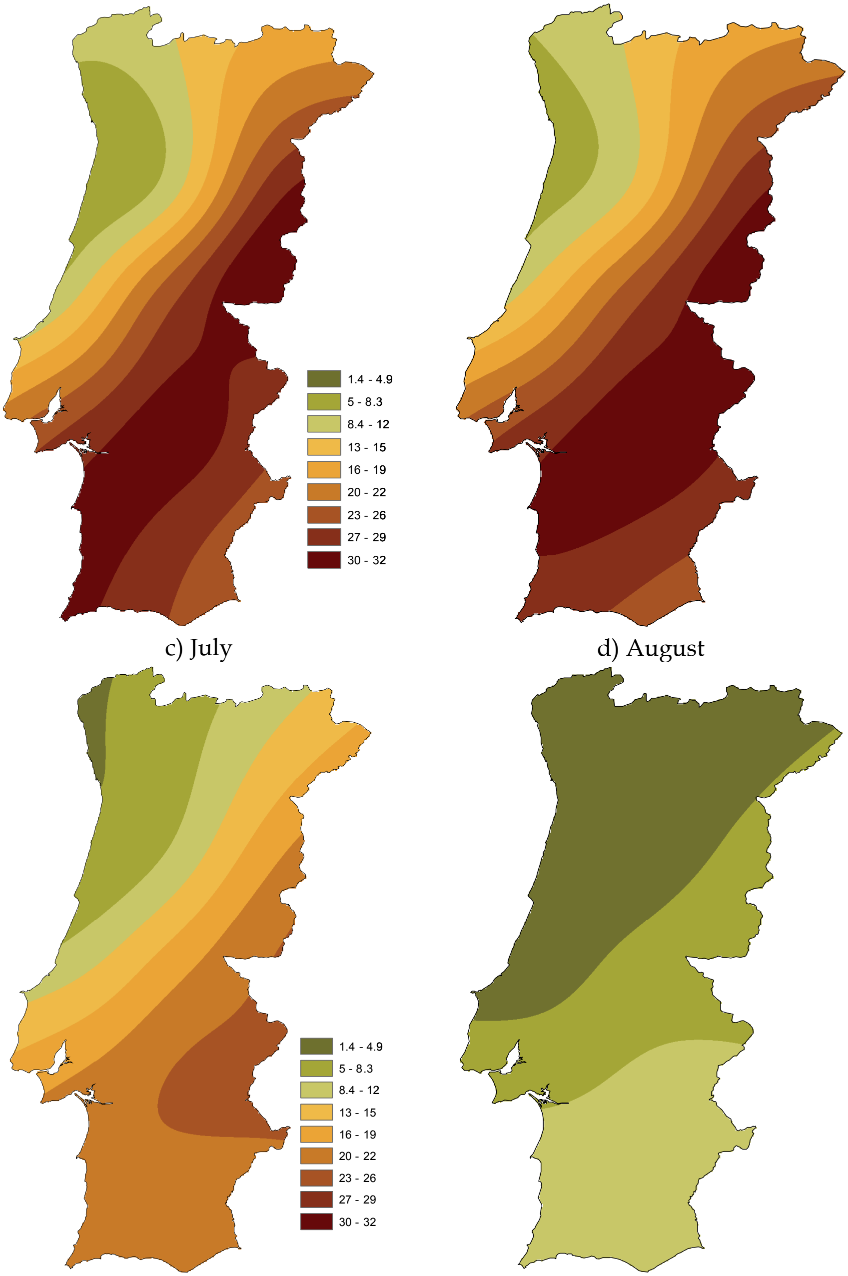


c)

Fig. 4. Daily fire weather index (FWI) between 1980 and 2005 by a) district, b) year and c) month.



a) May b) June



e) September f) October

Fig. 5. Monthly mean fire weather index (FWI) between 1980 and 2005 for a) May, b) June, c) July, d) August, e) September, and f) October.

