*Int. J. Environ. Res., 9(3):831-840, Summer 2015*
*ISSN: 1735-6865*

# Analyzing the Behaviour of Selected Risk Indexes During the 2007 Greek Forest Fires

**Mavrakis, A.[1*], and Salvati, L.[2]**

[1]Institute of Urban Environment and Human Resources, Department of Economic and Regional Development, Panteion University, 136 Syngrou Avenue, GR-17671 Athens, Greece

[2]Consiglio per la Ricerca e la sperimentazione in Agricoltura, Centre for the Study of Soil-Plant Interactions (CRA-RPS), Via della Navicella 2-4, I-00184 Rome, Italy

Received 21 Aug. 2014; Revised 27 Oct. 2014; Accepted 1 Jan. 2014

**ABSTRACT:**Greece has experienced particularly severe and frequent forest fires during Summer 2007 together with exceptionally dry meteorological conditions culminated in distinct heat waves. The present study analyzes the time pattern of daily values of two fire risk indices (Nesterov and Angstrom) based on meteorological data made available for a number of gauging stations between 1 June and 31 August over the 1998-2013 time interval. Weather data were supplemented with meteorological re-analysis profiles with the aim to validate the daily outputs of the two fire risk indices in extreme climatic conditions. Nesterov and Angstrom indices classified Summer 2007 meteorological conditions as exceptional with high probability of fire occurrence during the whole dry season in the majority of Greek regions. Meteorological re-analysis indicates a high deviation of selected upper atmospheric variables from the climatic average since early July 2007 representing persistent and widespread meteorological conditions favourable to fire occurrence in Greece. The crucial role of indicator-based monitoring of heat waves and exceptionally-dry meteorological conditions for mega-fire surveillance in the Mediterranean basin was finally discussed.

**Key words:** Climate, Heat Wave, Weather anomaly, Indicators, Mediterranean region

## INTRODUCTION

Climate models have shown that drought frequency and intensity are likely to increase in the Mediterranean region (see Founda and Giannakopoulos, 2009 and references therein). Despite forecasts' uncertainty, climate models predict a decrease in precipitation levels and changes in air temperature regimes accompanied by prolonged dry periods concentrated in winter and summer (Giannakopoulos *et al.*, 2011). This may exacerbate aridity conditions and drought episodes leading to land degradation and increased risk of desertification (Bajocco *et al.*, 2011; Salvati *et al.*, 2012). It was also demonstrated that fire risk increases with drought frequency and severity (Pausas, 2004; Moriondo *et al.*, 2006). Wildfires are major disturbances in Mediterranean ecosystems worldwide. Every year, over 60.000 fires are recorded in Europe, mainly in Mediterranean Europe, burning more than 0.6 MHa of land (Joint Research Center, 2013). Prediction models indicate an increase in fire risk due to climate change and landscape transformations (e.g. Krawchuk *et al.*, 2009). Meteorological indices were proposed for the assessment of fire risk in the Mediterranean region and early warning systems for fire frequency and severity often incorporate indicators evaluating the departure of target variables (e.g. temperature, wind, soil moisture) from the climate average (Good *et al.*, 2011). However, the short-term pattern of different fire risk indices in specific meteorological conditions (e.g. prolonged drought episodes) and over large areas was rarely investigated with the aim to compare reliability and prognostic capability (Pitman *et al.*, 2007; Turner *et al.*, 2011; Raulier *et al.*, 2013; Whitman *et al.*, 2013).

Since the mid-1970s the Mediterranean region experienced warming trends especially in the summer (Philandras *et al.*, 2008). Greece was subjected to extreme heat waves in 2007 that hit the country from late June to the end of August (see Theoharatos *et al.*, 2010; Mavrakis *et al.*, 2012 and references therein). Summer 2007 was the warmest

*Corresponding author E-mail: mavrakisan@yahoo.gr

summer ever recorded at the station of the National Observatory of Athens since the mid-19th century (Founda and Giannakopoulos, 2009). The extremely high temperatures combined with a prolonged dry period determined the most severe forest fires in Greece's modern history (Karamichas, 2007; Boschetti *et al.*, 2008; Liu *et al.*, 2009). Moreover, Koutsias et al. (2012a, 2012b) observed that 2007 fires affected, at least in part, non-fire-prone ecosystems with different characteristics compared to the normal fire regime including (i) higher average burnt area and (ii) higher frequency of repeated burning. Based on Joint Research Centre (2013) data, the number of fires in Greece averaged 1555 events per year during 1980-2012. Cumulated burnt land averaged 416 $km^2$ per year with the surface area burnt in Summer 2007 exceeding 2257 $km^2$. The biggest forest fires in 2007 were recorded in Peloponnese region (southern Greece), namely in the prefectures of Ilia (1144 $km^2$), Arcadia (88.1 $km^2$) and Achaia (14.3 $km^2$), and in the central Greece region of Attica (5.0 $km^2$).

Based on these premises, the present study is aimed at verifying the prognostic ability of two early-warning fire risk indices (Nesterov and Angstrom: see Mantzavelas *et al.*, 2006) for the exceptional fire conditions occurring during Summer 2007 in Greece. The temporal pattern of the two indices during a three-months interval (1 June - 31 August) of 16 consecutive years (1998-2013) was studied based on weather data recorded in gauging stations homogeneously distributed across Greece.