4. Climate change impacts on fire weather risk

To estimate the impacts of climate change on the fire weather risk, daily climatic data were collected from the regional climate model HIRHAM (Christensen et al., 1996), at 12 km spatial resolution from the Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects – PRUDENCE – project (Christensen and Christensen, 2007) considering the IPCC Special Report on Emissions Scenarios (SRES) A2 scenario. The IPCC SRES A2 scenario is characterized by a very heterogeneous world with a continuously increasing global population. The economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other IPCC scenarios. In this sense, the A2 is considered a high emission scenario. For the analysed time slices the IPCC SRES A2 is consistent to a 2 x CO_2 climatic scenario.

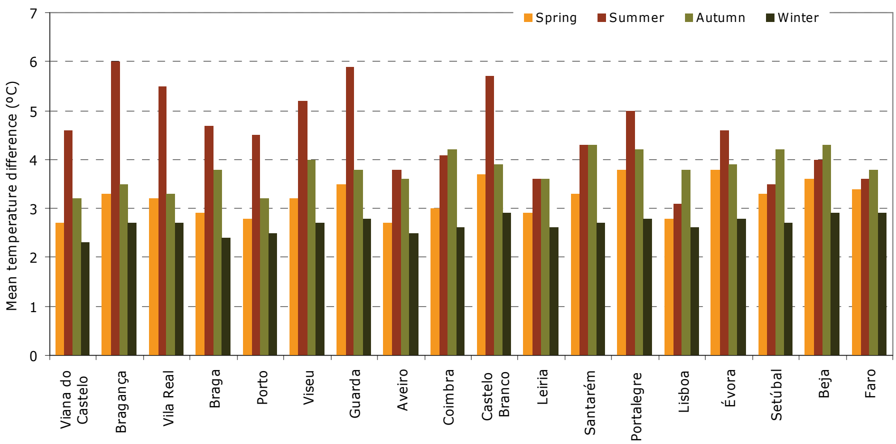
A detailed validation of the HIRHAM outputs was performed for 12 sites across Portugal between 1980 and 1990 (11 year period for which observed data were available). Using SAS version 9.1.3 monthly mean values of the simulated daily mean temperature, daily maximum temperature, daily mean wind speed, total precipitation, and daily mean relative humidity and fire weather risk variables were evaluated. According to the validation procedure the relative humidity presented significant differences against the observed data (Carvalho et al., 2010a). Concerning relative humidity the HIRHAM model presents drier values than the observed at the weather stations. In order to correct the relative humidity field the dew point temperature was evaluated and statistical significant differences were found. The HIRHAM model presents a cold bias in the dew point temperature fields and especially in the south of Portugal and in autumn. A correction factor was applied based on a monthly discrimination (Carvalho et al., 2010a). The correction factor was applied to the reference and to the future climate simulations. This approach has already been used in other works and is considered an adequate calibration procedure (e.g., Flannigan et al., 2005). The corrected climatic fields were used to estimate the FWI System components for reference (1961-1990) and future (2071-2100) scenarios.

The HIRHAM projections over Portugal point to an increase of the mean temperature in all seasons especially in summer, reaching almost 6 ºC in the inner districts of the country ($p<0.0001$) (Figure 6a). The daily precipitation decreases in all seasons especially in spring. The north and central part of Portugal will register the highest reductions in rainfall amounts (Figure 6b). These projections will deeply influence the fuel moisture conditions in future climate.

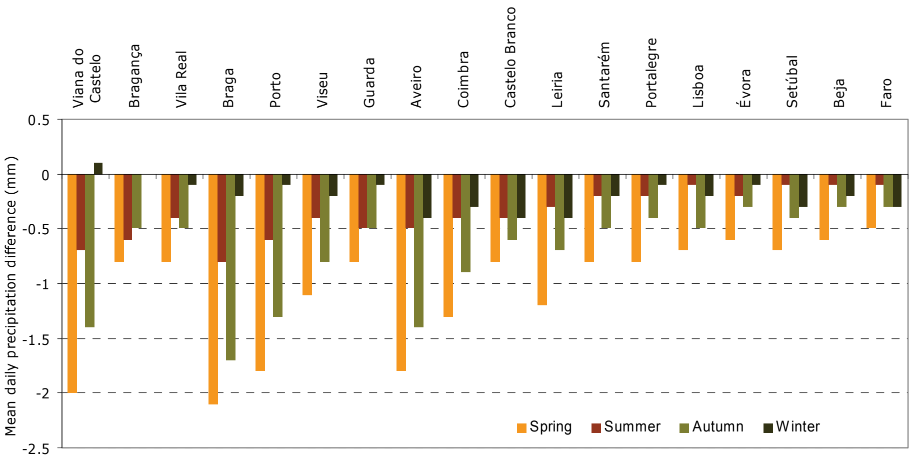
Concerning fire severity, all seasons experience an increase in the FWI component by the end of 21st century. The summer months of June, July and August show the highest FWI values. May registers the highest relative increases, October and November also exhibit high increases in the FWI index. This could lead to a clear anticipation of the fire season starting and an increase in its length. There is also a clear FWI increasing trend from north to south (Carvalho et al., 2010a).

Figure 7 exhibits the FWI cumulative frequency distribution for each scenario by district. To help on the discussion the districts are organized by north, centre and south of Portugal.

The obtained cumulative distribution functions clearly show the FWI shift to attain higher values in a future climatic scenario. The districts of the north formed by Viana do Castelo, Bragança, Vila Real, Braga, and Porto show an increase of the maximum FWI range of values from 26-53 to 45-76. The 50th percentile also shows an increase but not so pronounced. The districts in the Centre like Viseu, Guarda, Aveiro, Coimbra, Castelo Branco and Leiria, also present an increase in the FWI maximum values ranging from 39-55 to 55-71 from the reference to the future climatic scenario. The southern districts of Santarém, Portalegre, Lisboa, Évora, Setúbal, Beja and Faro present the highest FWI maximum values in the reference scenario and the same is verified in the future climate. The FWI values between the 25th percentile and the maximum show a clear increase in all southern districts. In this part of the country the FWI ranges from 50-71 and in future climate these values increase to 57-76.

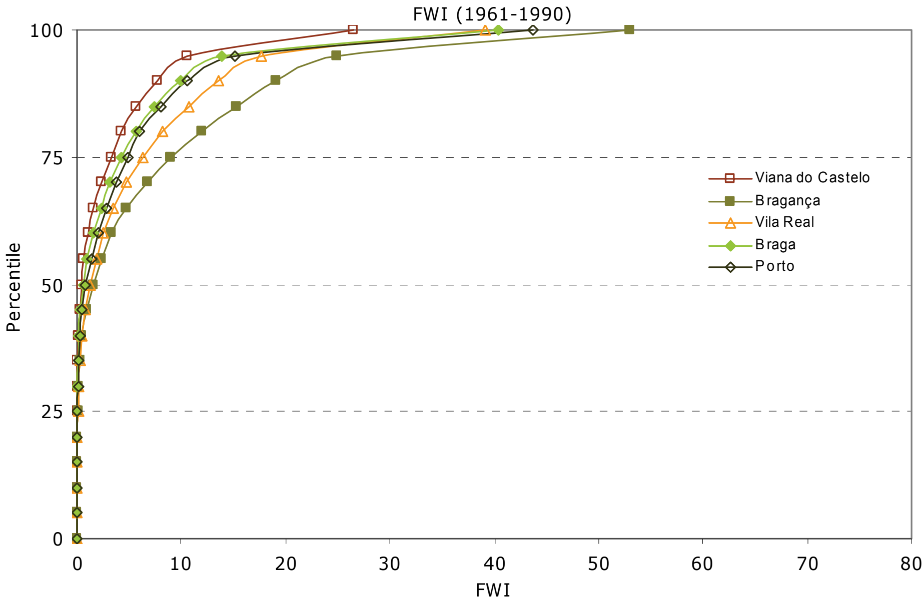


a)



b)

Fig. 6. Differences between future (2071-2100) and reference (1961-1990) climatic scenarios for a) daily mean temperature and b) daily precipitation, by season and for each Portuguese district.