Greece covers 130,875 $km^2$ at the southern tip of the Balkan Peninsula, with mostly mountainous topography and hundreds of islands. The climate is typically Mediterranean over most of the country, with hot and dry summers and mild winters. Little or no rain is generally recorded during late spring and summer with dry season starting in April. Areas in southern Greece receive, on average, 400 mm of annual rainfall and maximum air temperature in the summer may exceed 40°C for several days.

Forest vegetation in Greece reflects dry climate, undulated topography, and generally poor soil quality. Mountain forests host a variety of tree species including deciduous broadleaved species (*Quercus* spp., *Fagus orientalis*, *Castanea vesca*, *Populus tremula*, *Betula pendula*, *Fraxinus excelsior*, *Acer* spp.) and cold tolerant conifers (*Pinus nigra*, *Pinus silvestris*, *Abies cephalonica*, *Abies alba*, *Picea excelsa*). Low elevation forests and shrublands are formed by drought–resistant evergreen broadleaved species (*Quercus coccifera*, *Quercus ilex*, *Laurus nobilis*, *Ceratonia siliqua*, *Olea europaea*, *Arbutus* spp., *Cistus* spp., *Erica* spp. and *Pistacia* spp.), and pine trees (*Pinus halepensis*, *Pinus brutia*, *Pinus pinea*) occupying the lower elevations in the country up to 300 m and 800 m above sea level, respectively, in northern and southern Greece (Koutsias *et al.*, 2012a). Forest flammability is generally high. The most flammable vegetation types are Mediterranean pine forests and shrublands at lower elevation, especially in central and southern Greece. This vegetation, however, is well adapted to fire either through cone serotiny (pines) or through re–sprouting (shrubs). Weather and climate variability defines vegetation characteristics, whereas climate on inter-annual scales affects flammability of live and dead vegetation. Major factors underlying fire severity in Greece include climate changes (Koutsias *et al.*, 2012a), socioeconomic issues (Koutsias *et al.*, 2012b), land abandonment and natural (or poorly planned) forestation of former agricultural land leading to fuel accumulation (Moreira *et al.*, 2011).

## MATERIALS & METHODS

The daily values of air temperature, relative humidity, dew point, and precipitation were used to estimate Nesterov and Angstrom indices. Nesterov index (N) was calculated according to the following equation:

$$N = \sum_{i=1}^{w} (t_i - D_i) t_i \qquad (1)$$

where: w = number of days since last rainfall > 3 mm, $t_i$ = mid-day temperature (°C), $D_i$ = dew point temperature (°C). The sum is calculated for positive temperatures for a sequence of days with precipitation less than 3 mm. Rainfall above 3 mm resets N to zero. N is a cumulated index and reflects drying potential for fuel. High N values indicate long periods without rainfalls. The index classifies fire hazard in five categories (no fire danger: $0 < N \leq 300$; low fire danger: $300 < N \leq 1000$; medium fire danger: $1000 < N$ 4000; high fire danger: $4000 < N \leq 10000$; extreme fire danger: $N > 10000$).

The Angstrom index (I) is based on the following equation:

$$I = \left(\frac{R}{20}\right) + \left(\frac{27 - T}{10}\right) \qquad (2)$$

where R is relative humidity and T is air temperature. The index classifies fire hazard in four classes: (i) unlikely conditions for fire occurrence: I > 4.0; (ii) unfavourable conditions for fire occurrence: 4.0 ≥ I > 2.5; favourable conditions for fire occurrence: 2.5 ≥ I > 2.0; very favourable conditions for fire occurrence: I ≤ 2.0.

The two fire risk indices were calculated on a day base during the time window between 1 June 2007 and 31 August 2007 from data continuously collected for 24 meteorological stations of the Hellenic National Meteorological Service (see list in Table 1) covering homogeneously the entire country. Statistics of the two indices (average and maximum or minimum peak value) were calculated by month. Maps illustrating the spatial distribution of both indices in Greece were also provided. Maps were created using Quantum GIS software and were derived from the minimum curvature interpolation, a method widely used in the earth science (e.g. Yang *et al.,* 2004). The minimum curvature method tends to smooth out differences between neighbouring points. The domain size is a map of Greece with 35 – 42 N and 19 – 29 E coverage and contours of coastline scaled 1:5,000,000. All directions were considered equally significant (unity anisotropy).Table 1. Statistical distribution (average and maximum/minimum) of Nesterov and Angstrom indices observed in June, July, and August 2007 in Greece by selected meteorological stations (bold indicates high or extreme fire danger (Nesterov) and favourable or very favourable conditions for fire occurrence (Angstrom)).

A time interval of 15 years (1998-2013 with the exclusion of 2007) was considered a representative period to calculate summer (June-August) climatic figures for both indices (day values, monthly averages and maximum (Nesterov) or minimum (Angstrom) values). Based on data availability, a sub-sample formed by 13 stations (see list in Table 2) was used to compare the indices' behaviour in 2007 and during the climatic period 1998-2013. All weather data were obtained from the website of the University of Wyoming (http://weather.uwyo.edu/ accessed July 2014).