FWI (1961-1990)
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FWI
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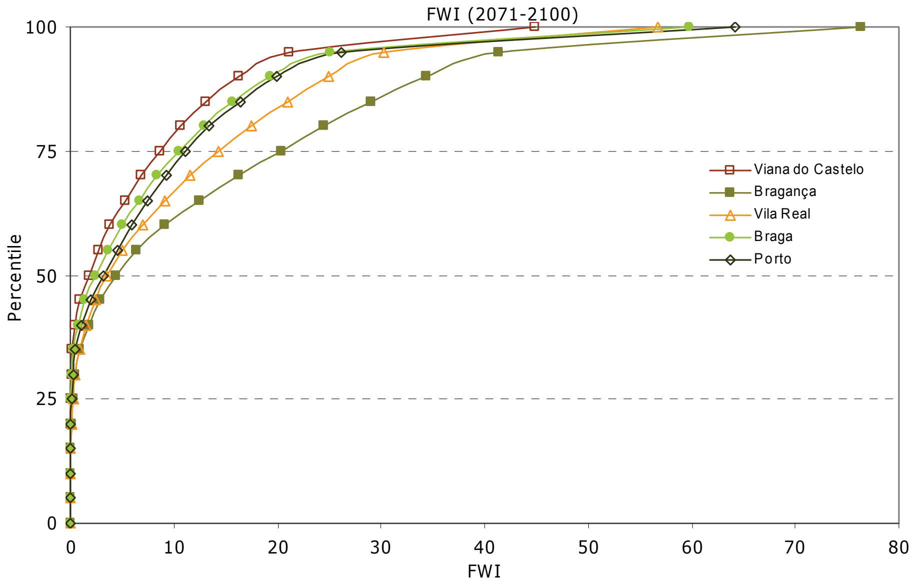
FWI (2071-2100)
Percentile
FWI
Viana do Castelo
Bragança
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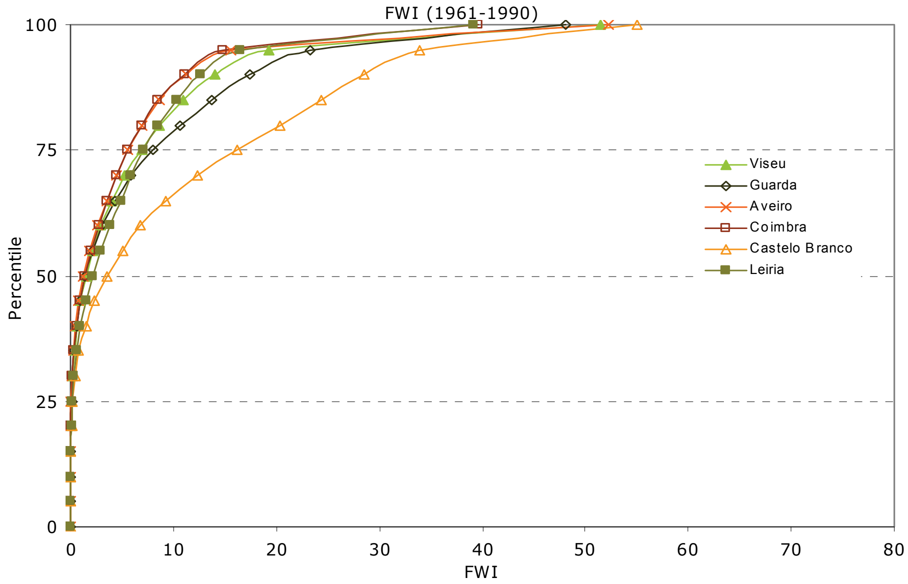
FWI (1961-1990)
Percentile
FWI
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Guarda
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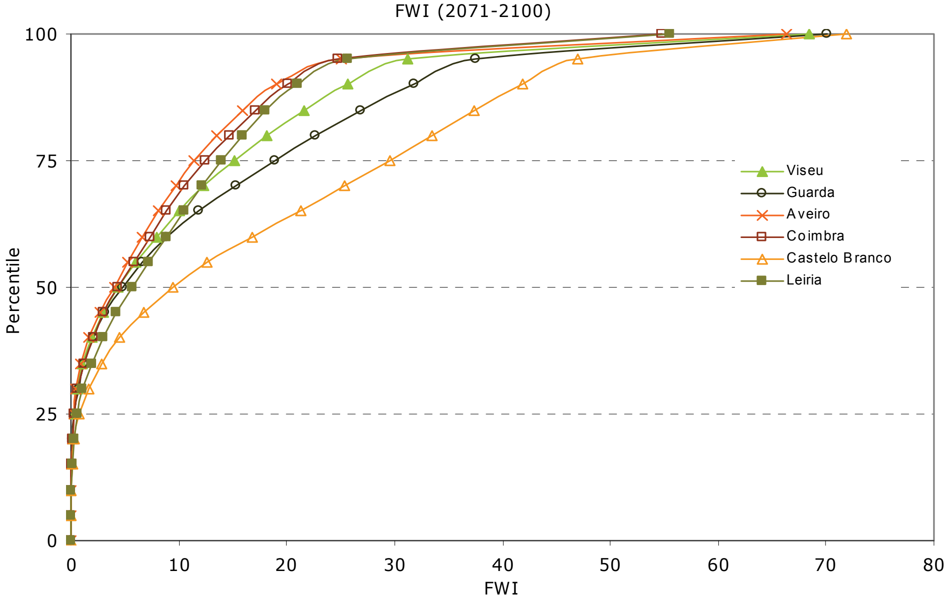
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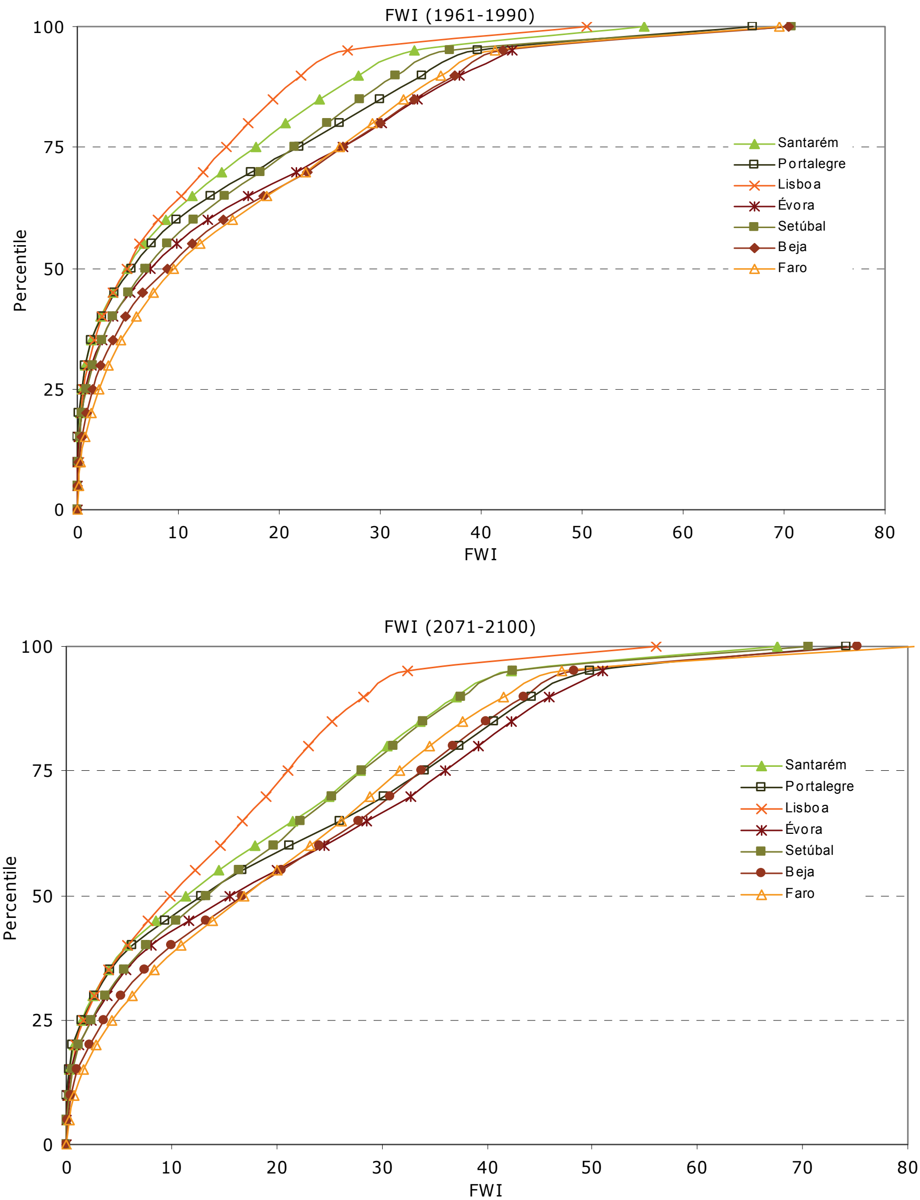