Finally, upper level weather reanalysis data were obtained from the National Centre for Environmental Prediction / National Centre for Atmospheric Research (NCEP/NCAR) covering the time interval between 1 June 2007 and 31 August 2007 with the aim to provide a general picture of the spatial distribution of key variables documenting the exceptional meteorological conditions occurring in Europe and in the Mediterranean basin during Summer 2007. Departures of air temperature and relative air humidity values from the long-term (1981-2010) climatic averages were examined at monthly base. The two variables were selected for re-analysis since they represent relevant climatic factors in fire risk and are primary inputs for both Nesterov and Angstrom indices. Re-analysis data derived from the interactive plots provided by the NOAA/NCEP service available online at http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl (accessed July 2014) and refer to 1000 hPa relative humidity anomaly and to 1000 hPa air temperature anomaly.

## RESULTS & DISCUSSION

Table 1 reports monthly statistics for both Nesterov and Angstrom indices. Nesterov index classified weather conditions as 'high' or even 'extreme' fire danger in 3, 21, and 17 stations out of 24 in June, July and August 2007, respectively. By considering the maximum value recorded in each month, 20, 24 and 23 stations out of 24 exceeded the threshold of 'high' or 'extreme' fire danger at least one day in June, July and August, respectively. A similar pattern was observed for Angstrom index with 5, 10 and 3 stations out of 24 showing an average index value exceeded the threshold indicating 'favourable' or 'very favourable' conditions for fire occurrence respectively in June, July and August. A total of 23, 23 and 20 stations out of 24 showed the highest monthly value of the index largely exceeded the 'favourable' threshold. In June 2007, the most critical conditions for fire occurrence were detected in traditionally dry areas in Attica (Spata, Elefsis), Crete (Souda) and partly, northern Greece (Alexandroupoli, Kozani). Since the first days of July 2007 both indices increased rapidly indicating widespread, critical conditions for fire occurrence throughout the country with few exceptions (Ionian islands and coastal areas: Kerkira, Kefallinia, Zakinthos and Preveza, together with some eastern islands: Kos). Critical meteorological conditions for forest fires maintained quite stable up to the end of August 2007. Two distinct and persisting time intervals were classified as 'very favourable' conditions for fires all over Greece (between 15 June and 5 August 2007 and between 9 August to 31 August 2007). The maximum value for both Nesterov and Angstrom indices was observed in Kalamata on 24 August 2007. On the same day wildfires broke out in neighbouring areas destroying more than 1140 $km^2$ of land with drastic consequences for local communities and the environment. Based on the maps illustrated in Fig. 1, the spatial distribution of the two

**Table 1. Statistical distribution (average and maximum/minimum) of Nesterov and Angstrom indices observed in June, July, and August 2007 in Greece by selected meteorological stations (bold indicates high or extreme fire danger (Nesterov) and favourable or very favourable conditions for fire occurrence (Angstrom)).**