Fig. 7. Cumulative frequency distribution of the daily FWI component by district and for each climatic scenario (reference and 2 x CO_2). The districts are organized by north, centre and south of Portugal.

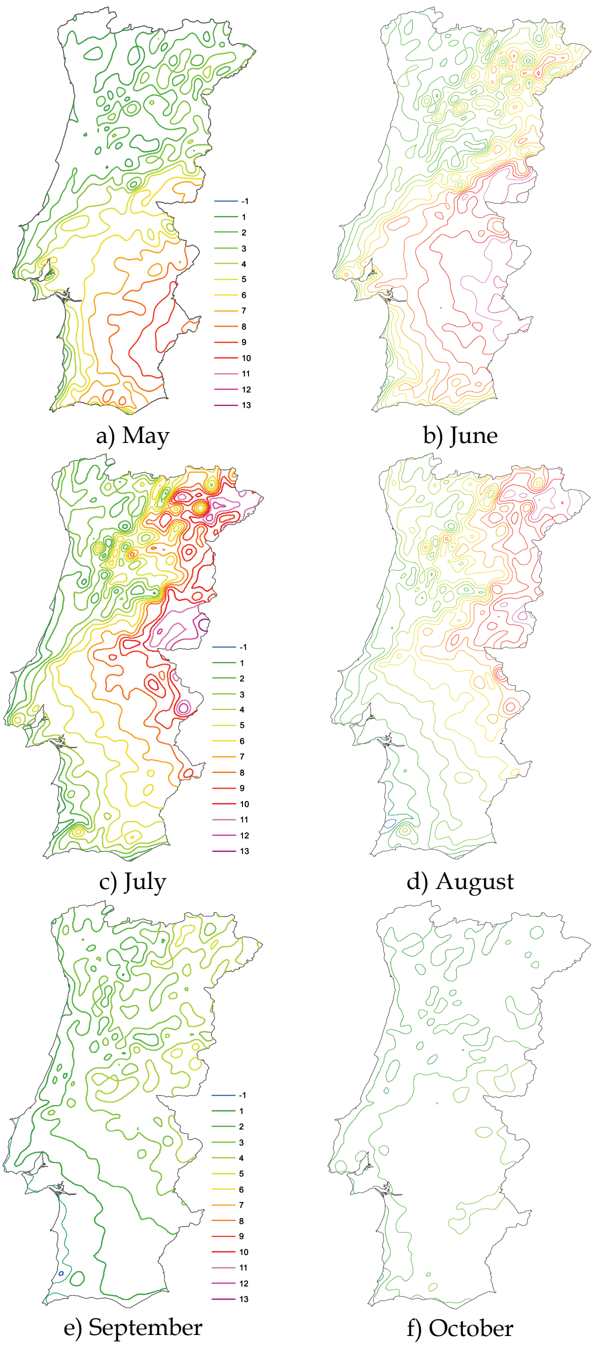

Fig. 8. FWI changes between future and reference scenarios for a) May, b) June, c) July, d) August, e) September, and f) October.

Figure 8 presents the differences on the FWI patterns for May, June, July, August, September, and October between future and reference climatic scenarios. As previously noted, all the districts across Portugal experience an increase on the FWI component but this is more pronounced in the inner regions. July and August show the highest increases namely in the districts of Bragança, Guarda, and Castelo Branco. These districts form a regional elongated pattern that goes from north to the centre just close to the Spanish border. September and October exhibit a very homogeneous pattern of increase from north to south.

The area burned and the number of fires in Portugal is strongly dependent on the weather conditions. So, it is expected that fire activity will increase with a changing climate. In Carvalho et al. (2008) statistically significant relationships were established between the area burned, the number of fires and the weather for different Portuguese districts. The authors have concluded that the weather explains the majority of the variance of the area burned and of the number of fires in Portugal. The obtained statistical models were used to estimate the area burned and the number of fires for future climate. The results point to a substantial increase in the area burned and on the number of fires ranging from 238 % to 643 % and 111 % to 483 %, respectively, depending on the Portuguese district (Carvalho et al., 2010a). The regions in the central part of the country will be the most affected. The monthly distribution of the area burned and number of fires indicates that an earlier fire season starting may be expected under future climate.