| Station | Code | Lat | Long | Nesterov | | | | | | Angstrom | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | June | | July | | August | | June | | July | | August | |
| | | | | Average | Max | Average | Max | Average | Max | Average | Min | Average | Min | Average | Min |
| Andravida | LGAD | 37.92 | 21.29 | 1040 | 3276 | **7161** | **14964** | **13656** | **46720** | 3.2 | **2.2** | 3.0 | **2.2** | 3.1 | **2.1** |
| Alexandroupolis | LGAL | 40.86 | 25.96 | 893 | 3900 | **9900** | **19440** | 3203 | **9720** | **2.4** | **1.5** | **2.2** | **1.7** | 2.6 | **1.7** |
| Spata | LGAV | 37.94 | 23.94 | **4074** | **18018** | **19113** | **38808** | **29009** | **62775** | **2.2** | **1.3** | **1.8** | **1.4** | **2.1** | **1.5** |
| Elefsis | LGEL | 38.06 | 23.55 | **5067** | **19440** | **24210** | **46176** | **33161** | **62000** | **2.3** | **1.3** | **1.9** | **1.5** | **2.2** | **1.4** |
| Iraklio | LGIR | 35.34 | 25.18 | 2715 | **11385** | **8301** | **22848** | **11753** | **20358** | 3.0 | **2.5** | 3.0 | **2.4** | 3.3 | 2.6 |
| Kefalinia | LGKF | 38.12 | 20.5 | 2208 | **8120** | **12553** | **35700** | **15571** | **60588** | 3.1 | **2.2** | 2.6 | **1.8** | 3.1 | **2.1** |
| Kalamata | LGKL | 37.07 | 22.03 | 1930 | **8050** | **9762** | **30912** | **18021** | **64610** | 2.6 | **1.9** | **2.5** | **1.8** | 2.8 | **1.7** |
| Kos | LGKO | 36.79 | 27.09 | 1716 | **7920** | 3302 | **13566** | **4213** | **9450** | 2.7 | **2.1** | 3.0 | **1.8** | 3.1 | **2.2** |
| Karpathos | LGKP | 35.42 | 27.15 | 2049 | **9216** | **7362** | **15686** | **10816** | **15428** | 3.0 | **2.3** | 3.2 | 2.6 | 3.5 | 2.8 |
| Kerkira | LGKR | 39.6 | 19.91 | 2274 | **7774** | 2966 | **7590** | **5922** | **12528** | 3.1 | **2.2** | 2.7 | **1.9** | 3.0 | **2.1** |
| Kavala | LGKV | 40.91 | 24.62 | 473 | 3136 | **4095** | **10584** | 1875 | **7245** | 3.0 | **2.3** | 2.7 | **2.2** | 2.9 | **2.3** |
| Kozani | LGKZ | 40.29 | 21.84 | 3844 | **17226** | **8140** | **19136** | 2429 | **10608** | **2.2** | **1.4** | **1.7** | **0.9** | **2.1** | **1.4** |
| Lemnos | LGLM | 39.92 | 25.24 | 2191 | **9135** | **11159** | **20700** | 3079 | **13110** | 2.9 | **2.2** | 2.6 | **1.9** | 2.9 | **2.0** |
| Mykonos | LGMK | 37.44 | 27.35 | 3937 | **16456** | **11222** | **33600** | **16461** | **35322** | 2.6 | **1.8** | **2.5** | **1.8** | 2.9 | **2.4** |
| Mitilini | LGMT | 39.06 | 26.6 | 3363 | **11880** | **13533** | **26367** | **21333** | **42160** | 2.6 | **2.1** | 2.7 | **1.9** | 2.8 | **2.3** |
| Preveza | LGPZ | 38.93 | 20.77 | 471 | 2028 | 3952 | **12150** | 732 | 2400 | 3.3 | 2.7 | 3.2 | **2.4** | 3.4 | **2.4** |
| Rhodes | LGRP | 36.41 | 28.09 | 3293 | **9300** | **8589** | **15080** | **14954** | **29388** | 2.9 | **2.2** | 3.3 | **2.2** | 3.4 | 2.9 |
| Araxos | LGRX | 38.15 | 21.43 | 1700 | **6264** | **12001** | **27342** | **4668** | **13464** | 2.9 | **1.6** | **2.5** | **1.9** | 3.0 | **1.9** |
| Souda | LGSA | 35.53 | 24.15 | **5151** | **20332** | **12938** | **33660** | **20331** | **40290** | **2.5** | **1.7** | 2.6 | **1.9** | 2.8 | **2.2** |
| Skiathos | LGSK | 39.18 | 23.5 | 3618 | **18648** | **5609** | **15776** | 3129 | **10240** | 2.8 | **2.0** | 2.7 | **2.2** | 3.1 | **2.3** |
| Samos | LGSM | 37.69 | 26.91 | 3076 | **9660** | **17253** | **38916** | **20879** | **39780** | 2.7 | **2.0** | **2.5** | **1.9** | 3.0 | **2.3** |
| Santorini | LGSR | 36.4 | 25.48 | 3486 | **12852** | **10434** | **23250** | **17338** | **28536** | 2.8 | **2.4** | 2.9 | **2.3** | 3.1 | 2.7 |
| Thessaloniki | LGTS | 40.52 | 22.97 | 1301 | **7623** | **6026** | **16320** | 1738 | **8370** | 2.7 | **1.9** | **2.4** | **1.4** | 2.9 | **2.1** |
| Zakynthos | LGZA | 37.75 | 20.88 | 2892 | **9720** | **15642** | **31350** | **5647** | **18117** | 2.7 | **1.6** | **2.4** | **1.6** | 2.8 | **2.3** |

**Table 2. The ratio between 2007 daily value and climatic (1998-2013) maximum (or minimum) daily value for Nesterov and Angstrom indexes observed in June, July and August by selected meteorological stations (bold indicates higher risk values recorded in 2007 than in the average time series).**

| Station | Code | Nesterov* | | | | | | Angstrom** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | June | | July | | August | | June | | July | | August | |
| | | Average | Max | Average | Max | Average | Max | Average | Min | Average | Min | Average | Min |
| Alexandroupolis | LGAL | 0.56 | 0.52 | **4.23** | **1.56** | 0.81 | 0.54 | **1.41** | 0.90 | **1.25** | 0.59 | **1.05** | 0.68 |
| Elefsis | LGEL | **1.55** | **1.22** | **2.56** | **1.10** | **2.53** | **1.12** | **1.02** | 0.46 | **1.00** | 0.37 | 0.85 | 0.18 |
| Iraklio | LGIR | **1.35** | **1.40** | **1.05** | 0.89 | **1.00** | 0.49 | **1.17** | **1.26** | **1.05** | 0.21 | **1.00** | 0.25 |
| Kefalinia | LGKF | **1.52** | 0.68 | **2.93** | **1.72** | **2.21** | **1.38** | **1.21** | 0.52 | **1.28** | 0.67 | **1.07** | 0.71 |
| Kalamata | LGKL | **1.51** | **1.11** | **2.35** | **1.14** | **4.12** | **2.63** | **1.35** | 0.76 | **1.23** | 0.39 | **1.12** | 0.53 |
| Kavala | LGKV | 0.85 | 0.86 | **3.92** | **1.43** | **1.04** | 0.58 | **1.25** | 0.91 | **1.22** | 0.77 | **1.14** | 0.72 |
| Kozani | LGKZ | **3.57** | **2.64** | **2.82** | **1.01** | 0.74 | 0.42 | **1.48** | 0.96 | **1.56** | 0.61 | **1.30** | 0.71 |
| Mitilini | LGMT | **1.65** | **1.33** | **2.07** | **1.00** | **2.09** | **1.00** | **1.19** | 0.81 | **1.02** | 0.71 | **1.01** | 0.52 |
| Preveza | LGPZ | 0.61 | 0.32 | **1.60** | 0.73 | 0.40 | 0.11 | **1.20** | 0.83 | **1.13** | 0.79 | **1.04** | 0.40 |
| Rhodes | LGRP | **1.28** | 0.85 | **1.03** | 0.66 | **1.25** | 0.86 | **1.22** | 0.82 | **1.00** | 0.75 | **1.00** | 0.48 |
| Araxos | LGRX | **1.07** | 0.62 | **2.39** | **1.36** | **1.00** | 0.48 | **1.23** | 0.88 | **1.25** | 0.68 | **1.02** | 0.55 |
| Souda | LGSA | **1.71** | **1.51** | **1.32** | **1.13** | **1.47** | 0.79 | **1.20** | 0.53 | **1.05** | 0.08 | **1.05** | 0.41 |
| Thessaloniki | LGTS | **1.12** | 0.70 | **2.94** | **1.10** | **1.01** | 0.76 | **1.15** | 0.82 | **1.12** | 0.86 | **1.00** | 0.71 |

* calculated as the ratio of 2007 average value to the 1998-2013 average value or as the ratio of 2007 maximum value to the 1998-2013 maximum value; ** calculated as the ratio of 1998-2013 average value to 2007 average value or as the ratio of 1998-2013 maximum value to the 2007 maximum value. In all cases 2007 data were not considered in the 1998-2013 climatology.

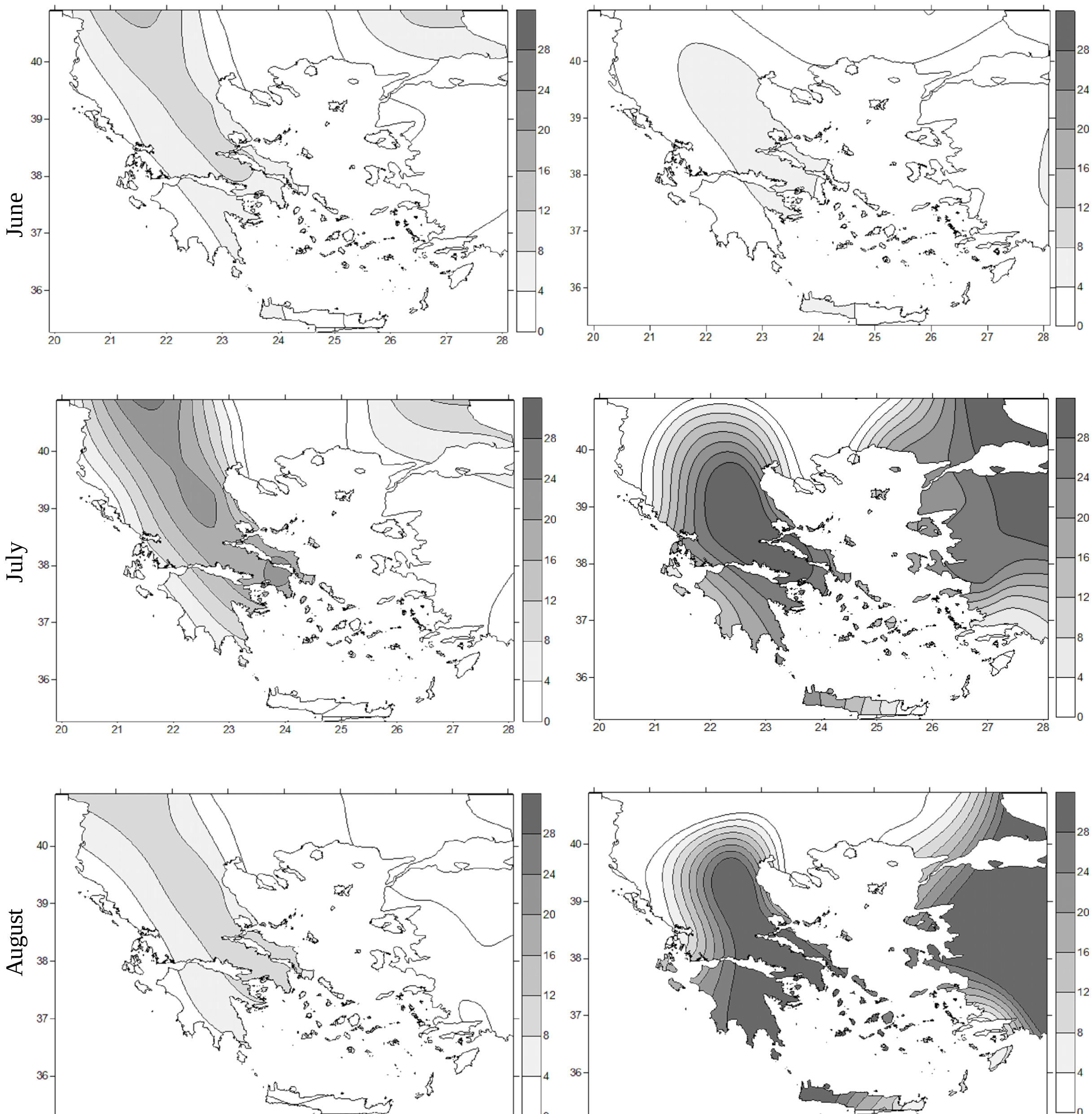


**Fig. 1. Number of days that exceed 'very favourable' conditions for fire occurrence based on Angstrom index (left maps) and number of days that exceed 'extreme fire danger' based on Nesterov index (right maps) observed in Greece during summer 2007**