5. Forest fires and climate change impacts in particulate matter and ozone levels

The impact of climate change and future area burned on forest fire emissions and consequently on regional air quality was assessed through the application of the MM5/CHIMERE numerical modelling system. This numerical system has been widely tested and successfully used over Portugal (Monteiro et al., 2005; Monteiro et al., 2007; Monteiro, 2007). The HadAM3P (Jones et al., 2005) simulations for the reference and the IPCC SRES A2 climatic scenario were used to driven the MM5/CHIMERE modelling system. The forest fire emissions for both scenarios were estimated and considered in the air quality simulations over Portugal.

The air quality modelling application was performed using the chemistry-transport model CHIMERE (Schmidt et al., 2001; Bessagnet et al., 2004), forced by the musicale model MM5 (Grell et al., 1994). The MM5 model has been used worldwide in several regional climate studies (e.g., Boo et al., 2004; Van Dijck et al., 2005). The MM5/CHIMERE modelling system has already been used in several studies that investigated the impacts of climate change on air pollutants levels over Europe (Szopa et al., 2006) and specifically over Portugal (Carvalho et al., 2010b).

The Fifth-Generation Penn State University/National Center for Atmospheric Research (PNU/NCAR) Mesoscale Model, known as the MM5, is a no hydrostatic, vertical sigma-coordinate model designed to simulate musicale atmospheric circulations. MM5 has multiple nesting capabilities, availability of four-dimensional data assimilation (FDDA), and a large variety of physics options. The selected MM5 physical options were based on the already performed validation and sensitivity studies over Portugal (Ferreira et al., 2004; Aquilina et al., 2005; Carvalho et al., 2006) and over the Iberian Peninsula (Fernandez et al.,