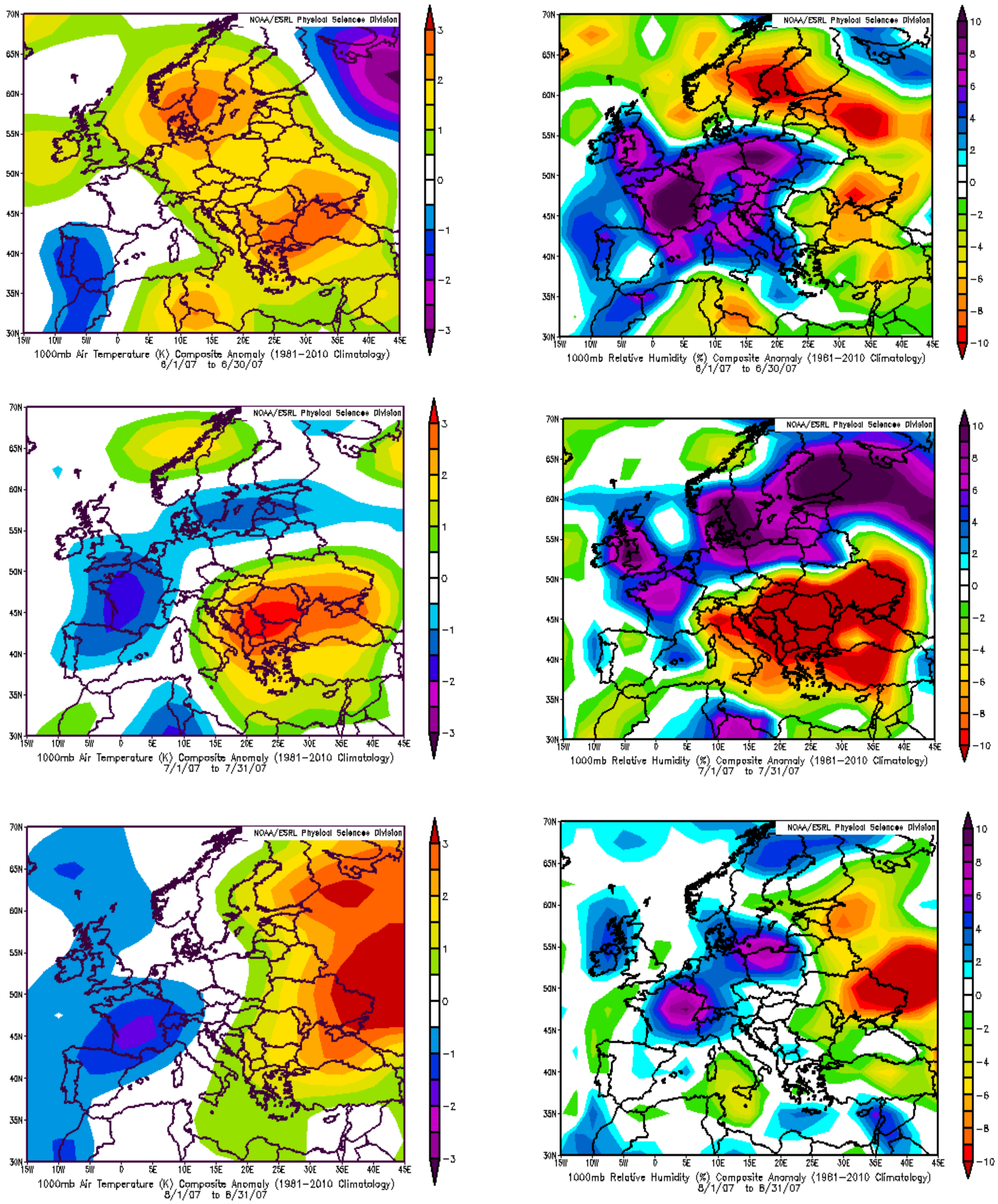


**Fig. 2. (left) Air temperature anomaly (°C) for June (a), July (c) and August (e) 2007. (right) Relative humidity anomaly (%) for June (b), July (d) and August (f) 2007**

risk indices in Greece varied during summer 2007. While in June the highest values of both indices concentrated in the Aegean region and in Eastern Greece, the highest values observed in July and August were found in Central, Western and Southern Greece.

Based on risk indices climatology (Table 2), average Nesterov index was higher in 2007 than in the reference period (1998-2013) in 10, 13 and 10 stations out of 13 respectively in June, July and August. The maximum Nesterov index observed on a daily base was higher in 2007 than in the reference period in 6, 10 and 4 stations out of 13 respectively in June, July and August. The average Angstrom index was lower in 2007 than in the reference period in 13, 13 and 12 stations out of 13 respectively in June, July and August. By contrast, the minimum Angstrom index observed on a daily base was lower in 2007 than in the reference period only in one day in June.Overall, the day values of Nesterov and Angstrom indexes observed in Summer 2007 exceeded those recorded in the reference period 6 times in June (n = 30), respectively 14 and 9 times in July (n = 31) and respectively 9 and 4 times in August (n = 31). The departure of month air temperature and relative humidity values from the long-term 1981-2010) climatic average was analyzed for June, July and August 2007 (Fig. 2). Meteorological re-analysis at the continental scale confirms for Greece the dominance of weather conditions characterized by positive and severe deviations from the corresponding climatic values for air temperature especially in July and August months. Air humidity showed a moderately positive deviation from normal values in June and a considerably negative deviation in July, determining very favourable conditions for fire outbreak.

## CONCLUSIONS

Summer 2007 wild fires in Greece have caused environmental and economic disasters and human casualties and were regarded as exceptional events (Koutsias *et al.,* 2012a). In the present study, two climatic indices (Nesterov and Angstrom) were tested for prognostic ability in predicting highly severe fire events and exceptional weather conditions. By considering a reference period of 15 years, both indices classified the meteorological conditions observed during Summer 2007 as very favourable for fire outbreaks since early July. The Nesterov index was estimated to be 18 times above the upper threshold (extreme danger) in the third decade of August 2007, in concomitance with the most severe fire outbreaks in central and southern Greece. Meteorological re-analysis confirms the persistence of weather conditions with significant positive deviation from the corresponding climate values. Interestingly, the response of the two indices to extreme meteorological conditions (e.g. hot waves) during Summer 2007 was only partly comparable. Based on the analysis developed in the present study using both average and extreme distribution values, Nesterov index effectively classified extreme weather conditions on a day scale while Angstrom index identified medium-term (e.g. decadal) departures from average conditions. The joint use of these two indices is thus encouraged in early-warning fire surveillance (Oliveras *et al.,* 2009).

It is known that extreme meteorological conditions and lack of forest management are both leading factors for mega fires in the Mediterranean region (De Jong *et al.,* 2003; Chen *et al.,* 2011; Lashley *et al.,* 2014). In Greece, extreme climatic conditions observed in 2007 summed up with poor forest management in turn linked with the abandonment of disadvantaged rural areas leading to fuel accumulation (Scarascia-Mugnozza *et al.,* 2000; Moreira *et al.,* 2011; Mancino *et al.,* 2013; Nolè *et al.,* 2013). However, the present study demonstrates that critical weather conditions leading to mega-fires can be easily detected using simplified, early-warning indicators of fire risk through computation of a restricted number of meteorological variables.

## REFERENCES

Bajocco, S., Salvati, L. and Ricotta, C. (2011). Land degradation vs. Fire: a spiral process? Progress in Physical Geography, **35(1),** 3–18.

Boschetti, L., Roy, D., Barbosa, P., Boca, R. and Justice, C. (2008). A MODIS assessment of the summer 2007 extent burned in Greece International Journal of Remote Sensing, **29(8),** 2433–2436.

Chen, X., Liu, S., Zhu, Z., Vogelmann, J., Li, Z. and Ohlen, D. (2011). Estimating aboveground forest biomass carbon and fire consumption in the U.S. Utah High Plateaus using data from the Forest Inventory and Analysis Program, Landsat, and LANDFIRE. Ecological Indicators, **11(1),** 140–148.

De Jong S.M., Pebesma E.J. and Lacaze B. (2003). Above-ground biomass assessment of Mediterranean forests using airborne imaging spectrometry: the DAIS Peyne experiment. International Journal of Remote Sensing, **24(7),** 1505–1520.

Founda, D. and Giannakopoulos, C. (2009). The exceptionally hot summer of 2007 in Athens, Greece – A typical summer in the future climate? Global and Planetary Change, **67,** 227–236.

Giannakopoulos, C., Kostopoulou, E., Varotsos, K., Tziotziou, K. and Plitharas, A. (2011). An integrated assessment of climate change impacts for Greece in the near future. Regional Environmental Change, **11,** 829–843.

Good, P., Moriondo, M., Giannakopoulos, C. and Bindi, M. (2011). The meteorological conditions associated with extreme fire risk in Italy and Greece: relevance to climate model studies. International Journal of Wildland Fire, **17(2),** 155–165.

Joint Research Centre (2013). Forest Fires in Europe, Middle East and North Africa 2012. Technical Report (Ispra: Joint Research Centre, Institute for Environment and Sustainability).
Karamichas, J. (2007). The Impact of the Summer 2007 Forest Fires in Greece: Recent Environmental Mobilizations, Cyber-Activism and Electoral Performance. South European Society and Politics, **12(4),** 521–533.

Koutsias, N., Arianoutsou, M., Kallimanis, A.S., Mallinis, G., Halley, J.M. and Dimopoulos, P. (2012a). Where did the fires burn in Peloponnisos, Greece the summer of 2007? Evidence for a synergy of fuel and weather. Agricultural and Forest Meteorology, **156,** 41–53.

Koutsias, N., Xanthopoulos, G., Founda, D., Xystrakis, F., Nioti, F., Pleniou, M., Mallinis, G. and Arianoutsou, M. (2012b). On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010). International Journal of Wildland Fire, **22(4),** 493–507.

Krawchuk, M.A., Moritz, M.A., Parisien, M.-A., Van Dorn, J. and Hayhoe, K. (2009). Global Pyrogeography: the Current and Future Distribution of Wildfire. PLoS One, **4(4),** e5102.

Lashley, M.A., Colter Chitwood, M., Prince, A., Elfelt, M.B., Kilburg, E.L., DePerno, C.S. and Moorman, C.E. (2014). Subtle effects of a managed fire regime: A case study in the longleaf pine ecosystem. Ecological Indicators, **38,** 212–217.

Liu, Y., Kahn, R.A., Chaloulakou, A. and Koutrakis, P. (2009). Analysis of the impact of the forest fires in August 2007 on air quality of Athens using multi-sensor aerosol remote sensing data, meteorology and surface observations, Atmospheric Environment, **43(21),** 3310–3318.

Mancino, G., Nolè, A., Ripullone, F. and Ferrara, A. (2013). Landsat TM imagery and NDVI differencing to detect vegetation change: assessing natural forest expansion in Basilicata, southern Italy. iForest (retrieved 14 January 2014 from http://www.sisef.it/iforest/contents/?id=ifor0909-007).

Mantzavelas, A., Apostolopoulou, I., Lazaridou, T., Partozis, T., Topaloudis, T., Lampin, C., Borgniet, L., Bouillon, C., Brewer, S., Curt, T., Ganteaume, A., Jappiot, M., Defossé, G., Gómez Fernán, M. and Lencinas, D.J. (2006). FIRE PARADOX: An Innovative Approach of Integrated Wildland Fire Management Regulating the Wildfire Problem by the Wise Use of Fire: Solving the Fire Paradox. European Commission, Bruxelles. Project no. FP6–018505.

Mavrakis, A., Spanou, A., Pantavou, K., Katavoutas, G., Theoharatos, G., Christides, A. and Verouti, E. (2010). Biometeorological and air quality assessment in an industrialized area of eastern Mediterranean – Thriassion Plain – Greece. International Journal of Biometeorology, **56(4),** 737–747.

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F. and Bilgili, E. (2011). Landscape – wildfire interactions in southern Europe: Implications for landscape management. Journal of Environmental Management, **92,** 2389–2402.

Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C. and Corte-Real, J. (2006). Potential impact of climate change on fire risk in the Mediterranean area. Climate Research, **31,** 85–95.

Nolè, A., Collalti, A., Magnani, F., Duce, P., Ferrara, A., Mancino, G., Marras, S., Sirca, C., Spano, D. and Borghetti, M. (2013). Assessing temporal variation of primary and ecosystem production in two Mediterranean forests using a modified 3-PG model. Annals of Forest Science, **70(7),** 729–741.

Oliveras, I, Gracia, M., Moré, G. and Retana, J. (2009). Factors influencing the pattern of fire severities in a large wildfire under extreme meteorological conditions in the Mediterranean basin. International Journal of Wildland Fire, **18,** 755–764.

Pausas, J.G. (2004). Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). Climatic Change, **63,** 337–350.

Philandras, C., Nastos, P. and Repapis, C. (2008). Air temperature variability and trends over Greece. Global Nest Journal, **10,** 273–285.

Pitman, A., Narisma, G.T. and McAneney, J. (2007). The impact of climate change on the risk of forest and grassland fires in Australia. Climatic Change, **84(3–4),** 383–401.

Raulier, F., Le Goff, H., Gauthier, S., Rapanoela, R. and Bergeron, Y. (2013). Introducing two indicators for fire risk consideration in the management of boreal forests. Ecological Indicators, **24(1),** 451–461.

Salvati L., De Angelis, A. and Bajocco, S. (2012). A satellite-based vegetation index as a proxy for land cover quality in a Mediterranean region. Ecological Indicators, **23,** 578–587.

Scarascia-Mugnozza, G., Oswald, H., Piussi, P., Radoglou, K. (2000). Forest of the Mediterranean region: Gaps in knowledge and research needs. Forest Ecology and Management, **132,** 97–109.

Theoharatos, G., Pantavou, K., Mavrakis, A., Spanou, A., Katavoutas, G., Efstathiou, P., Mpekas, P. and Asimakopoulos, D. (2010). Heat Waves observed in 2007 in Athens, Greece: synoptic conditions, bioclimatological assessment, air quality levels and health effects. Environmental Research, **110(2),** 152–161.

Turner, D., Lewis, M. and Ostendorf, B. (2011). Spatial indicators of fire risk in the arid and semi-arid zone of Australia. Ecological Indicators, **11(1),** 149–167.

Whitman, E., Rapaport, E. and Sherren, K. (2013). Modeling Fire Susceptibility to Delineate Wildland–Urban Interface for Municipal-Scale Fire Risk Management. Environmental Management, **52,** 1427–1439.

Yang, C.S., Kao, S.P., Lee, F.B. and Hung, P.S. (2004). Twelve Different Interpolation Methods: A Case Study of Surfer 8.0. Proceedings of ISPRS International Symposium, pp. 778–785 (retrieved 2 July 2014 from www.isprs.org/proceedings/XXXV/congress/comm2/papers/231.pdf).